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A STUDY OF THE CARCASS COMPOSITION AND MEAT QUALITY
OF SOUTHDOWN SHEEP SELECTED FOR
DIFFERENCES IN BACKFAT DEPTH

A thesis presented in partial fulfilment
of the requirements for the degree of
Doctor of Philosophy in Animal Science
at Massey University
Palmerston North
New Zealand

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1988

ABSTRACT

Southdown sheep from genetic lines that have been developed at Massey University by selecting for and against weight-corrected fat-depth measurements made ultrasonically on the live sheep, were evaluated for carcass and meat quality characteristics in 4 experiments, while their crossbred offspring from Romney ewes were evaluated in 2 experiments. No significant differences were found in daily live-weight gains between the two selection lines, but the fat-line animals had greater fat depths at C and to a lesser extent at J, S2, LG and L2. Tissue depth GR was also significantly greater in the fat line.

Comparisons at the same weight showed that sides from the meaty line contained more muscle and bone with less fat than those from the fat line, but the meaty-line carcasses had a relatively lower dressing-out percent. Carcass length was significantly longer for the meaty-line than the fat-line animals, but the maximum width behind the shoulder was greater for the fat line. The length of leg and several bones (femur, humerus, radius, and tibia and fibula) were greater for the meaty line than the fat line. With the exception of the higher rack cut percent in the fat line, the two selection lines did not differ in the weight distribution among the shoulder, loin, and leg cuts within the side, or in the distribution of muscle, bone and fat weights. When adjusted to the same side fat weight, the side from the fat line contained more subcutaneous fat, more intramuscular fat, and less intermuscular fat.

Based on succinic dehydrogenase staining procedures, M. semitendinosus from the fat line was found to have a significantly higher percent of red muscle fibre (β R) and a correspondingly lower percent of intermediate (α R) and white muscle fibre (α W). No significant line differences were observed for the diameter of the three muscle-fibre types.

For five adipose tissue depots (subcutaneous, intermuscular, kidney, omental and mesenteric) adipocyte size was greater for the fat line. In addition, the subcutaneous fat depot of fat-line sheep contained significantly more cells in one of the three experiments.

Equations relating side fat percent with fat percent of the rack cut (8 to 12 rib) differed significantly between the two lines with regard to intercept. This effect appeared to be due to the small overlap in fat percent values for the two lines.

Selection line differences in indices of meat quality (Warner-Bratzler shear force, sarcomere length, reflectance, expressed juice, cooking loss and pH) for four muscles (Mm. longissimus, biceps femoris, semitendinosus, semimembranosus) were generally small and non-significant. Meat from animals of the two selection lines did not differ significantly in the extent to which shear values decreased in response to electrical stimulation, to ageing for 15 days (M. semimembranosus), to the removal of cold-shortening conditions (M. biceps femoris), or to not trimming the subcutaneous fat over the M. longissimus. However, the shear force values and sarcomere lengths from both lines were significantly affected by all of these post-mortem treatments.

ACKNOWLEDGEMENTS

I owe a special debt to Dr R.W. Purchas for his sound guidance, constant encouragement, enthusiasm, and conscientious supervision of this study. His contribution to this project has been immeasurable. I wish to express my sincere gratitude to Professor A.L. Rae and Mr R. A. Barton for their invaluable advice and criticisms during the experimentation, statistical analyses of the data and the preparation of the manuscript. Their willingness to provide counsel whenever required was also greatly appreciated.

Without the contribution of Professor R.D. Anderson and the cooperation and facilities of the Animal Science Department, Massey University, this project would not have been possible.

I am indebted to Messrs M.A. Wycherley and M.G. Divehall for their cheerful technical assistance.

I am also grateful to Dr A.S. Davies, Department of Physiology and Anatomy, for his valuable instruction on anatomical muscle dissection. Mr M.J. Birtles, Mr R.I. Sparksman and Mrs P. Slack who each provided invaluable technical assistance in histological evaluation, are also gratefully acknowledged.

Mrs E.J. Baxter typed this thesis; her skill and patience deserve special thanks.

The generous financial support of the Government of the Republic of IRAQ is gratefully acknowledged.

I am grateful to the people of New Zealand for their friendship and hospitality during the period of my study.

Sincere appreciation and gratitude is due to my wife Samera Kasim Kalaf and also my little world Hamsah, Yasser and Shereen for the gift of their enthusiasm and discipline throughout this study.

Finally, very special thanks are due to my family for their encouragement and support during my absence from Iraq while studying at Massey University.

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CHAPTER 1 INTRODUCTION

INTRODUCTION

Meat and its role in the diet and health of humans are topics of continuing interest and discussion among nutrition and health professionals. The value of meat as a food and as a marketable product depends on a sequence of events and circumstances starting at conception and ending in consumption of the offspring.

Quality of meat is determined by intrinsic animal factors such as breeding and sex, and also by extrinsic factors such as post-mortem treatments. Consumers are concerned not only with the eating quality of meat, but also with its caloric content. Fat content is important in this concern because of its high caloric density compared with protein. The perception by the consumer of what constitutes an acceptable fat content of meat has been undergoing a change in favour of less fat. This change started with the increase in availability of consumer information pointing out the wastefulness of too much fat and with publicity being given to possible relationships between the intake of saturated fats and human heart disease. In this respect, however, the literature is much too ambivalent to evaluate accurately the importance of links between fat consumption and coronary heart disease in man. Additionally, because the level of physical activity in the past was greater than today for most consumers, the caloric density of fat probably was viewed as a positive factor. With the declining demand for fat leading to a decrease in its relative value the lean component has assumed a higher proportion of the value of meat. Thus, economic pressures to reduce the carcass fat content as a means of improving the value of livestock has become a significant production incentive. It is clear that changing the carcass composition is important, if the industry is to move toward more efficient production of meat. Considerable economic significance is attached not only to the total amount of carcass fat but also to the relative amounts of fat deposited in the various body depots (i.e. subcutaneous, intermuscular, internal and intramuscular).

As the consumer's perception of the relative values of fat and lean tissues changed, meat scientists began to question the widely-accepted belief that any increase in fat content would lead to a commensurate improvement in taste appeal. The realisation emerged that an increase in fatness beyond a certain but undefined point had a negative effect on value perception.

Because of the negative reaction to the word "fat" by many people, and because of the economic implications, the overfatness of sheep carcasses has become a common problem in many developed countries including New Zealand (Frazer, 1982). With increasing consumer affluence and competition from other foods the demand is not only for lean meat, but also for meat of high quality.

Some genetic variation in carcass composition of sheep does exist and can be used by the breeder to change the fat content of lamb carcasses. The effectiveness of improving carcass quality by selecting for a quantitative trait such as backfat thickness on live animals depends on both the heritability of the trait and its genetic correlation with carcass merit. In this respect, several methods have been developed for measuring backfat thickness in live sheep. Purchas and Beach (1981) and Bass *et al.* (1982) showed that ultrasonic fat depth measurements were moderately well related to the carcass fat content in live sheep. Furthermore, selection of lines of sheep for and against fatness based on ultrasonically measured fat depth measurements has been successfully undertaken at several centres in New Zealand. Information on changes in carcass traits due to selection for backfat thickness will allow theoretical genetic expectations to be checked against actual selection responses. Results of previous studies concerning relationships between fatness and quality of meat have been contradictory, but the effects of selection for fatness on carcass and meat quality of sheep do not appear to have been evaluated.

At Massey University, a breeding programme involving selection for fat and meaty Southdown sheep was initiated in 1976. The Southdown breed was chosen because of its extensive use in New Zealand as a sire of lambs for the export trade in carcasses and cuts. It was

considered that a considerable range in fatness could be obtained from within this breed.

The general aim of the experiments reported here was to study the carcass composition, and the biophysical and biochemical characteristics of muscle from sheep which were either representative of genetic lines selected for or against fatness or the crossbred offspring of rams from these lines.

Specific objectives of these experiments were to compare the animals from fat and meaty genetic lines with regard to:

- 1 - A wide range of carcass composition characteristics including the depth of subcutaneous fat used as the selection criterion.
- 2 - Chemical, physical and histological traits of muscle which have implications for meat quality characteristics.
- 3 - Interactions between the effects of level of fatness and several post-mortem treatments on meat quality characteristics, and, in particular, on measures of meat tenderness.

CHAPTER 2

REVIEW OF LITERATURE

2-1 INTRODUCTION

This review will be concerned with factors affecting carcass and meat quality and with relationships between muscle characteristics and meat quality. Few investigations have examined the effect of selection against fatness on carcass and meat quality of sheep, so important findings bearing on the general effect of fatness on carcass and meat quality characteristics will be considered. Carcass quality and meat quality aspects will be reviewed separately.

In the section on carcass quality, emphasis will be given to factors affecting carcass composition, including animal weight and age, genotype, nutrition and sex. Composition will be considered mainly in terms of proportions of muscle, fat and bone, but the partitioning of fat between depots and its distribution through the carcasses of meat animals will also be considered. In addition factors affecting cellularity of fat depots will be reviewed.

The section on meat quality will consider the ways in which meat quality has been defined and the basic structural and biophysical characteristics of muscle which have been shown to contribute to the palatability and appearance characteristics of meat. For each of these muscle characteristics particular attention will be given to evidence that it may be involved in mediating any relationship between fatness and meat quality.

2-2 BODY AND CARCASS COMPOSITION

2-2-1 DRESSING-OUT PERCENT

The dressing-out percent, which is a measure of carcass weight relative to live weight of the animal, will depend upon a number of factors, the most important being the state of maturity, the degree of fatness, breed, sex, and alimentary tract contents. The last factor will vary depending upon the period of fasting and the amount of feed consumed before slaughter.

2-2-1-1 Factors Affecting Dressing-out Percent

There is a wealth of information concerning the effect of the state of maturity, fatness and slaughter weight on the dressing-out percent (Hammond, 1932; Fourie et al., 1970; Purchas, 1978; Solomon et al., 1980; Lloyd et al., 1981; Sents et al., 1981; Kirton et al., 1984; Hawkins et al., 1985a; Lee, 1986a,b). According to Hammond (1932) fat animals yield a higher carcass percent than moderately fat ones. Fourie et al. (1970) showed that the dressing-out percent of the Southdown breed (based on empty live weight) varied with age from 47.6 at birth to 58.6 at maturity, and attributed this increase in dressing-out percent with age to the increasing proportion of muscle and fat in the carcass. The same authors found that the mature Southdown carried more fat than the mature Romney and the dressing-out percent was 58.6 and 55.7 respectively. Lee (1986a, b) reported that the dressing-out percent increased significantly with increasing carcass weight by 0.45-0.80 units/kg carcass weight.

Dressing-out percent is lower for rams than ewes or wethers, with this difference increasing with age (Hammond, 1932; Bradford and Sparlock, 1964; Purchas, 1978; Lloyd et al., 1981; Ahmad and Davies, 1986; Lee, 1986a,b). There are, however, some other reports in the literature where the differences in dressing-out percents of rams, wethers and ewes were 48.8, 50.0 and 50.8 respectively, the differences being non-significant. Cresswell et al. (1964a, b) found that rams and partial castrates had lower dressing-out percents than wethers, but the difference was not significant. Prescott and Lamming (1964) indicated that gut fill was greater in entire males than in castrated males. They found little difference in dressing-out percent between entire and castrated male sheep (55.6 and 56.9, respectively) when dressing-out percent was calculated on an empty body weight basis. Fourie et al. (1970) reported similar results and attributed the small difference in dressing-out percent between males and females to the higher percent of subcutaneous fat in the female carcasses. Furthermore the heavier bone of the head and lower extremities of the male also has an adverse effect on the dressing-out percent. Theriez et al. (1982) showed that the dressing-out percent of Ile de France X (Romanove X Limousin) females was significantly higher than the males (48.0 vs 45.4) at similar carcass weight. Ahmad and Davies (1986)

reported that the dressing-out percent was significantly higher for wethers and ewes than rams by 2.3 and 3.6 units respectively at similar fasted live weights. Similarly, Lee (1986a) found that wether carcasses dressed out 1.7 units heavier than those of rams at the same carcass weight. The same author in another experiment (1986b) found that at the same carcass weight (17.6 kg) wethers dressed 2.3% significantly heavier than rams. Lirette et al. (1984) compared the dressing-out percent between wether and ram lambs at 120 days of age and found no significant difference between sexes. More recently, Hawkins et al. (1985a) reported that the dressing-out percent of ewes and wethers were 52.0 and 51.2 at 128 and 120 days of age, the difference being non-significant.

Differences among breeds in dressing-out percent have been investigated widely (Fourie et al., 1970; Purchas, 1979; Solomon et al., 1980; Kirton et al., 1981; Lloyd et al., 1981; Morrison and Dahmen, 1983). An experiment conducted by Fahmy et al. (1972) showed that Southdown lambs had a 0.25% higher dressing-out percent than Suffolk lambs at the same weight, but this difference was not significant. This result is in agreement with Meyer et al. (1978) who showed no significant differences among Southdown, Oxford and Suffolk cross lambs. Similarly, no difference in dressing-out percent between Targhee and Suffolk X Targhee breed was reported by Lloyd et al. (1981). Further, the dressing-out percent of Southdown-sired lambs was 0.80 higher than the Hampshire-sired lambs in the study of Purchas (1979), but this difference was not significant. Kirton et al. (1981) reported that Southdown X Romney lambs had higher dressing-out percents than straight Romneys. A similar result has been reported by Fourie et al. (1970). Solomon et al. (1980) showed that the dressing-out percent was significantly higher for a (1/2 Suffolk, 1/4 Finnish-Landrace and 1/4 Southdown) group than a 3/4 Suffolk and 1/4 Rambouillet) group (51.9 vs 49.1%). Morrison and Dahmen (1983) showed no significant differences among four crossbreds at the same slaughter weight for dressing-out percents (Suffolk X White-face Suffolk and Lincoln Longwool X White-face Western). Recently, Hawkins et al. (1985a) compared two genetic types (SR) 1/2 Hampshire X Suffolk + 1/4 Rambouillet and (FS) 1/2 Hampshire X Finnish Landrace + 1/4 Southdown. The dressing-out percent was significantly higher for FS than SR, and

this difference was attributed to the greater quantity of fat in FS than SR.

Andrews et al (1969) studied the effect of five concentrations of metabolisable energy (2.80, 2.68, 2.56, 2.45 and 2.30 Mecal/kg DM) on the dressing-out percent of Romney X Swaledale lambs slaughtered at similar weights. The data indicated that lambs on the first three diets had significantly higher dressing-out percents than those on the last two diets. Twenty-four Merino X Border Leicester lambs were randomised into high- and low-energy diets by Ahmad and Davies (1986). They found that the high-energy diet lambs had significantly higher dressing-out percents than low-energy diet lambs (53.5 vs 50.9) at similar fasted live weight. In contrast, Lee (1986b) found that at the same carcass weight, lambs on the low level of nutrition provided carcasses dressing 1.3 units heavier than carcasses from lambs fed the high level of nutrition.

2-2-2 FAT PERCENT

2-2-2-1 Factors Affecting Fat Percent

2-2-2-1-1 Animal Age and Weight

Most of the variation in the body composition of sheep appears to be associated with the amount of fat relative to the non-fat portion (Black, 1983). In general an increase in carcass weight in lambs has been shown to be associated with an increase in fatness (Little and Sandland, 1975; Theriez et al., 1982; Hodge and Star, 1984; Bray et al., 1985). The amount of separable fat was highly correlated with carcass weight of mature sheep but less closely correlated with carcass weight when only light-weight carcasses were considered (Barton and Kirton, 1958b). Smith-Pilling and Barton (1954) reported that as the carcass weight of ewes increased there was a natural increase in the percent of fat. The fat tissue percent increased 22.77% when the carcass weight was increased from 21.77 to 33.11 kg and above. The corresponding decreases in percent of bone and muscular tissue were 2.14 and 5.13%, respectively. Barton and Kirton (1958b) indicated that the correlation between carcass weight and dissectible fat was 0.94 in wether lambs, 0.87 in ewe lambs and 0.94 in mature ewes. Results on lamb carcasses of several breeds published by Southam and

Field (1969) showed that as carcass weight increased there was an increase in percent kidney fat, fat depth over M. longissimus and body-wall thickness. Sents et al. (1982) reported that the percent of fat in carcasses of ram lambs increased by 0.04, 0.02 and 0.02 respectively, for each 10 kg increase in slaughter weight above 45.5 kg. Butler-Hogg (1984b) studied the growth of Southdown and Clun lambs over the period from birth to 415 days of age. Body composition changed significantly with age. Total body fat increased from 28 and 37 (g/kg live weight) at birth up to 455 and 432 (g/kg live weight) at 415 days of age for Southdown and Clun breeds, respectively, but there was no breed difference in the relative growth of total body fat. Regression analyses of compositional traits on hot carcass weight were performed by Campion et al. (1976). The regression analysis of their data indicated 45 kg lambs would have 2.5 mm and 73 kg lambs 6.1 mm depth of fat at the 12th rib, which is a rate of increase similar to that reported by Sents et al. (1982). Wood et al. (1980) demonstrated that as carcass weight increased from 15 to 21 kg there were increases in the percents of total fat, subcutaneous fat, KKCF and caudal fat of 4.80%, 4.89%, 1.00% and 1.07% respectively, but there was no change in percent of intermuscular fat.

2-2-2-1-2 Animal Genotype

A number of investigators have demonstrated large differences in total body fat between breeds (Fourie et al., 1970; Searle and Griffiths, 1976; McClelland et al., 1976; Coop et al., 1979; Wood et al., 1980). The general conclusion from their studies has been that at the same carcass weight, sheep from breeds of smaller mature size tend to produce carcasses with more fat than those from breeds of larger mature size. An overall assessment of reported results (Kirton, 1976) indicated that the Southdown - the smallest of the British Down breeds - when used as a sire, has the greatest tendency of all breeds to promote carcass fatness in its progeny, producing 3-6% more fat as a proportion of carcass weight than the Suffolk when compared at the same carcass weight. On the other hand, lambs sired by the Texel, Suffolk, Dorset Horn/Poll Dorset and Hampshire (Reid et al., 1968; Kirton, 1976) produce, on average, less fatty carcasses when compared at the same weight, making these terminal sire breeds more suitable for heavy-weight lamb production. The effect of the

Finnish Landrace breed on carcass composition was examined by comparing male progeny of Galway ewes which had been mated with Finn Landrace, Galway or Fingalway (1/2 Finn Landrace X Galway) rams (Hanrahan et al., 1978). At the same carcass weight, Finnish Landrace rams increased fat percent by five percent points compared with Galway rams. The composition of Merino, Romney, Corriedale, Perendale and Border Leicester X Romney wethers was studied by Kirton et al. (1974) with respect to subcutaneous fat thickness, percent perirenal fat and percent carcass fat. In general, the Perendale lambs were the fattest and the Merinos had the least fat, closely followed by the Romney, when the breeds were compared on an age-constant basis. However, at constant carcass weight, the Romney lambs were the leanest breed and the Perendale and Merino lambs were among the fattest for most measures. An investigation comparing crossbred lambs by Suffolk, Dorset Down and Southdown sires at the same carcass weight was reported by Kirton et al. (1978). The Suffolk-sired carcasses had significantly lower fat thicknesses at two sites (S1 and S2) on the shoulder, averaging around 30% less than the Southdown- and Dorset-sired carcasses. In addition, the Suffolk-sired lambs had more than 25% less kidney fat than lambs sired by the other breeds. These results are in agreement with those reported by Meyer et al. (1978) who showed that at the same carcass weight Southdown-cross lambs had greater amounts of total fat in the carcass than lambs sired by Oxford and Suffolk rams. Coop et al. (1979) reported that fat varied from 36.7% in the Southdown to 32.8% in the Coopworth and Romney and to 28.8% in the Dorset Down, Poll Dorset and Suffolk breeds of 18 kg. Purchas (1979) found that Hampshire-sired lambs were fatter than Southdown-sired lambs, when their carcass weights were 16.95 and 14.85 kg respectively. Crouse et al. (1981) found that at constant live weight, Suffolk lambs had significantly less kidney and pelvic fat than Rambouillet lambs, but that fat thickness was similar in both breeds. Theriez et al. (1982) found that Ile de France crossbred lambs were leaner than Berrichon crossbreds despite a higher carcass weight (16.2 kg vs 15.2). Butler-Hogg (1984b) compared Southdown with Clun lambs over a range of ages (0-415 days). At each slaughter age the two breeds had similar proportions of total body fat, despite big differences in live weight. However, McClelland and Russel (1972) noted that there is a shortage of published information on the relative mature size of different sheep breeds raised in common

environments. McClelland et al. (1976) demonstrated that in four sheep breeds of widely different mature weights, differences in body composition due to breed were largely eliminated by comparison at the same proportion of maturity. Butterfield et al. (1983a) used dissection data from 20 large mature-size strain and 19 small mature-size strain Merino rams, and found that at the same degree of maturity the carcass composition of mature rams of both strains was similar for the proportions of muscle and bone, but that there was a slightly greater proportion of fat in the larger strain. They concluded that the most accurate estimate of real breed difference is that made at the same state of maturity. Similarly, Cameron and Drury (1985) found that at the same proportion of subcutaneous fat, slaughter age and carcass weight were positively correlated between sire breeds, which suggested that breeds of heavier mature weight tended to take longer to reach a particular level of subcutaneous fat. Lee (1984) reported that in a study involving 219 lambs of the Welsh Mountain and Scottish Blackface breeds slaughtered in 6 groups at fortnightly intervals from 6 to 8 months of age, the Welsh Mountain lambs were more mature and had more kidney fat and a higher fat content in the loin region at the same age, while at the same degree of maturity, the Welsh carcasses had more kidney fat but the differences for fat in the loin region disappeared.

The design of genetic improvement schemes for any species depends on the heritability of traits of economic importance, and on the genetic relationships among traits (Wolf et al., 1981). A number of workers have reported that carcass composition, particularly the amount of fat in the various fat depots, are moderately to highly heritable and a good agreement between the heritability of fat thickness and the heritability of percent fat in the carcass is evident (Table 2-1). This suggests that the proportions of the major fatty tissues in the carcass can be changed by genetic selection within a breed in the long term. The most common measure of fat depth in the sheep carcass is one made over the M. longissimus, i.e., measurement C, on the cut surface of the rib or loin. The heritability of this trait in sheep has been determined by various workers and their estimates are summarized in Table 2-1. This indicates that fat depth in lambs could be changed by selection.

Table 2-1. Estimates of heritability of fat depth C, and certain other fatness measurements in sheep.

No. animals	No. sires	Breed	Data adjusted for	Heritabilities				References
				Fat depth C	Carcass fat %	Subcutaneous fat %	Kidney fat %	
218	40	4 breeds	age	-.36	-.28	-	-	Al-Barhawe (1966)
802	58	3 breeds	weight	.51	.54	-	.17	Botkin <u>et al.</u> (1969)
178	18	Poll Dorset						
		Horn	weight	.40	-	-	-	Bowman and Hendy (1972)
167	17	Suffolk X	weight	.26	-	-	-	Bradford and Spurlock (1972)
		Corriedale						
269	32	Poll Dorset						
		X Merino	age and weight	.37	-	-	.55	Cotterill and Roberts (1976)
474	12	Romney	age	.31	-	-	-	Mohamed (1976)
584	85	7 breeds	age	.28	-	-	.12	Olson <u>et al.</u> (1976b)
994	65	6 breeds	weight	.21	.37	.36	.37	Wolf <u>et al.</u> (1981)
500	-	Poll Dorset						
		X Border						
		Leicester X						
		Merino	-	.78	-	-	-	Ransom (1981)
1637	8 to 12	Southdown						
		X Romney	age	.36	.26	.33	.49	Bennett <u>et al.</u> (1981/1982)
1637	8 to 12	Southdown	weight	.28	.21	.19	.42	Bennett <u>et al.</u> (1981/1982)
		X Romney						Thorsteinsson and Bjornsson (1982)
1826	216	Iceland	age	.32	-	-	-	Sharma (1983)
612	-	Columbia	age	.20	-	-	-	Bennett <u>et al.</u> (1982/1983)
1600	51	4 breeds	age	.22	-	-	-	Bennett <u>et al.</u> (1982/1983)
1600	51	4 breeds	weight	.35	-	-	-	Bennett <u>et al.</u> (1982/1983)
850	51	Romney	age	.19	.37	.34	-	Clarke <u>et al.</u> (1984/1985)

The phenotypic and genetic correlations between subcutaneous fat depth and percent carcass composition in sheep at a fixed live weight were moderately high in the study of Wolf et al. (1981). In particular, the genetic correlations between subcutaneous fat depth and total fat percent, subcutaneous fat percent, intermuscular percent and KKCF percent were 0.74, 0.80, 0.50 and 0.55 (Wolf et al., 1981). Similar observations were made by Clarke et al. (1984/1985). The data indicated that the genetic correlation between dissected fat and chemical fat was close to 1, also genetic correlations between dissected fat, subcutaneous fat and intermuscular fat percents and fat depth over M. longissimus were 0.76, 0.74 and 0.77 respectively. These correlations indicated that genetic selection to change carcass composition at a fixed live weight should be successful (Wolf et al., 1981). For more details and references, see Table 5-1.

The difficulties of estimating carcass composition in the live animal may dictate the use of a progeny test with its disadvantages of higher cost, lower selection intensity and increased generation interval relative to the performance test (Wolf et al., 1981). Thus the correlation between traits which can be measured in the live animal and its carcass composition are of particular interest. Several ultrasonic machines have been developed to measure subcutaneous fat of the live animal, but Kempster et al. (1977), Thompson et al. (1977) and Clements et al. (1981) have concluded that the level of precision in measuring subcutaneous fat thickness was low relative to the actual fat thickness measurement, and that this would effectively lower the actual heritability and consequently the expected progress in a selection programme. In contrast, available evidence indicates that the ultrasonic instrument described by Gooden et al. (1980) and Purchas and Beach (1981) provides results which relate satisfactorily to comparable carcass measurements. However, the success in changing carcass fat depots by selection on the live animal depends on the accuracy of fat measurement (Purchas et al., 1981; Bennett et al., 1983). Selection for and against live animal fatness has resulted in significant changes in carcass fat in Coopworth sheep (Fennessy et al., 1982), with differences of 0.38 mm at fat depth C and 0.54 mm at GR between high and low fat progeny averaging 13.5 kg carcass weight. More recently, Fennessy et al. (1987) reported a difference of 3.24 mm fat depth at C between

selected fat and lean Coopworth sheep at 34 kg liveweight. Meyer et al. (1981/1982) used Southdown and Suffolk sires selected for high and low weight-corrected fatness showed that the C fat depth over the loin region was 10% less in progeny of the fat sires, but differences were not seen in GR fatness. They suggested that successful selection against fatness at one carcass site may not be as effective in reducing total carcass fatness.

2-2-2-1-3 Sex.

Differences between intact males, castrated males and intact females are also important determinants of body fat content in sheep (Wilson et al., 1972). Thus rams grow faster and contain less fat than ewes, and wethers are fatter than rams but less fat than ewes (Andrews and Orskov, 1970; Vezinhet and Prud'hon, 1975; Searle and Griffiths, 1976). Shelton and Carpenter (1972) suggested that not only was the amount of fat less in rams than in wethers or ewes, but also the rate of deposition was much lower at heavy weights (54 kg live weight) in rams. Differences in fatness between rams and ewes have been detected only when live body weight exceeded 14-15 kg in some studies (Andrews and Orskov, 1970; Searle and Griffiths, 1976). Similarly, comparison of sexes from Southdown and Romney breeds and their cross for carcass fat weight at the same carcass weight was carried out in a comprehensive experiment by Fourie et al. (1970), using regressions derived in logarithmic form. The data showed that ram lambs contained less fat than ewe lambs. This difference was on average 1.2% at 5 kg, 3.2% at 10 kg, 6.2% at 20 kg and 7.7% at 30 kg carcass weights. They attributed these differences, especially towards the heavier weight, to the earlier maturity of the ewe lambs. In general, the differences between sexes in fat measurements become greater as weight increased (Kemp et al., 1972). Purchas (1979) found that at an average carcass weight of 15.9 kg, ram lambs were of similar fatness to ewes with carcasses 2.2 kg lighter. Searle and Griffiths (1976) found that females deposited more fat at a lower body weight than male sheep, with the rate of deposition increasing at a lower body weight in females compared with males. These differences in rates of fat deposition in males and females may be related to differences in their mature body weights (Searle et al., 1972; Price, 1975). Ferrell et al. (1979) showed that at a constant empty body

weight of 36.4 kg rams contained significantly less fat than ewes. Similarly, Morgan and Owen (1973), Crouse et al. (1981), Theriez et al. (1982) and Ahmad and Davies (1986) concluded that female lambs have more fat in their carcasses than male lambs at the same weight. Lirette et al. (1984) reported that castration had no influence on the accumulation of fat deposits above the M. longissimus between the 8th, 9th and 13th ribs, but that castrated lambs accumulated significantly more kidney fat expressed as a percent of body weight. More recently, Hawkins et al. (1985a) showed that ewe lambs were significantly fatter over the rib and contained a higher percent of kidney-pelvic fat than wether lambs at the same weight.

2-2-2-1-4 Nutrition

Research evidence on the effect of nutritional factors on fatness in sheep is not unanimous. For example, the effect of a high plane of nutrition on the proportion of fat at the same or similar body weight has been reported to be positive (Palsson and Verges, 1952b; Lohman, 1971; Searle et al., 1972; Haugebak et al., 1974; Ahmad and Davies, 1986), negative (Andrews and Orskov, 1970; Kellaway, 1973) and non-existent (Gardner et al., 1964; Andrews et al., 1969; Arnold et al., 1969; Burton and Reid, 1969; Price, 1975; Theriez et al., 1982). According to Black (1974), both plane of nutrition and chemical composition of the diet can have a major effect on body composition when comparisons are made between animals of the same age, but these differences are substantially reduced when comparisons are made at the same body weight. Reports showing either a positive or no effect of increasing energy intake on body fat content can be explained by the relationship between energy intake and fat deposition for diets adequate in protein (Black, 1974). The experiments showing a decrease in body fat with increasing plane of nutrition have involved the feeding of low protein diets (Kellaway, 1973) or the feeding of diets in which the protein source was extensively degraded within the rumen (Andrews and Orskov, 1970), in which case increasing energy intake would be expected to stimulate protein absorption to a level that would satisfy the animals' requirements (Black, 1974, 1983). Furthermore, evidence on the effect of feed restriction followed by rehabilitation on fatness of lambs is also strewn with contradictions, with the fatness of lambs treated in this way having been reported as

increased (Meyer and Clawson, 1964; Hodge and Star, 1984), decreased (Drew, 1973; Little and Sandland, 1975; Burton et al., 1974), and unchanged (Morgan and Owen, 1972a, b; Drew, 1973; Searle and Graham, 1975; Kirton et al., 1981; Butler-Hogg, 1984a; Bray et al., 1985), relative to lambs of similar weight grown normally. Many of these differences can be explained by the rate of weight loss and the time spent on the treatment. For example, Searle et al. (1972) plotted the fat content of sheep losing weight rapidly and slowly against body weight and showed that, compared with sheep grown normally, they contained, respectively, more and less fat, but with time the body composition of both groups of animals returned to that of the normally-grown animal.

According to Elsley et al., (1964) fat is the component of the carcass which varies most in response to nutritional change. They showed that lambs on a low plane of nutrition had lower amounts of intermuscular and subcutaneous fats compared with those on higher feed intakes at the same weight. Similar observations were made by Palsson and Verges (1952a, b) who reported that sheep maintained on a low plane of nutrition for about nine months had a lower proportion of fat than those fed at higher levels to the same weight. Ferrell et al. (1979) concluded that fatness of lambs at a set weight tended to increase with increasing percent concentrate in the diet, but the values were not statistically significant. The effect of ratio of protein to energy in the diet on the level of fatness in lambs was shown by Andrews and Orskov (1970) to be curvilinear such that at 27.5 kg live weight, more fat and less muscle was deposited when 10% crude protein was fed than when 20% protein was fed. At 40 kg live weight, differences in fat and muscle deposition were less marked. Similar results were reported by Jagusch et al. (1970), who found that fat deposition was markedly increased relative to protein deposition in lambs on low protein diets. Barton and Ulyatt (1963) reported that fatter and heavier sheep were produced on a short-rotation ryegrass plus white clover diet than on diets of perennial ryegrass with or without white clover, or short-rotation ryegrass alone. A lucerne diet produced lambs with significantly less body fat and with more protein than the control at constant empty body weight (Mitchell and Jagusch, 1972). Hodge and Star (1984) showed that at a similar carcass weight, lamb carcasses of continuously-grown lambs on pasture

contained significantly more subcutaneous fat and kidney and channel fat than carcasses of the realimentated lambs at pasture. Purchas and Keogh (1984) reported that lambs grazed on lotus had less fat than lambs on clover at the same weight and attributed that to different amounts of protein between the two pastures. It was suggested that the protein of lotus was to some extent protected from rumen degradation by the tannins present. Suffolk- and Rambouillet-sired ram and wether lambs fed a high energy diet had significantly higher kidney and pelvic fat weights at the same carcass weight as a group fed a low energy diet, but the difference in fat thickness did not reach statistical significance (Crouse et al., 1981). Theriez et al. (1982) studied the effects of energy intake on lamb composition and found that carcass fat percent increased with increasing metabolisable energy (ME) concentration in the diets and with feeding level (moderate or high). But at the same carcass weight, none of the diet-induced differences remained significant.

2-2-3 FAT PARTITIONING AND DISTRIBUTION

The term partitioning of fat is used to describe its location in the various depots such as subcutaneous, intermuscular, kidney, omental and mesenteric fats, whereas the term distribution of fat refers to its location within these depots (Butterfield, 1976). Evidence concerning factors which may influence these two characteristics in sheep is reviewed below.

2-2-3-1 Factors Affecting Fat Partitioning and Distribution

2-2-3-1-1 Animal Age and Weight

It is well known that fat depots develop at different rates (Fourie et al., 1970; Vezinhet and Prud'hon, 1975; Wood et al., 1980; Butler-Hogg, 1985). Therefore, slaughter weight and age will influence the relative proportions of the fat depots as well as having a major bearing upon the total amount of fat in the carcass. Vezinhet and Prud'hon (1975) reported that at birth, carcasses of lambs were almost free of subcutaneous fat. However, a very rapid development was observed during the early stages of life. In contrast, internal fats were already well developed at birth, but their development afterwards was slower. Kempster (1980) reviewed the relative growth

of fat depots in cattle, pigs and sheep, and noted that in sheep relative growth rates for kidney knob and channel fat (KKCF) were high in comparison with those for intermuscular fat, and similar to those for subcutaneous fat. This observation is in close agreement with that of Wood et al. (1980) and Butler-Hogg (1985), where the order of relative growth of fat depots of lambs was subcutaneous fat > omental fat > KKCF > intermuscular fat. Similar results were reported by Fourie et al. (1970) where for sheep from birth to maturity, the relative growth of subcutaneous fat was significantly higher than that of KKCF (relative to the growth of the whole carcass). Seebeck (1968) reported that the proportion of the total subcutaneous fat in the loin and flank of two breeds (Merino and Dorset Horn cross breeds) increased and that in the leg decreased, as total subcutaneous fat increased. The proportion of the total intermuscular fat in the neck and the loin and flank increased and that in the thorax and the leg decreased as total intermuscular fat increased (Seebeck, 1968). The information available on the development of fat depots over the growing/finishing period in all three species (cattle, pigs, sheep) is consistent in that subcutaneous fat has a higher relative growth rate than intermuscular fat, but the growth of KKCF relative to other depots is more variable (Kempster, 1980). Butler-Hogg (1984b) studied the growth of Clun and Southdown lambs over the period birth, 50, 100, 150, 200 and 415 days of age. At birth intermuscular fat was the biggest depot, accounting for more than half the total fat, while KKCF was relatively well developed and almost as large as subcutaneous fat. By 150 days of age subcutaneous fat had become the largest depot, and caul (omental) fat had become a greater proportion than KKCF. At 415 days of age, when these sheep were probably approaching their maximum potential fatness, almost half the body fat was in the subcutaneous fat depot (Butler-Hogg, 1984b). Briggs and Brown (1985) showed that decreasing carcass weight from 17 to 9 kg for 20 Southdown X Mule castrates, had only slight effects on the proportional distribution of intermuscular fat in the shoulder.

2-2-3-1-2 Animal Genotype

2-2-3-1-2-1 Between Breeds

In sheep it has been known for some time that breeds differ in fat partitioning. Hammond (1932) reported that breeds of sheep differed considerably in their fat partitioning, and Palsson (1940) showed that milk breeds tend to accumulate more internal body fat than meat breeds. Seebeck (1968) showed that Merino lambs had a greater proportion of subcutaneous fat and intermuscular fat in the loin and flank cuts and less in the thorax than the Dorset Horn X Border Leicester-Merino. A comparison between Scottish Blackface and Finnish Landrace lambs showed that the latter deposited less fat in the carcass and more in the body cavity (McClelland and Russel, 1972). Kirton et al. (1974) showed that Merino lambs had lower subcutaneous fat and higher perirenal fat than Perendale lambs at the same carcass weight. Hanrahan et al. (1978) found that lambs by Fingalway sires had more kidney knob and channel fat (KKCF) than those by Galway sires as well as having more fat in the meat of the 7-12 rib cut. Dorset Horn and Corriedale breeds have a greater proportion of their fat in internal depots relative to the Romney (Geenty et al., 1979). Thompson et al. (1979a) studied the fat partitioning in Dorset and Border Leicester rams crossed with Border Leicester-Merino, Corriedale, or Merino ewes. They reported no differences in the partitioning of fat between the subcutaneous and intermuscular depots, but significant differences in the partitioning of fat between the carcass and internal fat depots, whereby the progeny of Dorset Horn rams and the progeny of Merino ewes had a greater proportion of internal fat than the progeny of Border Leicester rams, and Border Leicester-Merino, and Corriedale ewes, respectively. Distribution patterns for subcutaneous and intermuscular fat in the five cuts (hind limb, loin, thorax, fore limb and flank) were significantly related to the total amount of the respective fats in the carcass, but were not affected by genotype (Dorset Horn and Border Leicester rams mated to Merino, Corriedale, and Border Leicester X Merino) (Thompson et al., 1979b). Wood et al. (1980), in a survey of four pure breeds, also reported that the meat sire breeds (Suffolk and Hampshire) had less internal fat than the ewe breeds (Clun and Colbred). Lloyd et al. (1981) allocated 86 lambs randomly to heavy and light slaughter weight groups within two breeds,

Targhee and Suffolk X Targhee. The difference in percent kidney and pelvic fat between light- and heavy-weight Targhee lambs was greater than that between light- and heavy-weight Suffolk X Targhee lambs. Kirton et al. (1985), by using regression analysis with carcass fat weight as the independent variable found that the distribution of kidney fat was different between Romney, Dorset X Romney and Cheviot breeds, but a clear identification of breed was possible only for some Cheviot carcasses.

Kempster (1980) reviewed numerous results regarding the distribution and partitioning of fat for British sheep breeds and concluded that between sheep breed variation in the distribution of fat existed, although the differences were small. Butterfield and Thompson (1983) found no differences in the partitioning of fat in large and small sized Merino rams. A comparison of fat partitioning in the mature Merino rams in the study of Butterfield and Thompson (1983) and in the similarly-fed mature Dorset Horn rams from the study of Butterfield et al. (1985), revealed a large breed difference in the partitioning of fat between the carcass and non-carcass depots. Mature Dorset Horn rams had about 0.69 of total body fat in the carcass compared with about 0.63 in the mature Merino rams. The decreased proportion of non-carcass fat in the mature Dorset Horn rams relative to the Merino was due to decreased amounts of about 20 g/kg total body fat in each of the three major non-carcass depots. Butler-Hogg (1984b) studied the effect of breed on depot growth rate in Clun and Southdown lambs, using double logarithmic regressions of depot weight on total fat weight from birth to 415 days. No differences in the growth coefficients for the rib, kidney knob and channel fat, mesenteric, intermuscular, subcutaneous and omental fat depots were shown between breeds. At all ages the two breeds contained similar amounts of total fat, but the Clun had significantly more internal fat and the Southdown more carcass fat, suggesting that their fat distribution was different at birth. Gaili (1978) found some variation between Dorset Horn, Hampshire and Clun lambs. The neck and thorax regions contained the biggest intermuscular fat depots. Butler-Hogg and Whelehan (1984) stated that fat partitioning between depots was influenced by breed, with the major differences occurring in the proportions of subcutaneous fat and intermuscular fat, which were higher in the Texels compared with the Scottish Blackface. There

was a shift in subcutaneous fat and omental fat proportion, as relative to other fat depots, in the Texel and to a lesser extent with omental fat in the Scottish Blackface. Jones et al. (1985) examined dissection data for a total of 1400 crossbred lambs from the Meat and Livestock Commission's Ram Breed Evaluation. Significant differences were recorded between sire breeds in subcutaneous fat and intermuscular fat weights at equal side weight, and in fat partition between depots (subcutaneous and intermuscular fats) at equal total fat weight. Lirette et al. (1984) stated that breed had an important influence on fat deposition. Among the intact lambs of Suffolk and Finnish Landrace breeds, the former presented a higher accumulation of fat at the level of the spinous process of the 8, 9 and 12 ribs. These lambs also showed thicker dorsal fat deposits above the M. longissimus between ribs 8 and 9 and 12 and 13. On the other hand, Finn lambs accumulated more kidney fat than Suffolk lambs. Similar findings were reported by McClelland and Russell (1972) and Boylan et al. (1976) who noted that the influence of the Suffolk breed produces thicker dorsal fat deposits, whereas Finnish Landrace breed favours deposition of kidney fat.

In an attempt to provide a physiological explanation for breed differences in fat partitioning in sheep, Wood et al. (1980) suggested that the more prolific and heavier-milking breeds generally required greater internal fat deposition for the maintenance of lactation.

2-2-3-1-2-2 Within Breed

Genetic alteration in the fat content of any species depends on the heritability of depots, and on the genetic relationships among depot weights. According to Wolf et al. (1981), in most lamb studies from which genetic parameters have been derived only one fat depot has been increased, although where more than one depot was measured, genetic correlation between individual depots was often low. So, if there is a poor genetic relationship between the growth of different depots, selection based on one depot is unlikely to provide an effective reduction in other fat depots (Kempster, 1980). For example, at present live animal predictors of fatness are generally based on the subcutaneous fat depot and may result in a change in only this depot, rather than total fat (Thompson, 1982).

Progeny tests were used by Meyer et al. (1981/1982) over 2 years for Southdown and Suffolk breeds to investigate the selection for high and low backfat on lamb carcass characteristics. Fatness measures were adjusted for carcass weight. The results showed that, on average, progeny of low sires had 10% less fat at C fat depth, but this difference was not seen in tissue depth at GR. They concluded that successful selection against fatness at one carcass site may not be as beneficial as hoped in reducing total carcass fatness. Fennessy et al. (1982) used ultrasonic fat thickness measurements over the 12th rib on 41 Coopworth ram lambs to select the four fattest and leanest in order to investigate the effect of selection on carcass fatness. Ten to 12 male progeny of each of these rams generated from Perendale ewes were slaughtered at 4 to 7 months of age and 4 parameters of carcass fatness measured. The data indicated that differences between the progeny of the lean sires and the fat sires was significant for C backfat thickness over the 12th rib and S2, a fat depth in the shoulder region, but not for GR and total chemical fat. They concluded that selection on the basis of backfat thickness could be an effective means of reducing carcass fat thickness in lambs.

2-2-3-1-3 Nutrition

The influence of plane of nutrition or dietary energy level on patterns of fat partitioning and distribution have rarely been studied. Kempster et al. (1982a) suggested that increase in plane of nutrition may cause a shift of fat partition with greater quantities of fat being deposited in the subcutaneous depot at the expense of the other depots. Little and Sandland (1975) showed that nutritional restriction caused a relatively greater loss of fat from the subcutaneous fat depot than occurred through the body fat as a whole. The data showed that restricted animals had significantly lower proportions in the subcutaneous fat depots than had continuously-grown lambs. Similar responses to weight loss in ewes were recorded by Russel et al. (1968) in that a decrease in wool-free empty body weight of 22%, reduced fat by 51%. Elsley et al. (1964) indicated that the level of nutrition influenced lamb intermuscular fat to a smaller extent than subcutaneous fat. The effect of live weight loss and subsequent rehabilitation on fat distribution in sheep has been studied by Little and Sandland (1975). They found that the chemical

fat content of subcutaneous fat formed a lower percent of total chemical body fat (composed of intermuscular, subcutaneous, skeletal, visceral, viscera and blood fat) in two animals with interrupted growth path than in continuously-grown animals. Russel et al. (1971) studied fat distribution in two groups of Scottish Blackface ewes reared either in nutritionally poor or nutritionally better conditions. Their data showed that the amount of chemically determined fat in the muscular tissue and associated fat tissue, and that in the subcutaneous fat depot, formed a higher and a lower proportion, respectively, of carcass fat in the animals from the better nutrition group. The effect of three feeding systems (high (H), low (L) and high-maintenance-high (HMH) feed intake) from 15 to 40 kg live weight on the body composition of lambs was investigated by Murray and Slezacek (1976). They found that at the same total side fat, the weight of subcutaneous fat formed a greater proportion of total side fat in the high feeding group as compared with other groups, but the proportion of intermuscular fat was greater in both HMH and L groups than in the H group. However, the contrary results between the two experiments may be because of the greater live weight range (34 to 64 kg) of animals in the experiment of Russel et al. (1971), which made a valid comparison difficult. The differences in fatness between the pasture-fed lambs and those receiving a grain-based ration (Purchas, 1978) showed a clear treatment effect on the distribution of fat among the various fat depots measured. Thus the pasture-fed lambs had significantly more kidney + pelvic fat, omental fat and M. longissimus intramuscular fat but significantly lower fat depths at the 12th rib. Rib cut intermuscular fat did not differ significantly between the groups. Crouse et al. (1978, 1981) found that lambs fed a high energy diet had significantly greater amounts of kidney and pelvic fat, but not subcutaneous fat. Jones et al. (1983) found that lambs fed ad libitum had more fat in the intermuscular fat depot, but not in the subcutaneous fat than lambs fed 70% of expected ad libitum intake.

2-2-3-1-4 Sex

Few studies have specifically examined sex effects on fat partitioning at similar levels of fatness. Hammond (1932) showed that at 5 months of age, the percent of fat in the carcass of ewe lambs was greater than that of the ram lambs. He concluded that the difference was more marked in the case of intermuscular fat than the subcutaneous fat, corresponding with earlier maturity of the ewe lambs. The percent of caul and kidney fat of the ewe lambs was also slightly greater, although the gut fat remained about the same (Hammond, 1932). According to Butterfield et al. (1984), studies on fat deposition in the large species have generally been confined to the carcass depots and have shown little or no effect of sex on fat partitioning. Seebeck (1968) showed small differences between sexes (rams, wethers and ewes) in the distribution of subcutaneous fat and intermuscular fat, the only significant difference being that ewes had higher distribution of intermuscular fat in the loin and flank than rams and wethers. Thompson et al. (1979a, b) showed that the partitioning of total dissectible fat between the subcutaneous fat and intermuscular fat depots was not affected by sex (wether and ewe lambs). In the study of Fourie et al. (1970) no major differences were shown in the partitioning of subcutaneous, intermuscular and perinephric fat depots between ram and ewe lambs over the period from birth to maturity. Vezinhet and Prud'hon (1975) found that beyond 100 days of age, total fat was higher in female than in male lambs. This difference between the sexes was observed in the perirenal, pelvic and omental fats, but no difference was shown in subcutaneous and intermuscular fat. Similar observations were made by Jones, (1982) with no difference between rams and ewes in the rate of fat deposition in the carcass depots relative to total carcass fat, although at the same total carcass fat weight, the ewes had a slightly greater weight of intermuscular fat than the rams. At the same carcass weight, Butler-Hogg et al. (1984) found that ram lambs contained significantly less subcutaneous, intermuscular fats and KKCF than ewe lambs. The same authors found that the weight distribution of subcutaneous fat between four carcass regions (crop and neck, brisket, hind limb, and lumbar and abdominal) at the same weight of subcutaneous fat was the same for ram and ewe lambs, with most subcutaneous fat deposited in the crop and neck region. The data indicated also that small differences in

the weight distribution of intermuscular fat with rams having more in the fore limb and less in the lumbar and abdominal region than ewes. In both sexes the major site of intermuscular fat deposition was the neck and thorax (Butler-Hogg et al., 1984). Butterfield et al. (1985) indicated that Dorset Horn rams had a lower proportion of subcutaneous fat and higher proportion of intermuscular and mesenteric fat than wethers. However, the proportions of total carcass dissectible fat (subcutaneous fat and intermuscular fat) and of the total non-carcass depots (kidney and channel fat, omental fat, scrotal and thoracic fat) relative to total body fat did not significantly differ between rams and wethers. In a comparison of fat partitioning in mature Merino rams and ewes, Thompson et al. (1987a) reported that ewes had greater proportions of dissected subcutaneous fat and kidney fat, and lower proportions of dissected intermuscular fat than the mature rams. They attributed these differences to site-specific action of sex hormones on fat deposition in the body (Thompson et al., 1987a).

2-2-4 FAT TISSUE CELLULARITY

The amount of adipose tissue in an animal is determined by the number and size of the constituent fat cells (Goldrick, 1967). This statement implies that adipose tissue mass can expand by hyperplasia (cell proliferation), hypertrophy (cell enlargement), or a combination of the two (Greenwood and Hirsch, 1974; Garbutt et al., 1979; Hood, 1982; Cianzio et al., 1985). In order to understand the cellular basis for excessive adiposity, this review will be concerned with the factors which affect cellularity in ovine adipose tissue.

2-2-4-1 Factors Affecting Fat Tissue Cellularity

Development of adipose tissue occurs in three phases: an initial period of hyperplasia; a period of combined hyperplasia and hypertrophy; and a period when fattening occurs only by hypertrophy (Hood, 1982). Similar conclusions were drawn from the study of Haugebak et al. (1974), which reported that hyperplasia was more important to fat deposition than was hypertrophy in the early part of the finishing phase, but that in the later stage of finishing adipocyte hypertrophy appeared to be more responsible for adipose tissue accumulation than hyperplasia even though hyperplasia was still

occurring. According to Haugebak et al. (1974), when the weight of adipose tissue in a lamb reaches 25% of its body weight, the proliferation of adipocytes appears to be complete. The pattern for the development of adipose cells of sheep was described by Hood and Thornton (1979). Their data indicated that increases in adipose tissue mass was a function of both cellular hypertrophy and hyperplasia during the first 11 months with the increase in cell number being most rapid between 7 and 11 months of life. After 11 months, further increases in adipose tissue mass were expected to occur solely by hypertrophy of existing cells. These results have been substantiated by other investigations (Haugebak et al., 1974; Thornton et al., 1983). The contribution of hyperplasia and hypertrophy of adipocytes to the growth of subcutaneous fat, perirenal and omental fat depots of 32 growing Border Leicester X Merino wethers was examined in a 120-day growth experiment by Thornton et al. (1984). The animals were serially slaughtered over the live weight range of 29 to 56 kg, and they found that differential hypertrophy of existing adipocytes could alone account for the growth of all three adipose tissue depots. Broad et al. (1980) using a histological method, reported that cell number increased in sheep up to five years of age, although the results were variable. Butler-Hogg and Wood (1983) examined the cellularity of subcutaneous and kidney knob and channel fat from five lambs at 0, 50, 100, 150 and 200 days of age. The data indicated that hyperplasia was apparently complete at birth in KKCF, but that it was still continuing at 200 days of age in subcutaneous fat.

According to Allen (1976), adipocyte size varies among different fat depots of meat animals and two- to four-fold differences in the average size of adipocytes between the intramuscular and perirenal or subcutaneous depots may be found, with adipocytes within a depot ranging from 20 to 200 μm in diameter. Broad et al. (1980) concluded that in three carcass depots in Romney sheep (subcutaneous, intermuscular and perirenal fats), rates of hyperplasia could explain the differences in rates of development as hypertrophy occurred at the same rate in all three. Average adipose cell volume in sheep depot fats usually decreases in the fattening order: omental and perirenal > subcutaneous > intermuscular (Haugebak et al., 1974; Hood and Thornton, 1979). Thornton et al. (1983) found that average

subcutaneous fat diameter from the brisket region was smaller than that from the shoulder or rump regions in Dorset Horn X Merino lambs. Thornton et al. (1984) compared three fat depots (subcutaneous, perirenal and omental) in sheep ranging from 29 to 56 kg live weight and found that subcutaneous fat had the largest population of adipocytes, but that its cells were the smallest and showed the slowest rate of volume increase. Omental fat had the lowest number of cells, but its cells were the largest and grew the fastest, while perirenal fat was intermediate in terms of cell number, size and growth rate.

Merkel et al. (1973) studied the effect of breed on adipose tissue cellularity in Southdown and Suffolk lambs. There were no significant differences between the two breed groups for adipocyte volume or the number of adipocytes per gram of tissue. Butler-Hogg and Wood (1983) studied the effect of breed on cellularity of subcutaneous and KKCF depots in Clun and Southdown lambs from birth to 415 days. The data indicated that the difference between the two breeds in the cellular development of the two depots was of minor significance. Similar observations were made by Vigneron et al. (1984), when comparing 21 Merinos d'Arles and 17 crossbred Berrichon X Merinos d'Arles. They found no significant breed differences in the cellularity of the perirenal, omental and inguinal adipose tissue depots.

Cellular differences due to sex have been reported in adipose tissue of lambs (Merkel et al., 1973; Allen et al., 1976; Thompson and Butterfield, 1987; Thompson et al., 1987b). Merkel et al. (1973) reported that at eight weeks, adipocytes from the ewes had larger diameters than those from either wethers or rams although they were 8 kg lighter. Adipocytes were not different at 16 weeks, but adipocytes from rams were smaller than from ewes at 32 weeks. They concluded that cellular differences due to sex may change with maturity, which suggests that sex hormones may affect that distribution. Similarly, as discussed by Hood (1977), sex differences in cellular characteristics reflect the specificity of action of sex hormones. Allen et al. (1976) reported results of an experiment in which ewes had larger adipocytes in subcutaneous fat than rams. More recently, Thompson et al. (1987b) reported that mature ewes had larger and fewer adipocytes in the subcutaneous and intermuscular fat depots than mature rams.

The same authors found that sex had no effect on adipocyte volume in the kidney, omental and mesenteric fat depots in the mature animals, although the mature ewes had fewer adipocytes than the mature rams in the omental and mesenteric fat depots. Furthermore, Thompson and Butterfield (1987) reported that castration had the effect of increasing adipocyte volume and decreasing the estimated number of adipocytes in five dissected fat depots (subcutaneous, intermuscular, kidney, omental and mesenteric) in mature sheep.

Burton et al. (1974) have reported significant differences in the diameter of adipocytes between sheep which had a maximum growth rate to 71 kg full body weight and sheep which had been given a sub-maintenance ration from 70 to 50 kg. However, the diameters were similar when the 50 kg sheep were re-alimentated back to 71 kg full body weight. Similarly, Hood and Thornton (1979) showed that when sheep were subjected to nutritional restriction resulting in negative growth, and then rehabilitated, the relationships of number and volume of adipocytes with carcass weight, boneless carcass fat, and weight of fat-free muscle weight were similar to the respective relationships for sheep with normal growth patterns. Thornton et al. (1979) reported that loss of fat from the body of immature sheep were associated with atrophy and hyperplasia of subcutaneous adipose cells, but in mature sheep there was atrophy without hyperplasia of adipose cells. In the study of Haugebak et al. (1974), 40 crossbred western wether lambs were divided into two equal groups. During a 150-day growth period, 20 lambs received a maintenance diet and 20 lambs were fed ad libitum. At the end of the growth phase, lambs fed ad libitum contained significantly larger subcutaneous and perirenal adipocytes than lambs fed at maintenance, but there was no difference in the size of breast intermuscular adipocytes due to energy intake.

2-2-5 MUSCLE TO BONE RATIO

Increases in the percent of muscle in a carcass are brought about either by decreases in the percent of fat or by increases in the muscle:bone ratio (Butterfield, 1976). In general, comparisons of muscle:bone ratios are made at the same level of fatness, at equal muscle plus bone weights, or if the range of fatness is not great, at equal carcass weights (Berg and Butterfield, 1966; Butterfield, 1976).

2-2-5-1 Factors Affecting Ratio of Muscle to Bone

The effect of age/size, genotype, sex and nutrition on the muscle:bone ratios of sheep are reviewed.

According to Kirton (1982), it is generally accepted for lambs of a given breed and sex that carcass weight is the most important factor associated with variation in composition. The ratio of meat to bone in the carcass increases in a linear manner with increasing live weight (Fourie et al., 1970; Rouse et al., 1970; Shelton and Carpenter, 1972; Campion et al., 1976; Sents et al., 1982). In general, these studies concluded that fat becomes an increasing proportion of heavier sheep or lamb carcasses and the proportion of muscle and bone decreases with increasing carcass weight. Wood et al. (1980) showed that as the carcass weight increased from 15 to 21 kg the muscle to bone ratios increased significantly from 4.22 to 4.72, respectively. Sents et al. (1982) found that the increase in muscle to bone ratios between 45.4 and 72.6 kg slaughter weights was 0.45.

Breeds of smaller mature size tend to produce carcasses with more fat and less muscle and bone than those from breeds of larger mature size when carcass composition is compared at the same carcass weight (Kirton, 1982). Of the breeds measured by Fourie et al. (1970), the Southdown had a higher muscle to bone ratio than the Romney or Southdown X Romney cross at the same carcass weight. Similar findings were reported by Fahmy et al. (1972), based on data for 396 lambs born to crossbred ewes and by Southdown or Suffolk rams. Furthermore as a result of increased age and weight, muscle to bone ratio increased (Butler-Hogg, 1984b) and there was a higher muscle to bone ratio for Southdown rams than Clun rams. Kempster et al. (1976) analysed carcass data for 424 lambs comprising seven breed-type groups (Welsh Mountain, Blackface, Longwool crosses, Suffolk crosses, Intermediate, Southdown crosses and Lowland Longwool) and found muscle to bone ratios to be higher for crosses of the Southdown breed than the Suffolk. These results are what would have been expected from the mature sizes of the breeds concerned, to the extent that this is known (Kirton, 1982). Butler-Hogg and Whelehan (1984) used Texel and Scottish Blackface rams ranging in age from 6 months to 4.5 years to investigate the effect of mature size on carcass composition. As

expected by the breed's greater mature size, the Texels were heavier and had a greater weight of carcass and lean tissue than the Scottish Blackface rams. Bone weight was not significantly different. They concluded that muscle to bone ratio at constant subcutaneous fat percent increased with increasing weight and age, and was higher in the Texel than the Scottish Blackface rams.

A study reported by McClelland et al. (1976) compared a range of contrasting breed types (Soay, Finnish Landrace, Southdown and Oxford) which were fed ad libitum on a standard diet and serially slaughtered at 40%, 50%, 60% and 70% of their estimated mature weight. When body composition was expressed as a percent of carcass weight at equal stage of maturity, the Soay sheep had the highest muscle percent (59.7) while the Oxford had the lowest (50.1). For bone percent the Soay breed had the highest (21.9) and Southdown the lowest (14.8) to give differences between these breeds in muscle to bone ratio at the same degree of maturity, with values of 2.51 for the Soay breed and 3.85 for the Southdown. Tempest and Boaz (1977) studied the carcass composition of lambs bred so as to illustrate the influence of fine Merino ancestry, which made up from 0% to 100% of the genotype. The data indicated that the only tissue which significantly decreased was bone. This resulted in a significant increase in muscle to bone ratio from 4.34 to 5.02 as the proportion of Merino increased from 0% to 100%. The effect of the Finnish Landrace breed on carcass composition was examined by comparing male progeny of Galway ewes which had been mated with Finn, Galway or Fingalway (1/2 Finn X Galway) rams (Hanrahan et al., 1978). At the same carcass weight, breed differences in the muscle weight were significant with the Finnish Landrace genes not affecting bone, but causing an increased muscle to bone ratio in the 7-12 rib cut. Wood et al. (1980) found that Suffolk sheep had significantly lower muscle to bone ratios (4.38) than either Clun Forest (4.64) or Hampshire (4.56). From their studies on the maturity patterns of carcass muscle and bone, using dissection data from 20 large-mature-size strain and 19 small-size strain Merino rams Butterfield et al. (1983a) concluded that composition of mature rams of both strains was similar with respect to the proportions of muscle and bone, and muscle to bone ratio.

Carcass results from the MLC's Ram Breed Evaluation project were reported by Kempster et al. (1983) for 10 sire breeds (Border Leicester, Dorset Down, Hampshire Down, Ile-de-France, North Country Cheviot, Oxford Down, Southdown, Suffolk, Texel and Wensleydale). Texel crosses had higher lean percents than other crosses and also a lower total dissectible fat, a lower bone content and a higher muscle to bone ratio than other sire breed crosses in both early- and late-maturing flocks. Oxford Down crosses had a lower lean to bone ratio in both types of flock, although they did not differ significantly from some of the other Down breeds in this respect. Recently, Cameron and Drury (1985) recorded the carcass composition for the progeny of matings of Oxford, Texel, Texel-Oxford, Charollais, Charmoise and Meatline rams with crossbred ewes. At a fixed weight the carcasses of Charmoise crosses had a lower total lean weight and bone weight than the other breeds. The Texel crosses had proportionately more lean than the Charmoise due to their higher muscle to bone ratios while the Oxford crosses had the lowest muscle to bone ratio.

It is generally conceded that male sex hormones specifically stimulate muscle growth to give the entire male a higher muscle for bone ratio (Butterfield, 1976). Furthermore, because androgens generally are considered responsible for bone development, it would be logical to expect rams to have heavier and larger bones than wethers (Seideman et al., 1982). So rams contain on average more muscle, more bone and less fat (Ahmad and Davies, 1986) than wethers of similar live weight, and wethers contain less fat and more muscle than ewes, but the muscle to bone ratio is generally highest for ewes, lowest for wethers and intermediate for rams. The expected differences between rams and ewes have also been reported by Fourie et al. (1970) with rams having more muscle and bone and less fat than similar weight ewes, but the muscle to bone ratio was higher for ewes than rams at the same weight. A similar conclusion was drawn by Theriez et al. (1982), whose study showed that ewes had higher muscle to bone ratios than rams. McClelland et al. (1976) proposed that differences in body composition of rams and ewes at equal weight could be explained by the more advanced stage of maturity of the ewes. The carcass composition of 15 ram and 15 ewe purebred Dorset Down lambs was investigated (Butler-Hogg et al., 1984) at a mean carcass weight of 16.8 kg. Rams contained significantly more muscle and bone than the ewes, with the

higher bone content resulting in a significantly lower muscle to bone ratio in the rams. These results are in good agreement with the data of Fourie et al. (1970) and reflect the greater degree of maturity of the ewe at any body weight. Wood et al. (1980) compared wether and ewe lambs at the same carcass weight and found that ewe lambs had significantly higher muscle to bone ratios than wether lambs. Purchas (1978) and Lirette et al. (1984) reported no effects of castration on the muscle to bone ratio in sheep.

Several research comparisons have shown that longer sheep carcasses contain more muscle and bone and less fat than blockier carcasses of similar weight (Kirton and Pickering, 1967; Fourie et al., 1970). However, according to Kempster et al. (1981), breed differences indicated that breeds with better conformation do not necessarily have higher lean to bone ratios. Suffolk crosses for example, have low lean to bone ratios but good conformation while the Texel crosses stand out in lean to bone ratio but do not have sufficiently higher conformation scores to identify their advantage. Relationships of this type were also evident in the survey of Kempster and Cuthertson (1977), which showed that in seven groups of British breed types and crosses the Suffolk crossbred group had the second highest conformation score but the lowest lean to bone ratio. The poor relationship between conformation and lean to bone ratio was also apparent in the results of Jackson and Mansour (1974) and may reflect differences in bone structure (Kempster et al., 1982b). Selection of well- and poorly-muscled lamb carcasses of the same weight by trained meat industry personnel (Kirton et al., 1983) revealed that the poorly-muscled group had a higher percent of muscle (55.4 vs 52.6) and bone (18.9 vs 14.7) than the good group, but that the muscle to bone ratio was higher for the carcasses with good muscling (3.58 vs 2.93).

As mentioned previously, carcass composition changes in sheep are primarily a function of maturity or body weight. The principal effect of plane of nutrition on fat content of the sheep body is by virtue of its influence on growth rate and hence upon body weight. Purchas (1978) compared lambs on pasture with lambs receiving barley for the composition of a rib cut, and found muscle to bone ratio was significantly higher for the pasture group than for the grain group. Asghar and Yeates (1979) found that lambs on a maintenance ration had lower

muscle to bone ratios than control lambs, but the latter group were heavier than the maintenance group. Theriez et al. (1982) found that at the same weight, lambs fed a diet including 50% of alfalfa and 50% concentrate had higher muscle to bone ratios than other diets (80:20) or (20:80) of the same alfalfa and concentrate, respectively. Recently, the carcass composition of 48 Merino X Border Leicester lambs fed higher or lower energy diets were investigated by Ahmad and Davies (1986) at a similar live weight. The high-energy diet lambs had significantly higher muscle to bone ratios than the low energy diet lambs (3.93 vs 3.59).

2-2-6 MUSCLE WEIGHT DISTRIBUTION

More precise information is available on the growth of the musculature than on the growth of any other tissue of meat animals (Butterfield et al., 1983b). A number of studies have investigated differential muscle growth patterns in serially slaughtered sheep by anatomical dissection into the separate muscles, and by grouping muscles into standard muscle groups of anatomically defined regions. Lohse et al. (1971) and Jury et al. (1977) reported allometric growth coefficients (AGCs) above 1.0 for the proximal muscles for the hind limb while distal muscles of the hind limb had allometric coefficients below 1.0. Muscles surrounding the spinal column have been shown to constitute an increasing proportion of total muscle in the immediate post-natal phase (AGC>1), but a constant proportion of the whole in later stages of growth (AGC=1) (Lohse et al., 1971; Jury et al., 1977). In the study of Butterfield et al. (1983b), growth patterns were established for 93 individual muscles and nine anatomical groups of muscles, using half carcass dissection data from 39 Merino rams. The data indicated that the muscles of the limbs and those surrounding the column had maturity coefficients greater than 1.0 and were earlier-maturing than total muscle. In contrast, the muscles of the cranial end of the trunk had maturity coefficients less than 1.0 and were late maturing, while the muscles of the abdominal wall matured at the same rate as total muscle. However, Butler-Hogg (1984b) showed that for the growth of muscle over the period from birth to 415 days, the highest relative growth was in the forelimb, followed by the neck and thorax, hind limb and lastly the lumbar and abdominal regions. The above-mentioned studies have shown that some individual muscles

differed in their growth patterns relative to total muscle. Different workers have not always agreed on growth classifications of individual muscles. Therefore, the importance of the effects of breed, sex and growth rate on muscle distribution of sheep relative to total muscle will be reviewed.

2-2-6-1 Factors Affecting Muscle Weight Distribution

Genetic variation in muscle weight distribution in different anatomical joints could be of great importance commercially. According to Lirette et al. (1984) at the same degree of maturity, differences between breeds in muscle distribution within the different cuts were small. In the study of McClelland et al. (1976), breed differences (Soay, Finnish Landrace, Southdown and Oxford Down) in muscle distribution at equal stages of maturity of sheep were not found. They also showed that muscle as a percent of fleece-free empty body weight remained unchanged from one stage of maturity to another in the range from 40 to 76% of mature body weight. As a percent of carcass weight, however, total muscle did decline as maturity increased and there were significant between-breed differences. However, according to Seebeck (1968) changes in the distribution of muscles do occur during developmental growth. In particular, the proportion of the total muscle found in the leg decreased as total muscle increased. The same author showed that the differences in the distribution of muscle that occurred between Merino and Dorset Horn X Border Leicester-Merino lambs were significant. There was 15.7% more muscle in the neck and 6.2% less muscle in the thorax of the Merino than in the crossbreds at a constant side muscle weight. Jury et al. (1977) studied the muscle distribution in the Romney and Southdown breeds and their cross. At constant total muscle weights, there were no differences between breeds, except for the muscles of the neck and thorax regions which had higher growth rates and proportions for the Romney breed, while abdominal muscles were higher for the Southdown breed. Kempster and Cuthbertson (1977) found that breed means for the proportion of total lean in the higher-priced joints of commercial lamb carcass of British breeds ranged between 547 and 573 g/kg. Croston et al. (1979) reported sire breed means for this trait between 535 and 554 g/kg for crossbred lambs compared at a constant level of subcutaneous fat in the carcass. In both reports the majority of

breeds did not differ significantly for this trait. Taylor et al. (1980) compared muscle distribution of four breeds (Soay, Southdown, Finnish Landrace and Oxford Down) at 40, 52, 64 and 76% of their estimated mature body weight. Comparisons were based on 12 muscles obtained from the prime retail joints. Highly significant breed differences in the weight of individual muscles were obtained, but these differences were greatly reduced when comparisons were made at a constant proportion of expected mature body weight. In muscle distribution, the Southdown had the highest percent of the four breeds for 6 of the 12 muscles examined, whereas the Oxford Down had the lowest percent for 6 of the 12. The Finnish Landrace was distinguished by being intermediate for most muscles, and differed from the Soay which tended towards the extremes, being highest for two, lowest for four and intermediate for six of the muscles examined. The distribution of lean tissue between eight standard joints was examined by Wolf (1982) in 956 crossbred (Dorset Down, Ile-de-France, Oldenburg, Oxford, Suffolk and Texel) lambs. The results revealed that sire breed did not have a significant effect on the proportion of total carcass lean found in the higher-priced joints, but did influence the proportion of total carcass lean found in individual joints, with a maximum difference of 7.7 g total lean per kg joint being recorded. Similar conclusions were drawn from the study of Kempster et al. (1983), with the range of differences between sire breeds in the distribution of total lean between various joints being small. Nevertheless significant differences were recorded. Ile-de-France crosses had a higher proportion of total lean in the leg than North Country Cheviot crosses, and Texel crosses had a lower proportion of total lean in the loin than Southdown crosses and Hampshire Down crosses. In terms of the total proportion of higher-priced cuts, the Hampshire Down cross had the highest values. These observations were substantiated by the studies of Butler-Hogg and Whelehan (1984) and Butler-Hogg and Whelehan (1987) in which small differences between breeds for muscle distribution were reported.

Sex differences in muscle weight distribution become apparent after puberty. Bradford and Spurlock (1964), Prescott and Lamming (1964), and Kemp et al. (1970a) reported that ram lambs have a higher proportion of neck and shoulder cuts than wethers. The distribution of muscle in five cuts (neck, thorax, loin and flank, shoulder and

leg) was compared among ram, wether and ewe lambs of Merino and Dorset Horn crossbreds by Seebeck (1968) and it was found that there were no significant differences between the sexes for muscle distribution. Jones et al. (1983) found some differences between sexes in muscle distribution with rams having more muscle in the shoulder and less in the leg than ewes. Furthermore ewes had a higher proportion of total lean in the chump, breast and higher-priced joints and a lower proportion in the shoulder and scrag than castrated males in the study of Wolf (1982). These results were in keeping with the more detailed analyses of Lohse (1973), Jury et al. (1977) and Taylor et al. (1980). These workers related their findings to the functional role of muscle differentiation in sexual development. Lohse (1973) reported differences in the relative growth and distribution of certain muscles between rams and ewes, particularly with respect to the neck muscles which were a higher proportion of muscle in rams than in ewes. Similar results were found by Jury et al. (1977). At constant total muscle weight the rams had a higher muscle proportion in the neck and thorax regions, but the ewes had greater abdominal muscle weight. They attributed this effect to androgens which stimulate the neck muscles in the entire male sheep, although it is difficult to explain why androgens would not equally affect all the carcass muscles of the male animal (Jones et al., 1983). An alternative hypothesis is that the heavier weight of the head of the entire male animal stimulates the growth of the neck muscles due to the greater load they have to support (Lohse, 1973). Taylor et al. (1980) found highly significant sex differences in the weight of 12 muscles at the same degree of maturity with heavier muscles in ewes than rams, but these differences were greatly reduced when values were expressed as a percent of total muscle weight. Lirette et al. (1984) showed that the proportion of muscle was significantly higher in the necks of entire Finnish Landrace X Suffolk and Finnish Landrace lambs, while the muscle content of the roast cut was significantly higher for castrated Suffolk lambs. Butler-Hogg (1985) compared the distribution of individual muscles and muscle groups in rams and ewes of Dorset Down carcasses at constant carcass weight (16.8 kg). The data indicated that differences in muscle weight proportions were significant for 17% of the 72 muscles, with the largest being 2.5 units in favour of ewes in the M. biceps femoris. Also rams had significantly less of their total

muscle in the proximal pelvic limb and more in the distal thoracic limb and neck.

The muscle distribution of Border Leicester X Merino and Dorset lambs which were grown along three growth paths: high (H), high-maintenance-high (HMH) or low (L), have been reported by Murray and Slezacek (1975). The relative growth and final proportion of proximal muscles of hind leg, distal muscles of the fore leg, thorax and total side muscle formed by some groups was greater in the L treatment than H or HMH treatments. The differences were interpreted in terms of the greater age and hence skeletal size in the L treatment. Lohse et al. (1971) compared two groups, a continuously-grown group and a group which suffered a six-weeks period of live weight loss followed by recovery, and found that the relationship of the weight of the low impetus muscles to that of total muscle was not significantly different between groups, but the same relationship for the high impetus muscles was highly significantly different in favour of a continuously-grown group. They concluded that the weight relationship of high impetus to total muscle was a sensitive test to differentiate between normal and recovering muscle. Small differences in muscle distribution were found by Jones et al. (1983) between dietary energy intake groups, with sheep on the high energy level (ad libitum) having more muscle in the loin and shoulder and less in the leg than those sheep fed 70% of expected ad libitum. Murray and Slezacek (1975) reported no nutritional effects on muscle distribution in sheep. However, the differences found in the study of Jones et al. (1983) were small and commercially unimportant in the weight range that was studied.

2-3 MEAT QUALITY AND ITS EVALUATION

Within recent times the study of meat quality has become increasingly scientific with less reliance being placed on personal judgement and more on physical and chemical tests (Asghar and Pearson, 1980). This is because all sensory evaluation, regardless of whether it involves laboratory panels or consumers, is faced with many methodological, psychological and physiological problems (Brady and Hunecke, 1985). In addition, it is both costly and time-consuming (Harris, 1976). To avoid these problems and to obtain the advantages

of speed, reproducibility and relative ease of standardisation, instrumental methods of measuring physical aspects of meat have been sought (Brady and Hunecke, 1985).

2-3-1 DEFINITION OF MEAT QUALITY

Pearson (1968) suggested that meat quality is a combination of the attributes of flavour, juiciness, texture, tenderness and appearance that contributes to the eatability or the desirability of the product. The consumer relates to quality in terms of the tenderness, juiciness and flavour of the cooked products (Bray, 1966). In general, however, a given consumer's acceptance of cooked meat is determined by his singular or combined responses to the flavour, juiciness and tenderness of the product (Jeremiah et al., 1970).

2-3-2 EVALUATION OF MEAT QUALITY

Only palatability and appearance characteristics will be considered in this section. Characteristics contributing to palatability include tenderness, juiciness and flavour, and those contributing to the appearance of the meat include the colour of lean, the colour of fat, and texture. The subjective and objective methods available to assess these parameters will be reviewed separately.

2-3-2-1 Subjective Evaluation

This involves evaluation by the physical senses of the consumer. Weir (1960) pointed out that the overall subjective impression of tenderness consists of at least three components: 1, the initial ease of penetration of the meat by the teeth; 2, the ease with which the meat breaks into fragments, and 3, the amount of residue remaining after chewing. Similarly an impression of juiciness comprises the combined effects of the liquid released from the meat and of the amount of saliva added to it (Weir, 1960). Flavour is a complex sensation involving odour, taste, texture, temperature and pH (Lawrie, 1985). Colour and general attractiveness are judged visually. Subjective quality evaluation is not simple, for it involves the physiological, psychological, social and economic status of the consumer (Pilgrim, 1957), so that quality and its components mean

different things to different people. Subjective evaluations are often made by a panel of judges, and this leads to one of the most logical methods for assessing meat quality (Asghar and Pearson, 1980). Taste panels range in size from a few very highly-trained people of exceptional sensitivity, up to as many as several hundred untrained, randomly-selected consumers (household type) (Abbott, 1972). Frequently, a score card utilising a hedonic scale, where each quality criterion is described on an arbitrary numerical scale, is used by the panel.

2-3-2-2 Objective Evaluation

Various methods have been used to assess meat quality objectively. The results are satisfactory for some of the criteria (e.g. tenderness, water-holding capacity, juiciness and colour) but less so for characteristics such as flavour and odour (Lawrie, 1985).

2-3-2-2-1 Tenderness

The measurement of meat tenderness is extremely difficult because meat is not a simple one-component system (Cover et al., 1962a,b,c,d). It is instead the result of two structural components, muscle fibres and connective tissue, and is further complicated by the presence of fat interspersed within these structural elements. A variety of instruments has been developed to measure tenderness of meat, usually based on a shearing, penetrating, biting, stretching, breaking or compressing action (Pearson, 1963; Szczesniak and Torgeson, 1965). The Warner-Bratzler Shear device has been widely used for the evaluation of meat tenderness (Asghar and Pearson, 1980).

The usefulness of any objective method can arise from either its correlation with taste panels or on its sensitivity to structural changes (Harris, 1976). Reports of correlations between shear values, measured as maximum shear force and taste panels have ranged from being highly significant to being non-significant (Asghar and Pearson, 1980; Hayward et al., 1980; Moskowitz, 1981; Brady and Penfield, 1982; Brady and Hunecke, 1985).

The variation of the reported correlations between objective and subjective measurements of tenderness is to be expected, because the mechanical devices and the taste panelists are measuring different structural properties of the meat (Szeszaniak, 1968). There are large differences in connective tissue strength between samples (Bouton et al., 1973b; Paul et al., 1973; Penfield and Meyer, 1975) and the results obtained with the Warner-Bratzler Shear device have indicated that peak shear-force values relate more closely to the myofibrillar component of toughness than to the connective tissue component (Bouton and Harris, 1972; Paul et al., 1973; Cross et al., 1973). Brady and Hunecke (1985) studied the correlations between sensory and instrumental tests, and found that the sensory parameters related to work required to masticate samples. Hardness, deformation, chewiness and overall tenderness, were all correlated with shear firmness and with the exception of deformation, these same sensory parameters were not found to be associated with penetration or compression test parameters (Brady and Hunecke, 1985).

2-3-2-2-2 Juiciness

Juiciness refers to the liquid detectable during the chewing of a bite of meat (Blumer, 1963). According to Harris (1976) meat juiciness has been attributed to both moisture released by the meat during chewing and moisture from salivation induced by flavour factors. He noted that moisture released by the meat is considered to relate to expressible juice whereas the amount of saliva produced is highly subjective and can be best measured by a sensory panel. Expressible juice values and cooking losses have been reported to be highly correlated ($r=0.97$ and 0.92) with sensory panel measurement of juiciness (Bouton et al., 1975b). Many investigators have estimated the amount of juice expressed under pressure as an objective index of juiciness. Such a measurement may also reflect the water-holding capacity of the meat (Wierbicki and Deatherage, 1958; Briskey et al., 1959; Sanderson and Vail, 1963; Tsai and Ockerman, 1981; Hofmann, 1982; Hofmann et al., 1982; Matyniak and Ziolecki, 1983). The basic principle in most of the methods described is the same, but there are slight variations with respect to the degree of pressure applied and the way of interpreting the results.

Expression of juice from meat by standard centrifugation conditions has also been used as a measure of juiciness and water-holding (Bouton et al., 1971, 1972a; Jauregui et al., 1981; Tsai and Ockerman, 1981).

It should be expected that a positive correlation would exist between the expressed juice content of cooked meat and its juiciness such that more juicy meat should contain more expressible juice. Low correlations between objective and subjective evaluations have been reported in some studies (Gaddis et al., 1950; Smith and Carpenter, 1970; Lundstrom et al., 1979), while other studies have reported significant correlations between scores for quantity of juice and amount of expressible juice (Tannor et al., 1943; Hardy and Noble, 1945). A positive significant relationship between percent press fluid and initial juiciness and for juiciness scores was noted for cooked beef M. semitendinosus (Gullett et al., 1984) but not for M. longissimus. Expressible juice values for cooked beef samples and cooking losses have been found to be highly correlated with subjectively determined juiciness (Bouton et al., 1975b). Harris (1976) concluded that cooking loss was inversely related to amount of free or expressible moisture of the cooked sample. It appears that a great deal of the disagreement in the literature must be due to different interpretations of juiciness (Hamm, 1960) and to different techniques for the determination of expressible fluid.

2-3-2-2-3 Colour

Meat colour measurements involve two basic methods: human visual appraisal and instrumental analysis. Both methods inherently involve an assessment of the concentration and the chemical form of myoglobin, the morphology of the muscle structure, and the ability of the muscle to absorb or scatter incident light (Walter, 1975).

Subjective evaluation of muscle colour is difficult, because environmental conditions such as light intensity, light colour and colour of background influence these ratings. Therefore objective meat colour appraisal has been attempted by several methods, including spinning discs (Hiner, 1954); colour paddles (Hiner, 1954); pigment extraction (Tauber and Simon, 1963); and reflectance (William and

Solberg, 1971; Govindaraja, 1973; Strange et al., 1974; Francis and Clydesdale, 1975; Davis et al., 1978; Harrison et al., 1980). Reflectance spectrophotometry is used extensively for studying coloured food products and biological materials (Davis et al., 1978). Usually, specific reflectance measurements are related to visible changes resulting from changes in the concentration or the chemical state of pigments due to processing, storage and/or packaging. Several workers have reported correlations between visual and reflectance spectrophotometry measurements ranging from -0.77 to 0.88 depending on the wavelength used (Hunt, 1980). The latter author attributed the variable correlations between the two techniques to: 1, uneven surface discolouration of meat causing visual panels to give an "average" colour score; 2, spectrophotometers and colourimeters scanning a limited area of the meat surface, thereby creating a sampling problem; 3, physical factors like glossiness, structural differences, meat juice and packaging flaws being disregarded by panelists but not by instruments, and 4, the fact that an instrument cannot make a decision on colour acceptability (Harrison et al., 1980). Renner and Mazuel (1985) studied the relationships between instrumental and sensory measurement methods of meat colour of beef M. longissimus and M. triceps brachii (caput longum). They found that the highest correlation with panel preference ($r=0.93$) was at R630-R580.

2-3-3 FATNESS AND MEAT QUALITY

The relationship between fatness and meat quality has received considerable attention for many years. Fat occurs in the body as adipose tissue, both within and between muscles, as well as intracellularly (Asghar and Pearson, 1980). Intramuscular fat, commonly known as marbling, and subcutaneous fat have received the most attention as factors affecting quality.

2-3-3-1 Fatness and Meat Tenderness

Consumer acceptance studies have indicated that tenderness is very often the most important attribute determining overall eating satisfaction (Jeremiah and Martin, 1982; Lawrie, 1985).

Some attention has been paid to the relationship between back fatness and intramuscular fat or marbling scores, and it has been suggested that the primary advantage of marbling may be its association with increased carcass fat covering, which will in turn decrease chilling rates and produce more tender meat indirectly rather than directly (Smith et al., 1976; Bowling et al., 1977). Marbling score is positively associated with the level of fatness, with a higher degree of marbling being associated with greater fat thickness (Wellington, 1968). Tatum et al. (1982) examined the combined effects of marbling and fat thickness on beef palatability, and found that marbling had a more pronounced effect on cooked beef tenderness than did fat thickness. The minimum response in tenderness occurred when low levels of marbling were combined with subcutaneous fat levels below 2.5 mm and above 22.9 mm. The highest tenderness was observed among steaks with high levels of marbling and intermediate levels (7.6 to 20.3 mm) of subcutaneous fat (Tatum et al., 1982).

2-3-3-1-1 Marbling and Tenderness

Marbling is the common name used to indicate the more explicit term intramuscular fat. However, according to Blumer (1963), marbling in the strictest sense refers only to that which appears visible to the unaided eye on the cut meat surface, while intramuscular fat includes this visible fat and also microscopic deposits within various muscle cells, some of which are not fat cells. Therefore, marbling may be considered as a representation of the larger neutral fat deposits of muscle.

Hammond (1932) found practically no relation between marbling and tenderness in lamb, but concluded that "no doubt" such a correlation (a positive relationship between marbling and tenderness) does exist with animals of different degrees of fatness. Cover et al. (1956) found that although correlations between ether extract and beef tenderness were positive, none was very high. Similar observations were made by Batcher et al. (1962a) for lamb. The opposite views are represented by those of Naumann et al. (1960), who found that heavily-marbled pork chops had the lowest Warner-Bratzler (WB) shear values. In the work of Batcher et al. (1962b), pork tenderness was related to marbling score or to intramuscular fat content in only a few cases,

and the correlation varied with the muscle. These results contradict earlier findings of Batcher and Dawson (1960) in which marbling was significantly correlated with sensory tenderness of cooked pork. Tuma et al. (1962b) found that steaks from M. longissimus with marbling levels of slight and slightly abundant did not differ significantly as evaluated by a taste panel, but WB-shear values were significantly lower for the slightly abundant marbled steaks. Blumer (1963) summarised the many studies on the relationship of marbling and beef tenderness and reported on the basis of the 2600 cattle used in the several studies, that only 5% of the variation in tenderness could be accounted for by marbling. Szczesniak and Torgeson (1965) presented the argument of other workers that marbling enhances the tenderness of meat. However, they also presented other reports suggesting that marbling is not necessarily an infallible criterion of meat tenderness. Smith and Carpenter (1976) reviewed numerous investigations relating marbling or intramuscular fat content to the tenderness of lamb, pork and beef. These studies suggested that fatness had a moderate relationship to tenderness in pork and a low to moderate relationship to tenderness in lamb and beef. The same authors listed mechanisms by which marbling may improve the tenderness. These included: by lowering the bulk density and decreasing the mass per unit, by decreasing the width and thickness of connective tissue through deposition inside connective tissue wall, by spreading in around each muscle fibre and serving to lubricate, and by improving the cooking method because marbled meat can endure higher external cooking temperatures. The relationship between intramuscular fat percent and beef quality was investigated in a group of Friesian steers in which the relationship between fatness and chronological age had been minimised by having six levels of nutrition to produce a wide range of body composition (Purchas and Davies, 1974b). Up to 38% of the variation in shear force of M. longissimus could be accounted for by variation in intramuscular fat percent, but in another two muscles (M. rectus femoris and M. semitendinosus, which had not shortened) the relationship between shear force and intramuscular fat percent was not significant. Martin and Fredeen (1974b) found that lean pigs produce less tender meat than fat pigs. Similar observations were reported by Jennings et al. (1978), who reported that beef loin steaks possessing modest or above marbling levels had lower shear values and higher tenderness than steaks of slight or lower marbling levels. In sheep,

similar observations were made by Cross et al. (1972) who reported significant correlations between intramuscular fat content and sarcomere length in lamb, suggesting that marbling might also be related to tenderness via an insulatory effect in reducing the severity of cold shortening induced by low temperature chilling. Smith et al. (1976) studied the effects of intramuscular fat deposition on the tenderness of meat from 40 lamb carcasses. The results showed that increased deposition of intramuscular fat in the M. longissimus at the 12-13th rib interface was associated with increased tenderness of the M. longissimus, M. biceps femoris and M. semimembranosus, but that the relationship was not linear. From the study of Jost et al. (1983) regression analysis indicated a 16-unit increase in marbling would be required to produce a unit increase in taste panel tenderness. In the study of Tatum et al. (1980), sensory panel ratings generally increased and shear force values generally decreased as degree of marbling increased. However, the differences associated with each successive increase in marbling were not always directionally consistent, nor were they always statistically significant. Steaks with marbling scores of "modest" had significantly lower shear force values than steaks with marbling scores of "slight minus" or "traces-plus". The chemical, cooking and physical properties of M. semimembranosus, M. semitendinosus and M. biceps femoris of ham were determined by Lin et al. (1985). Fat content of muscle was significantly and negatively correlated to the force required to penetrate the ham samples. This is due to the plastic properties of fat, which requires less force to penetrate when compared to protein fibres. Similar results were reported by Smith et al. (1984) who concluded that loin, top round, bottom round and eye of round steaks from steer carcasses with higher marbling scores (more intramuscular fat) were more desirable in tenderness and had lower shear force values than steaks from carcasses with lower marbling scores. Softness increased and chewiness scores decreased as the level of fat increased (Costello et al., 1985). Steaks that contained 20% and 25% fat scored softer and yielded significantly more readily than did steaks that contained 15% fat. The differences may have been related to the lower number of coagulated muscle fibres present in the cooked steaks with the higher fat percent. Cross and Stanfield (1976) reported that restructured steaks that contained 30% fat had higher panel ratings for tenderness than did steaks that contained 20% fat. Keeton (1983) observed similar

trends but differences were not significant. Purchas and Davies (1974a) studied the effect of nutrition (cereal vs pasture) on 25 Friesian steers. At the same carcass weight (457 kg) all measures of fatness were at least 20% greater in the cereal group, the greatest difference being in the percent of intramuscular fat and the dissectible fat in the 9-10-11 rib cut. The fatter cereal-fed group had more acceptable meat tenderness than the other group.

2-3-3-1-2 Subcutaneous Fat and Tenderness

The relationship between fat thickness and the tenderness of meat has been intensively studied (Smith et al., 1976; Bowling et al., 1977, 1978; Meyer et al., 1977; Dikeman et al., 1979; Lochner et al., 1980). These studies have indicated that increased subcutaneous fat thickness may improve the tenderness through its effect on the rate of postmortem chilling.

Reports on the relation of subcutaneous fatness to tenderness of lamb meat have been contradictory. Joubert (1956) reported that more tender meat was associated with fatter animals. In contrast, Solomon et al. (1986) found that meat from fatter carcasses was evaluated by the objective and subjective methods as being significantly less tender than that from leaner carcasses. On the other hand, Gaddis et al. (1950) noted that variation in tenderness was not related consistently with fatness of the animal. The correlations between fat percent in lamb carcasses and tenderometer values or tenderness scores of cooked samples were investigated by Woodhams et al. (1966). Their data indicated that the fatness had no influence on the tenderness of the meat from carcasses ranging in fatness from 20-41%. They concluded that the significant negative relationship of age with tenderness scores showed the necessity for eliminating age effects when studying tenderness, unless the influence of age is one of the variables being studied. Similar results were reported by Batchner et al. (1962a) and Carpenter et al. (1964).

Marsh et al. (1968) and Smith and Carpenter (1973) recognised that the cooling rate within a carcass is determined not only by ambient temperature, humidity and air velocity, but also by the size of the cooling body and the depth below overlying tissues of the

particular muscle being considered. The latter authors showed that a fat covering of 2.5 mm at the 12th rib of lamb carcasses prevented excessive postmortem shrinkage during chilling. Increases in fat thickness above 2.5 mm were associated with decreased weight loss, but within the approximate range of 2.5 to 9.1 mm the advantage was usually small and not significant. The results of Wenham et al. (1973) suggested that larger carcasses chill more slowly than smaller carcasses and thus are more tender. Smith et al. (1974), working with goat carcasses of widely varying sizes and degrees of finish, noted that carcasses from lean animals sustained extensive shortening of the myofibrills when subjected to cold temperatures.

Early sheep, beef and pork production studies were thoroughly reviewed by Smith and Carpenter (1976) who concluded that fatter animals usually produced meat that was more tender than that from leaner animals. Smith et al. (1976) showed that there was a significant relationship between subcutaneous fat thickness of lamb carcasses and tenderness. Forty carcasses with thick (>7.5 mm), intermediate (2.5 to 7.5 mm) and thin (<2.5 mm) subcutaneous fat coverings over the M. longissimus in the 12-13th rib region gave respective shear force readings of 4.6, 6.1 and 7.5 kg for loin chops and 7.8, 8.6 and 10.8 kg for rib chops. Smith et al. (1976) provided further evidence for an effect of back fat thickness on palatability of lamb by removing subcutaneous fat from over the M. longissimus of one side only of each carcass to facilitate comparisons on a within-carcass basis. The M. longissimus from the untrimmed sides gave significantly lower shear force values than that from the trimmed sides for loin chops (6.1 vs 6.8) and for rib chops (8.6 vs 9.6) at 1+1⁰C chilling. They concluded that increasing thickness of subcutaneous fat on lamb carcasses caused the meat to chill more slowly, increased enzyme activity, lessened sarcomere shortening and improved meat tenderness. Subsequent investigations have substantiated these conclusions and suggested that delay of chilling and high temperature chilling disrupts lysosomal membranes and increases the effect of proteolytic enzymes cathepsin C and β -glucuronidase in beef (Dutson and Lawrie, 1974; Dutson et al., 1975; Moeller et al., 1976; Marsh et al., 1980/1981). Results similar to those of Smith et al. (1976) were obtained in the study of Meyer et al. (1977) in which carcass backfat was removed from one side only of each of 10 Angus steers within an hour of their slaughter and all

sides were cooled in the same chiller at 0°C. Taste panel assessment showed that all palatability attributes were very significantly affected by the fat-stripping operation. Tenderness was the most influenced trait with a difference of almost one unit being observed on a scale spanning only six units (4.66 vs 3.74). Bowling et al. (1977) reported that increases in fat thickness on beef carcasses from 1.27 to 8.9 mm were associated with increases in sarcomere length and improved beef tenderness, while subcutaneous fat in excess of 10.2 mm provided no further enhancement of tenderness. Dolezal et al. (1982) classified 326 steer and 68 heifer carcasses into three subcutaneous fat thickness classes (<5.07, 5.08 to 10.15 and >10.16 mm). Rib steaks from carcasses with at least 10.16 mm fat thickness received significantly higher ratings for tenderness and had significantly lower shear force values than did steaks from carcasses that had less than 5.08 mm fat thickness. Steaks from carcasses with less than 2.54 mm of fat thickness received the lowest tenderness scores and had the greatest resistance to shear force. Similar results were given by Tatum et al. (1982). They pointed out that steaks from carcasses with less than 5.08 mm of subcutaneous fat over the M. longissimus at the 12th rib had significantly higher shear force values than carcasses with more than 5.08 mm. In general, sensory panel ratings increased as subcutaneous fat depth increased to 12.7 mm, but differences associated with successive increases in fat thickness between the levels of 5.08 and 12.7 mm were not statistically significant. Riley et al. (1983b) found that subcutaneous fat thicknesses of 7.6 mm or more were associated with significantly higher tenderness values for M. longissimus than for fat thicknesses less than 7.5 mm in bulls and steers. In lamb, taste panel results showed only minor differences in tenderness between 4.1 vs 5.7 mm fat thickness over the rib region (Kemp et al., 1982). Parrett et al. (1985) found that sensory panel evaluation in beef showed no differences between 5, 10 and 15 mm of subcutaneous fat thickness for tenderness, but WB shear values decreased with increasing fat thickness and the 15 mm subcutaneous fat had significantly lower values than the 5 mm or 10 mm fat groups. This result agrees with the research of Davis et al. (1979).

2-3-3-2 Fatness and Meat Juiciness

The meat juices may serve to lubricate the meat during the chewing process (Jeremiah et al., 1970), so it is quite possible that fat, by being melted during the heating process, may contribute directly to juiciness and even indirectly to tenderness. According to Lawrie (1985), the values for pH, expressible juice and fatness were directly related to juiciness scores for cooked meat. Smith and Carpenter (1970) and Smith et al. (1976) reported that juiciness in lamb muscle was positively related to fatness and negatively related to pH. Similar conclusions were reported by Kauffman et al. (1964) and Carpenter et al. (1965) for pork muscle. Kemp et al. (1972) suggested that as sheep become heavier and fatter, the cooking losses increase, but the meat is juicier and more tender.

Blumer (1963) summarised the earlier scientific studies on the relationships between marbling and juiciness in beef. Stronger relationships were found between marbling and juiciness (16% of the variation) than between marbling and tenderness or flavour (5%). Goll et al. (1965) and Walter et al. (1965) studied 72 beef carcasses with six degrees of marbling, and found that juiciness was not related to muscle fat content. Similar findings were reported by Tuma et al. (1962b). Breidenstein et al. (1968) found that juiciness scores for beef M. longissimus increased with an increase in marbling, but the correlation coefficient was not significant. Level of fatness has been shown to be related positively to juiciness scores for lamb cuts by Paul et al. (1964a, b), and Oldfield et al. (1966). Bratzler (1971) showed a closer positive relation between juiciness and fat content of the meat than between juiciness and amount of expressible juice (as a measure of water-holding capacity) from meat, apparently because juiciness during chewing left a more lasting impression than did the initial release of juice. Since marbling would increase the sensation of sustained juiciness in less tender meat (Smith and Carpenter, 1976), its association with juiciness is apparent. Briskey and Kauffman (1971) suggested that if intramuscular fat enhanced juiciness by serving as a lubricant around muscle bundles, then it is important that fatness be uniformly and finely dispersed throughout the muscle. Renk et al. (1985) suggested that the retention of intramuscular fat within boundaries of muscle is very high, because most

intramuscular fat is stored in the interfascicular spaces of the muscle and, because these spaces are not necessarily continuous from one end of the muscle to the other, fat could not easily escape when it is rendered during cooking. Results of earlier studies relating fatness to juiciness of cooked meat were reviewed by Smith and Carpenter (1976). The consensus from these data was that fatness had a moderate relationship to juiciness in lamb, a moderate to high relationship to juiciness in pork and a low to moderate relationship to juiciness in beef. Forty lambs were selected by Smith et al. (1976) to vary in amount of fat (7.1, 3.3, 1.1 mm fat thickness at 12th rib). The juiciness rating for M. longissimus and M. biceps femoris did not differ among samples from lambs in these fatness classes, despite rather large differences in amount of intramuscular fat.

The relationship of juiciness and fat content was examined by Gullett et al. (1984) using data from seven beef studies examining meat quality. Percent fat was negatively correlated with juiciness scores for both M. longissimus and M. semitendinosus and they attributed that to the low temperature of the samples because these samples were evaluated at room temperature. This conclusion was supported by the study of Harries et al. (1972) who reported that cold samples were perceived as being drier than hot samples due to solidification of the fat and the gelatinisation of the aqueous phase.

2-3-3-3 Fatness and Meat Flavour

Flavour is an important aspect of meat quality that is sometimes the determining criterion in acceptance or rejection of the product (Ford and Park, 1980). Sink and Caporaso (1977) reported that low consumption of lamb and mutton has been attributed, in part, to the flavour of these meats. According to Lawrie (1985), meat flavour is a complex stimulus involving such characteristics as odour, taste, texture and temperature. The flavour sensation is a combination of volatile compounds produced during the cooking of meat (Herz and Chang, 1970; Macleod and Coppock, 1976). Herz and Chang (1970) suggested that heat serves several functions including: releasing flavour precursors from fat; allowing intimate mixing of fat and water-soluble components, and accelerating browning reactions. In general, the flavour of cooked meat is due to a mixture of compounds

including: nonvolatiles, or water-soluble compounds with taste-tactile properties, potentiators and synergists and volatiles which give rise to the odour properties (MacLeod and Seyyedain-Ardebili, 1981). According to Moody (1983), of these three, the volatile compounds are by far the most important and most frequently discussed.

The contribution of fatty tissue to the flavour of cooked meat has been the subject of a number of studies, and it is generally agreed that fat has some effect on meat flavour, but the extent of this effect is still unclear (Moody, 1983). Hornstein and Crowe (1960) confirmed the observations of Kramlich and Pearson (1958), Wasserman and Gray (1965) and Pearson et al. (1973), in indicating that the basic meaty flavour resides in the water-soluble fraction, and that it was essentially the same for all species, whereas the characteristic species flavour and aroma appeared to arise from the lipids. Furthermore, MacLeod and Seyyedain-Ardebili (1981) concluded that the volatile components responsible for species differences are provided from lean muscle, and if lipid per se is an important contributor, the intramuscular fat alone is sufficient. It appears that the distinctive flavour of sheep meat (Wasserman and Talley, 1968) especially from heavy rams (Campion et al., 1976; Misock et al., 1976; Crouse et al., 1978) is one reason for its low consumption. There is a convincing wealth of information indicating that lamb flavour is not associated with fat cover or fat content (Woodhams et al., 1966; Smith et al., 1970a,b; Batcher et al., 1962a, 1969; Solomon et al., 1980). Moreover, Purchas and Kadim (1985) and Purchas et al. (1986) found no difference in desirability of meat flavour between the progeny of the lean and fat Southdown X Romney crossbreed. In beef, Tatum et al. (1982) showed that steaks from carcasses with less than 5.08 mm of subcutaneous fat over the M. longissimus at the 12th rib had significantly lower sensory panel ratings for flavour desirability than those with more than 5.08 mm fat cover. According to Costello et al. (1985), there was a decrease in the off-flavours associated with the steaks as the amount of fat increased. They attributed that to the decreasing proportion of lean meat with increasing fat. Smith et al. (1984) reported that beef steaks from carcasses with higher marbling scores were significantly more desirable in flavour than those with lower marbling.

Intramuscular fat exists in close association with proteins and contains a large percent of phospholipids (Gokalp et al., 1983). Wilson et al. (1976a) reported that the phospholipid content for sheep muscle was 0.80% of tissue weight, and according to Hornstein et al. (1961) the phospholipids developed rancid odours much more quickly than the neutral fats due to their high unsaturated fatty acid content (Gokalp et al., 1983), especially the phospholipids of red muscles which are more unsaturated than those of the white muscle (Lawrie, 1978). This would lead one to expect both a greater susceptibility to oxidative rancidity and a concomitantly higher degree of discolouration on storage. Though the phospholipid content of meat is relatively low relative to tissue weight, the susceptibility of the phospholipids to oxidation makes them important in determining meat quality (Gray and Pearson, 1984). Fat oxidation is a major cause of deterioration in the quality of meat with respect to undesirable changes in colour, flavour and nutritive value of meat due to interactions with other meat constituents such as pigments and other proteins, carbohydrates and vitamins (Love and Pearson, 1971).

The lipid-soluble flavour components are the most important for determining meat flavour (Sink, 1973) and many factors contribute to their expression (Sink and Caporaso, 1977). Caporaso et al. (1977) identified 51 compounds from ovine subcutaneous fat which contributed to the characteristic flavour of the meat. Analysis showed that most of the volatile flavour components were in the neutral fraction and some in the acidic fraction, but few were detected in the basic fraction. Fourteen components (10 aldehydes, 3 ketones and 1 lactone) were suggested as being important contributors to the overall flavour. Wong et al. (1975a) observed 4-methyloctanoic acid to be correlated with mutton flavour. The 4-methyl branched-chain acids have also been considered primarily responsible for the sweaty odour of mutton (Wong et al., 1975b).

Crouse et al. (1982) suggested that variation in flavour or lamb would be associated with variation in fat composition and not variation in the quantities of fat. Moody (1983) concluded that fats can influence meat flavour in two ways: first, by providing a substrate for oxidation, with the formation of carbonyl compounds in organoleptically significant amounts (these compounds may produce

desirable flavours or undesirable off-flavours, depending on their concentration) and secondly, by serving as depots of fat-soluble compounds that volatilise upon heating and strongly affect flavour.

Soft fat of lambs is considered by some to be a serious problem as it contributes to oxidised flavours (Campion et al., 1976; Misock et al., 1976). However Field et al. (1978) did not find any relationship between the level of polyunsaturated fatty acids and aroma scores for meat. It has been established that soft and oily fat on sheep carcasses may result from high proportions of relatively low melting-point methyl-branched chain and odd-numbered fatty acids and low proportions of relatively high melting-point saturated fatty acids and low proportions of fatty acids such as palmitic and stearic acids (Duncan et al., 1974; Miller et al., 1980a; Busboom et al., 1981). The association between yellow fat and lower flavour scores led Krugel et al. (1982) to search for the cause of discolouration in lamb fat and to relate it to flavour. They found that higher levels of lutein in subcutaneous lamb fat were associated with yellower fat colour and with more intense flavour, but the fat was not softer.

2-3-4 MUSCLE CHARACTERISTICS AND MEAT QUALITY

2-3-4-1 Muscle Fibre Parameters

Skeletal muscle fibres of mammals can be characterised using histochemical methods for the identification of highly specific enzyme activities (Moody and Cassens, 1968; Ashmore and Doerr, 1971; Suzuki, 1971a,b; Suzuki and Tamate, 1974). Stein and Padykula (1962) recognised three types of fibres by their characteristic patterns of succinic dehydrogenase activity as shown by difformazan granules. The fibres were classified into type A with low succinic dehydrogenase activity, type C with high activity and B with intermediate activity. Ogata and Mori (1964) also classified mammalian muscle fibres into three types on the basis of their oxidative enzyme reaction. The three types were small red muscle fibres showing high activities of oxidative enzymes, large white fibres with low activities and "medium fibres" which were intermediate in size with enzyme activities between those of red and white muscle fibres. Samaha et al. (1970)

demonstrated three fibres based on a myosin ATPase histochemical assay, and the three types were designated α , β and $\alpha\beta$. Ashmore and Doerr (1971) reported that skeletal muscles of meat animals comprised a heterogeneous mixture of red (β R), intermediate (α R) and white (α W) fibres, which differed from one another in their morphological, physiological and biochemical properties. Ashmore and Addis (1972) described the fibre types as follows. The (β R) red fibres (slow ATPase activity) fatigue slowly when stimulated, are small in diameter, are rich in oxidative (aerobic) enzyme activity, mitochondria, lipid and myoglobin, but have relatively weak glycolytic activity. White fibres (α W) are fast-acting (high ATPase activity), but fatigue rapidly, are large in diameter, have high glycolytic (anaerobic) enzyme activity and are low in oxidative capacity, mitochondria, lipid and myoglobin. Intermediate fibres (α R) are fast-acting (medium ATPase activity), fairly high in glycolytic activity and myoglobin but intermediate in oxidative capacity, diameter, mitochondria and lipid. Young (1984) examined the biochemical basis of the histochemical assay for myofibrillar ATPase, and found that the activity of myofibrillar ATPase is determined by the myosin heavy chain. He concluded that in spite of wide metabolic variability within types, a classification based on myofibrillar ATPase activity is still useful.

2-3-4-1-1 Quality Characteristics Affected by Muscle Type

Several studies have reported significant negative correlations between overall untyped fibre diameter and tenderness indicating that lower fibre diameters are associated with more tender meat in sheep (Hammond, 1932; Smith et al., 1970a; Cross et al., 1972; Solomon et al., 1981), pigs (Carpenter et al., 1963) and beef (Hiner et al., 1953; Tuma et al., 1962a; Berry et al., 1974). Inconsistent or non-significant correlations between fibre diameter and meat tenderness have also been reported for sheep (Ray et al., 1966; Tichenor et al., 1969; Moody et al., 1970, 1980) and beef (Romans et al., 1965; Melton et al., 1974; Ockerman et al., 1984; Seideman et al., 1986). The discrepancies between those studies could be due to the fact that some researchers used instrumental methods to measure tenderness, whereas others relied on panel scores. Also different muscles, breeds, postmortem treatments and weights at slaughter were involved.

Several studies have reported positive correlations between proportion of (β R) red fibres and tenderness in beef (Melton et al., 1975; May et al., 1977; Calkins et al., 1981; Ockerman et al., 1984; Hawkins, 1986). These results are supported by the finding that (β R) red fibre proportion is more highly correlated with intra- and inter-fibre fat depots than is (α W) white fibre proportion. In sheep, Moody et al. (1980) found a significant correlation between (β R) red fibre diameter and tenderness in lamb M. longissimus in one trial, but it was not significant in another trial. Solomon et al. (1981) found significant negative and positive correlations between (β R) red muscle fibre proportion and meat tenderness in lamb M. longissimus and M. semi-membranosus, respectively. However, in cattle, Seideman and Theer (1986) found that M. longissimus tenderness was positively and negatively correlated to the proportions of white and intermediate muscle fibres respectively, but the proportion of red muscle fibres was found to be unrelated to tenderness. Solomon et al. (1981) and Ockerman et al. (1984) did not find strong relationships between muscle fibre parameters and juiciness or flavour in sheep meat and beef, respectively. Similar results with cattle were reported by Seideman and Theer (1986) and Seideman et al. (1986). In contrast, Seideman and Crouse (1986) reported that a high proportion of red muscle fibres was associated with less off-flavours. However, drip loss, taste panel tenderness, and juiciness were significantly positively correlated with the diameter of (β R) red fibres (Moody et al., 1980), and they concluded that these relationships further support the idea that it is the (β R) red fibre rather than the (α R) intermediate or (α W) white fibres that make the greatest contribution to meat palatability. Staun (1968) showed that tenderness, water-holding capacity and colour of pork improved with a decrease in muscle fibre diameter. Water-holding capacity (WHC) was compared in muscular fractions from pig muscles of different metabolic types, including M. longissimus, a "fast white" muscle, and both Mm. intraspinus and superspinatus "slow red" muscles (Laborde et al., 1985). They found that the (β R) red fibre had slightly higher water-holding capacity than the (α W) white fibre of pork, so the most juicy meat was also the most tender meat.

Cassens (1977) stated that the properties of a muscle, be they visual appearance, physiological parameters or biochemical

characteristics, were a reflection of the proportion of muscle fibres present. This point can be construed to mean that the fat or collagen characteristics of a muscle are a reflection of the proportion of red vs white muscle fibre types. The relationships between fatness and muscle fibre types will be reviewed separately. It may be possible that collagen amount and/or solubility may be a reflection of white muscle fibre types. Beatty et al. (1966) investigated the connective tissue content of predominantly red and white muscle in primates by the use of histochemical staining with sirius red and by use of a biochemical method for detecting hydroxyproline. Both methods produced results that showed more connective tissue in white muscle than red muscle. Biochemically estimated collagen as a percent of weight was 0.9% for M. soleus (red), 1.36% for M. sartorius (predominantly red), and 2.63% for M. superficialbrachioradialis (predominantly white). Seideman and Theer (1986) and Seideman et al. (1986) found that the amount of connective tissue was positively correlated to the proportion of white muscle fibres and negatively correlated to the proportion of intermediate muscle fibre, with no relationship with the red fibre proportion. Seideman (1986) studied the effect of sex on the relationships between muscle fibre types and connective tissue and found these correlations were 0.54 and -0.54 for bulls and -0.31 and 0.31 for steers for the proportions of red and white fibres respectively. The correlation between the amount of soluble collagen and proportion of red and white muscle fibres were 0.32 and -0.32 for bulls and -0.46 and 0.46 for steers, respectively. Part of the conflict can be explained by the fact that Beatty et al. (1966) found that white muscle fibres were positively correlated to collagen due to muscle fibre size being larger for white fibres. In the study of Seideman (1986), the size of the white fibre for steers and bulls was similar, but red fibres in bulls were substantially larger.

It may be possible that as a muscle cell, regardless of type, approaches its maximum size, collagen crosslinking begins (Seideman, 1986). Tenderness has been attributed to numerous other muscle characteristics which include cold-shortening, enzymatic proteolysis and pH decline. All of these phenomena can be ultimately linked to muscle fibre type characteristics and will be reviewed separately within the section on these characteristics.

2-3-4-1-2 Factors Affecting the Proportions of Muscle Fibre Types

2-3-4-1-2-1 Animal Age and Weight

It is well established that muscle fibre numbers remain essentially unchanged from, or shortly before, birth throughout an animal's life (Hammond, 1932; McMeekan, 1940a, Joubert, 1956; Staun, 1963; Stickland et al., 1975). Hammond, (1932) demonstrated that average muscle fibre diameter in seven muscles of the leg and thigh was 12.8 μm for newborn rams, 40.3 μm at the age of five months and 54.1 μm at four years. Joubert (1956) found that the average diameter of fibres from M. longissimus, M. rectus femoris and M. gastrocnemius in newborn lambs was 9.3 μm , at the age of 60 days it was 33.6 μm , and in the fully-developed sheep, 49.2 μm . Ashmore and Addis (1972) reported that all growth of muscle in lambs after 140 days of gestation was the result of an increase in the size of fibres present at that time. White et al. (1978) reported that in ovine quadriceps muscle the mean fibre diameters increased markedly after birth. Similar results were reported by Moody et al. (1980).

McMeekan (1940a) studied the effect of age on the diameter of muscle fibres in pigs from birth to 28 weeks of age, and noted significant increases in the muscle fibre diameter of M. longissimus at intervals of four weeks. Hiner et al. (1953) found in a study of the slaughter quality of beef cattle that the diameter of the muscle fibres in M. longissimus increased with increasing age of the animals. Similar results for cattle were found by Tuma et al. (1962a) and Guenther et al. (1981).

The reports referred to above have dealt with untyped fibres. Since fibre types have been shown to differentiate at various stages and have different metabolic functions in the body (Ashmore et al., 1972), age-related changes in fibre type profiles need to be considered as well. Cornforth et al. (1973) reported a general decrease in the proportion of red muscle fibres in Holstein and Hereford muscle with an increase in animal age. Dreyer et al. (1977) reported that muscles of younger animals contain more red muscle fibres than those of older animals. Furthermore, Seideman et al. (1986) showed that with an increase in age from 12 to 16 months, the proportion of red

muscle fibre did not significantly change, whereas a significant decrease in the proportion of intermediate fibres resulted in a significant increase in the proportion of white fibres. White et al. (1978) reported that in ovine quadriceps the number of (α R) intermediate fibres decreased and that of (β R) red fibres increased with increasing age from 1 day to 5 years. Shifts in the proportions of the different fibre types as weight increased have also been reported, with (β R) red becoming a significantly lower proportion while (α R) intermediate and (α W) white fibres become a greater proportion (Moody et al., 1980). They concluded that this finding could have important implications for muscle growth and development since it shows that ATPase activity may not be fixed at birth. However, no significant changes in fibre types were shown in a second experiment by the same authors, and they attributed that to differences in nutrition and breed. These authors pointed out that the proportion of intermediate fibres remained fairly constant, whereas the white fibres increased with age. Furthermore, Marinova et al. (1984) reported that in ovine M. longissimus the proportion of (α R) intermediate fibres increased and the proportion of (β R) red fibres and (α W) white fibres decreased with increasing weight from 25 to 35 kg live weight, with similar data being obtained for the M. supraspinatus muscle. Similar conclusions were drawn from the study of Hentges et al. (1983) with chickens. In the study of Kiessling et al. (1982) the muscle fibre profile for pigs changed with an increasing proportion of white fibres with increasing weight from 25 to 100 kg. Thus the number of (β R) red and (α R) intermediate fibres decreased by about 8% in porcine M. longissimus and 10% in M. semimembranosus with corresponding increases in the number of (α W) white fibres. In a similar study with Large White pigs, Lefaucheur and Vigneron (1986) found that the proportion of red muscle fibres increased from birth to 23 kg body weight and little change occurred until 120 kg body weight, while the proportion of white fibres increased rapidly up to 30-50 kg body weight to reach 60%, 30% and 12% with decreases by 30%, 45% and 55% in the proportion of intermediate fibres for M. longissimus, M. psoas major and M. tibialis cranialis respectively and therefore, these values only changed slightly. However, Lindholm and Piehl (1974) found that in the horse the number of (α R) intermediate fibres increased and (α W) white fibres decreased with increasing age, and attributed that to the fact that the horse skeletal muscle is designed for both rapid speed of contraction and

great endurance, as called for in trotting, for example. These observations are in agreement with other studies (Close, 1972; Gollnick et al., 1972) in suggesting that after endurance training the oxidative enzymatic activity and mitochondrial content of fast-twitch fibres increased and the changes in energy metabolism were reflected in the histochemical profile, such that the proportion of fast-oxidative fibres was higher in trained muscles.

2-3-4-1-2-2 Animal Genotype

Investigations of muscle fibre size and the distribution of the muscle fibre types have demonstrated differences between breeds of sheep (Solomon et al., 1981) and cattle (Dreyer et al., 1977; Bartlett et al., 1980; Spindler et al., 1980; Jeremiah and Martin, 1985). Staun (1963) found the diameter of muscle fibres was larger in Pietrain than in Danish Landrace pigs at the same weight. Spindler et al. (1980) reported that Holstein steers had smaller muscle fibre diameters than Hereford or Angus steers at the same age, and that Angus steers had a higher proportion of (αW) white fibres and a lower proportion of (αR) intermediate fibres than the other two breeds. Breed effects on muscle fibre types have been reported by Dreyer et al. (1977), who found that Friesland cattle had a higher proportion of white muscle fibres and a lower proportion of red muscle fibres than the Afrikaaner breed. In contrast, Johnston et al. (1975, 1981) reported that there were no significant differences between Angus and Charolais steers in one experiment and between Angus and Simmental crosses in another experiment for the proportions of any muscle fibre types. However, the Charolais group had larger muscle fibre diameters than the Angus and the latter had larger muscle fibre diameters than the Simmental cross. In contrast to these results, Guenther et al. (1981) found that Angus calves had larger muscle fibre diameters than Charolais at three ages (25, 240 and 650 days). Bartlett et al. (1980) reported that at 25 days old, Angus calves had a greater proportion of (αR) intermediate and (αW) white fibres and a lower proportion of (βR) red fibres than Charolais calves. They concluded that even at this early age the muscles of the Angus calves were more mature than those of the Charolais calves. May et al. (1977) showed that Hereford Cross steers had more (αW) white fibres and slightly fewer (βR) red and (αR) intermediate fibres than the

Simmental and Limousin crosses, but that there were no differences in muscle fibre diameters at the same age. Hawkins (1986) found that loin steaks from Brahman steer carcasses were tougher and had a higher percent α -white fibre area than did loin steaks from Hereford steer carcasses. In sheep, Solomon et al. (1981) reported that Suffolk X (Finnish Landrace-Southdown) lambs had a significantly higher proportion of (α W) white fibres and lower proportion of (α R) intermediate fibres than Suffolk X (Suffolk-Rambouillet) lambs, slaughtered at the same weight. Recently, muscle types were analysed on muscle biopsies (M. longissimus and M. gluteus medius) obtained preslaughter at 100 kg live weight from Hampshire, Swedish Landrace and Swedish Yorkshire pigs (Essen-Gustarsson and Fjelkner-Modig, 1985). Fibre identification was based on the ATPase stain, and it was found that both muscles had a high proportion of type II fibres (77-78%) and a low proportion of type I fibres (13-23%) with no significant difference being found between the three breeds.

Little information is available concerning a possible role of genetic selection upon the alteration of "Fibre-type profiles" in muscles of meat animal species. However, the suggestion that unidirectional selection for lean content may produce fundamental changes in muscle metabolism (Ashmore, 1974) is supported by results reported by Weiss et al. (1971a, b), which showed that genetic selection for the meat-type pig has influenced metabolic and hormonal functions, which directly or indirectly have influenced quantitative and qualitative characteristics. For example, lean strain pigs possessed lighter-coloured muscle than the fat strain pigs, which pigs had greater quantities of sarcoplasmic protein while the lean strain pigs had greater quantities of myofibrillar protein. Ashmore (1974) suggested that factors which act to promote large-scale transformation of (α R) intermediate fibres to (α W) white fibres may prove to be advantageous for improving the quantity of meat per animal but that such a transformation may be disadvantageous to meat palatability since red fibres are more highly correlated with intra- and inter-fibre fat depots than are white fibres.

Early histological work on the effect of selection for or against fatness on muscle fibre diameter of pigs at the same weight carried out by Staun (1963), showed no significant changes. However, skeletal

muscle growth of swine differing in rate of growth and muscularity was studied by Ezekwe and Martin (1975) using the M. semitendinosus of fast-growing lean pigs (Yorkshire) and the slow-growing obese pigs (Ossabaw). At the same age the Yorkshire pigs had significantly greater muscle fibre diameter and number than the Ossabaw. These results are supported by those of Buhlinger et al. (1978) who showed a significant difference in muscle fibre diameter between lean (Yorkshire) and obese (Ossabaw) pigs, with the former having more RNA and DNA at a similar live weight.

Nostvold et al. (1979) reported that a high-fat line in pigs had smaller muscle fibre diameters than the low-fat line at the same weight, but differences were significant for the (α W) white fibres only. However, Field et al. (1970) showed no significant differences in fibre diameter between two selection lines of Hereford bulls (leaner line and tenderness line). In sheep Moody et al. (1970) found similar results between two groups representing faster- and slower-growing lambs.

Smith (1963) reported that selection of chickens for increased body weight resulted in increased muscle fibre number and fibre diameter. Aberle and Stewart (1983) found that at the same body weight, white muscle fibres were larger in broilers than in layers and had a larger diameter during muscle growth. In contrast, red muscle fibre type and intermediate muscle fibres were larger in the layers than in the broilers. The number and sizes of muscle fibres in various domestic fowl muscles were determined by Prentis et al. (1984). They concluded that in contrast to the situation in mammals, fibre diameter in the domestic fowl was of greater importance than fibre number in determining muscle size, when compared at different body weights. For example Hanrahan et al. (1973), using lines of mice that had been selected for high and low body weights, concluded that selection for body weight can have various effects on the structure of individual muscles. In most cases large-line mice had a greater fibre number, but not all had a significant increase in fibre diameter as well. Luff and Goldspink (1967) also showed that selection of mice for size had a greater influence on fibre number than on fibre diameter. Purchas et al. (1985) showed no significant differences between genetically obese and lean mice in muscle fibre diameter in

spite of the fact that the obese mice had significantly lighter muscle weights. However, Campion et al. (1984) showed that after 5 weeks of age, fibres in M. gastrocnemius of obese mice had a smaller diameter than did the fibres of lean mice. In M. soleus, fibre diameter was initially smaller then larger at 3 and 5 weeks of age, before again becoming smaller at 8 and 16 weeks of age for the obese mice when compared to lean mice. Neither of those studies evaluated the effects of selection on the profile of fibre types.

Post-mortem myofibre histochemistry was studied by Lax and Pisansarakit (1982) in mice randomly sampled from 8 litters in each of 5 selection lines for high and low 10-week body weight. The high 10-week-weight line had a significantly higher proportion of white fibres in the M. longissimus than the low 10-week-weight line. Nostvold et al. (1979) studied lines of pigs that had been selected for or against fatness, and concluded that the high fat line possessed a significantly higher proportion of (α R) intermediate fibres and a corresponding lower (α W) white fibre proportion with no difference in the proportion of (β R) red fibre.

Hausman et al. (1983) reported similar muscle fibre parameters in M. semitendinosus in 110 day-old foetuses of lean and obese pigs. They concluded that the early differentiation of fibre types in obese and lean foetuses could be reflecting a lack of selection pressure for increasing muscling. For instance, lean pigs were selected only on the basis of low backfat thickness and were not selected for increased muscling (Hetzer and Harvey, 1967). According to Ashmore (1974), selection of animals for increased body weight would not be expected to necessarily produce the same results as selection for high yield, or for muscularity, since the selection for high muscularity would tend to counter high fat deposition as a component of the larger body size. Increased body weight as a selection parameter could, on the other hand, encourage extensive fat deposition rather than having its most significant effect on muscle tissue. More recently, Hausman et al. (1985) showed similar patterns of lipid deposition and similar development of cytoplasmic and mitochondrial enzymes in muscle fibres of lean and obese pigs during foetal development.

2-3-4-1-2-3 Nutrition

Nutrition is the principal antemortem environmental factor that regulates muscle composition (Asghar and Pearson, 1980). It has been shown in sheep that at a set age a low plane of nutrition results in small muscle fibres, while a high plane of nutrition results in an enlargement of fibre diameter (Hammond, 1932; Joubert, 1956; Moody et al., 1980), pigs (McMeekan, 1940b; Staun, 1963; Kiessling et al., 1982) and cattle (Johnston et al., 1981).

Research on the skeletal muscle of laboratory animals has shown that different nutritional states can affect the size of a muscle by altering the size of the fibres within it (Goldspink, 1964; Timson and Dudenhoefter, 1985), although the total number of fibres does not change. However, male rats were undernourished by Bedi et al. (1978) either during the gestational and suckling periods or for a period of time immediately following weaning, and had muscles which showed deficits in weight, fibre number and fibre size. McMeekan (1940b) observed that pigs reared on a high nutritional plane until 16 weeks of age had fibres approximately 50% larger than their low plane counterparts. He attributed this to a difference in live weight of 34 kg between the two nutritional groups. Similar results were found by Joubert (1956), who showed that starvation decreased the diameter of the muscle fibres in sheep at the same age, but at the same carcass weight starvation had not affected the diameter of muscle fibres. Staun (1963) studied the effect of various levels of dietary protein on the skeletal muscle of pigs at 90 kg live weight, and found that fibre diameter increased with increasing protein supplement and was related to a heavier muscle and more lean meat in the whole ham. Yeates (1964), working with bovine muscle, also found that there was a decrease in cross-sectional area of muscle in starved adult cattle, and this was associated with a reduction in the mean diameter of the muscle fibres. With regain of live weight, a full recovery of cross-sectional area of the muscle and of its fibre diameter was observed. Hight and Barton (1965) found that the diameter of muscle fibres was negatively affected by a low plane of nutrition for mature ewes, but only minor differences (51.7 vs 47.8 μm) in muscle fibre diameter were observed. Similarly, Asghar and Yeates (1979) showed that lambs kept on a maintenance diet had a smaller mean fibre diameter than those

lambs on the control feeding; the difference, however, was not significant (36.1 μm vs 39.3 μm). They concluded that loss in body weight was evidently necessary to cause a pronounced decrease in the diameter of the muscle fibres. The same authors showed that only the lambs on sub-maintenance feeding had significantly smaller muscle fibre diameters than the control group. Stickland et al. (1975) studied the effect of "well-nourished", "low energy" and "low protein" treatments on the muscle fibre diameter of pigs and found that the "low energy" group had smaller fibres while the "well nourished" pigs had larger fibres than the "low protein" group at the same age.

Little evidence is available concerning nutritional influences on the proportion of muscle fibre types in muscles of meat animals. Johnston et al. (1981) reported that the proportion of (αR) intermediate fibres decreased and the proportion of (αW) white fibres increased as energy level increased in cattle, when the slaughter age for low and high energy levels was 16 and 20 months respectively. Seideman and Crouse (1986) reported that at the same age, cattle fed a low-energy diet had a significantly higher proportion of red muscle fibres than cattle fed a high-energy diet. Johnston et al. (1975) reported that the proportions of intermediate and white muscle fibres decreased as the protein content of the diet increased. Moody et al. (1980) postulated that the available source of energy in lamb rations appeared to cause a physiological shift from (αR) intermediate to (αW) white fibre with increasing energy. The effect of nutrient density level in pig muscle fibre profiles has been studied by Kiessling et al. (1982). At the same weight and in the same muscles, low-energy fed pigs had more (βR) red fibres than the others. Recently, histological properties of M. longissimus from 47 crossbred lambs (1/2 Hampshire, 1/4 Suffolk and 1/4 Rambouillet) were studied by Nicastro et al. (1985) in order to compare two protein sources (soybean meal and distillers' dried grain with solubles) and three protein levels (12.5%, 15.7% and 18.9%). Lambs fed soybean meal protein had larger (αW) white fibres and significantly smaller diameters of (βR) red fibres and (αR) intermediate fibres than lambs fed grain protein. Among protein levels, lambs fed the 12.5% protein level exhibited a significantly higher proportion of (αR) intermediate fibres and a greater diameter of (αW) white fibres.

2-3-4-1-2-4 Sex

According to Hammond (1932), untyped muscle fibres are largest in male animals, intermediate in castrates and smallest in females. This order was confirmed by Moody et al. (1980), who showed that at the same weight for (β R) red fibres only, rams had significantly larger fibre diameters than wethers and the latter larger than ewes. These results are in agreement with the suggestion of Moody et al. (1970) that rams had larger fibres because they grew faster and were heavier at the same age. In pigs, Staun (1963) showed that gilts had non-significantly larger fibre diameters than castrates at the same weight. Spindler et al. (1980) reported that heifers had larger muscle fibres than steers at the same age, which disagrees with the results of West (1974) and Johnston et al. (1981), showing that heifers had smaller muscle fibre diameters than steers at the same age. Mean fibre diameters for both red and white fibres from M. semitendinosus and M. semimembranosus have been reported to be larger for bulls than for steers at the same live weight (Dreyer et al., 1977).

Sex condition has been found to affect the muscle fibre composition in mammals (Seideman et al., 1986). Brooke (1970) reported that in humans, fibre type proportions between males and females were not different and the size of the red fibres of the two sexes were comparable, but that the white fibres were smaller than the red fibres in females and larger in males. Steers had a higher proportion of (β R) red fibres and a lower proportion of (α W) white fibres than heifers in the study of Johnston et al. (1981). Dreyer et al. (1977) reported a significantly higher proportion of red fibres and a lower proportion of white fibres in M. semitendinosus of bulls than steers. The proportion of intermediate fibres was higher for bulls than for steers, but the difference was not significant. Young and Bass (1984) also reported that in M. longissimus of steers, the proportion of white fibres was 32%, but in bulls it was only 8%. The difference was highly significant. A similar conclusion was reported by Seideman et al. (1986), where bulls had a significantly higher proportion of red and intermediate muscle fibres and less white muscle fibres in M. longissimus than muscle from steers. However, muscle fibre type distribution in the M. longissimus was not significantly different for

bulls vs steers in the study of Ockerman et al. (1984). In sheep, Nicastro et al. (1985) showed that wether lambs had a significantly higher proportion of (α R) intermediate fibres in M. longissimus and a significantly lower proportion of (α W) white fibres than ewes. In contrast, Solomon et al. (1981) found that ewe lambs had a significantly higher proportion of (α R) intermediate fibre than wethers in M. semimembranosus. However, Moody et al. (1980) found that ram lambs had a significantly higher proportion of (β R) red fibre than wether lambs and the latter had a higher proportion than ewe lambs, with no effect of sex on (α R) intermediate or (α W) white fibre proportion. Similar results were reported for pigs by Kiessling et al. (1982) with the proportion of (β R) red fibres being significantly higher in castrates than gilts. They concluded that the effect of sex on the proportion of muscle fibre types was very limited.

2-3-4-1-3 Relationships Between Fatness and Muscle Fibre Type

Although an essential feature of skeletal muscle is its fibrous structure (Swatland, 1982), few investigators have conducted experiments to examine associations between muscle fibre type, fatness and meat quality. The relationship between fatness and meat quality has been reviewed previously (Section 2-3-3), so the scope of this section of the review will be restricted to findings bearing on the question of whether relationships between fatness and meat quality may arise from relationships between fatness and muscle fibre parameters.

Histochemical investigations have established that red muscle fibres contain more lipid than white muscle fibres in pigeons (George and Naik, 1958), rats (Padykula and Gauthier, 1963), pigs (Moody and Cassens, 1968) and in cattle (Hunt and Hedrick, 1977; Suzuki et al., 1978). In addition the total lipid content of muscles with predominantly red muscle fibre types is higher than white muscle. For instance in pigs, Beecher et al. (1965) showed that pig M. trapezius (red) contained more than twice as much lipid as did M. longissimus (white). Similar results were reported by Moody and Cassens (1968) in studies with M. trapezius and M. longissimus (55.64% vs 15.06% red fibres respectively). There was more ether-extractable material on a dry-weight basis in M. trapezius (53.16%) than in M. longissimus

(38.69%). They concluded that M. trapezius usually contains larger quantities of extrafascicular fat compared to M. longissimus and the greater number of red fibres in the former probably contributes to the larger fat content. These data agree with earlier work of George and Naik (1958) who reported that the narrow or red fibres of pigeons were high in lipid content compared to the broad or white fibres which contained more glycogen. Rahelić and Puač (1980) pointed out that the proportion of (β R) red fibre in pigs was significantly higher in M. supraspinatus (5.4% lipid) than the M. longissimus (1.88% lipid). Furthermore, Kiessling and Hansson (1983) observed a close correlation between the rate of fatty acid oxidation and (β R) red or (α W) white fibre proportion in the various muscles of pigs (correlation coefficients +0.76 and -0.79, respectively).

Tuma et al. (1967) found that muscle fibre diameter was greater for moderately marbled beef than for beef with a small amount of marbling. These results were in agreement with those of Melton et al. (1974), May et al. (1977) and Pinkas et al. (1981), in showing that the diameter of (β R) red fibres was positively correlated with fatness at the same age. Livingston et al. (1966) showed a negative correlation between muscle fibre diameter and fat depth of pigs at the same weight. Romans et al. (1965) found a significantly greater fibre diameter in beef with moderate marbling compared to that with slight marbling and hypothesised that this indicated a deposition of fat within the fibre. Low and non-significant correlations of fibre character with ether extract were found by Cooper et al. (1968) for beef. Similar analyses by Calkins et al. (1981) did not reveal any relationship between muscle fibre diameter and marbling. Ockerman et al. (1984) found that the mean red and white fibre diameters were positively correlated with marbling, but the values were not large enough to be significant at the same age.

Reddy (1971) found significant positive correlations between marbling, intramuscular fat and (α W) white fibre proportion in beef, while Melton et al. (1975) indicated that the proportion of fibre types as demonstrated by alkaline stable ATPase was not closely associated with marbling, but the proportion of (β R) red fibres was positively related with fat thickness. Hunt and Hedrick (1977) compared several muscles relative to their fibre type composition and

fat content. In general, muscles with higher proportions of red muscle fibres had more fat and vice versa. Calkins et al. (1981) reported that the proportion of red muscle fibres was positively correlated to marbling and tenderness rating in heifers and steers. In contrast, Seideman et al. (1986) found a positive relationship between the proportion of white fibres and numerous measures of carcass fatness, whereas the proportion of the intermediate fibres was negatively correlated to fatness measurements with no relationship between fatness and proportion of red muscle fibres. However, Rae et al. (1968) and Pinkas et al. (1981) suggested that no consistent relationships between proportions of various fibre types and marbling, or ether extract, existed within a muscle.

2-3-4-2 Connective Tissue

According to Asghar and Henrickson (1982), connective tissue consists of the following distinct components: a, fibrous proteins, b, ground substance and c, cells. The major fibrous proteins include mainly collagen with some elastin and reticulin. The main functions of connective tissue are structural, providing physical strength, cementing the cells together and at the same time serving a sieve-like function for passage of metabolites from cell to cell (Asghar and Henrickson, 1982). Collagen constitutes the major protein component of skin, bone, tendon and other forms of connective tissue. The basic structural unit of collagen is tropocollagen, which is composed of three peptide chains wound around each other to form a strong unit (Bailey, 1972). Because of its unique physical and chemical properties and its relationship with meat quality, collagen has received considerable attention from a meat quality, medical and industrial view-point (Miller et al., 1983).

2-3-4-2-1 Quality Characteristics Affected by Connective Tissue

For many years connective tissue (collagen, elastin and reticulin) was believed to be primarily responsible for any lack of tenderness of meat (Seideman and Durland, 1984). Seideman and Durland (1984) reviewed a number of studies into the relationship between collagen and tenderness of meat and concluded that total collagen

content in muscle had little effect on the ultimate tenderness of meat. They also reviewed other research work which indicated that the collagen content of meat had a significant negative association with ultimate meat tenderness. Similar conclusions from several other studies have been reviewed by Asghar and Pearson (1980). They indicated that the amount of connective tissue in muscle had little effect on the ultimate tenderness of meat when the same muscle was compared between animals. However, some muscles have been shown to have more collagen than others (Cross et al., 1972; Smith et al., 1976; Seideman, 1986) and it is generally accepted that muscles containing more connective tissue are less tender than those containing little connective tissue.

The degree of intramuscular collagen cross-linking has been shown in many investigations to be an important factor affecting the tenderness of meat (Asghar and Pearson, 1980). The solubility of the connective tissue has been reported to be positively correlated with tenderness in beef (Williams and Harrison, 1978; Hall and Hunt, 1982). Reagon et al. (1975) concluded that solubility of collagen influenced objective tenderness assessments, whereas subjective tenderness was more affected by amount of collagen. However, when the effect of age and maturity was removed, the effect of collagen solubility on tenderness became insignificant (Asghar and Pearson, 1980). As defined by Goll et al. (1964) the thermal shrinkage temperature of collagen is that temperature at which collagen fibres suddenly contract to about one-third of their original length. The importance of degree and type of cross-linking in intramuscular collagen to meat tenderness was substantiated by Pfeiffer et al. (1972) in a study which showed a closer relationship between tenderness and the number of cross-links within and between collagen fibres than between tenderness and total collagen content or its solubility.

2-3-4-2-2 Relationships Between Fatness and Connective Tissue

According to Swatland (1984) and Wood et al. (1986), the proportion of connective tissue decreases as animal fatness increases. Jennings et al. (1978) found no significant correlations between marbling score, fat thickness, and amount of connective tissue in beef. However, Smith et al. (1984) found that beef steaks from

carcasses with higher marbling scores (indicative of more intramuscular fat) were significantly more desirable for amount of connective tissue by a sensory panel.

Cover and Hostelter (1960) demonstrated that fat along the fibres and between the muscle bundles made the meat more tender. Similar conclusions were reached by Lawrie (1985), who noted that fat tended to dilute the connective tissue elements of the muscle in which it is deposited.

A number of studies have shown relationships between fat thickness and connective tissue (Smith et al., 1976; Dolezal et al., 1982; Riley et al., 1983a,b; Wood et al., 1986). Smith et al. (1976) found that lamb which had 7.1 mm back fat thickness had lesser quantities of connective tissue than did samples from carcasses with 1.1 mm fat. In beef, Dolezal et al. (1982) found that steaks from carcasses with at least 10.16 mm subcutaneous fat received significantly higher ratings for connective tissue amount than those from carcasses that had less than 5.08 mm of fat thickness, while steaks from carcasses with less than 2.54 mm of fat thickness received the lowest rating for connective tissue. These findings were substantiated by the studies of Tatum et al. (1982) and Riley et al. (1983b). However, Riley et al. (1983a) studied the effect of fat thickness on palatability of beef from young bulls and found that there was no relationship between fatness and connective tissue. Lawrie (1985) suggested that there was a strong tendency for higher connective tissue contents in carcasses with lower commercial grading and lower fat content. Significant negative and positive correlations of fat thickness in cattle with total collagen and salt soluble collagen of rib muscle samples, respectively, were found by Hall and Hunt (1982), while correlations with acid-soluble collagen were non-significant. However, Tatum et al. (1980) reported that fat thickness and marbling were much more variable than connective tissue characteristics of beef.

2-3-4-3 Degree of Muscle Contraction

The phenomenon of rigor mortis which usually takes place between the death of the animal and the death of its musculature, is accompanied by a contraction of the contractile units of the

myofibrils, the sarcomere (Honikel et al., 1986). Shortening is induced by the release of Ca ions from the sarcoplasmic reticulum into the inter-myofibrillar space. The movement of Ca ions within the muscle cells postmortem depends on temperature, pH and ATP concentration present (Cornforth et al., 1980; Whiting, 1980; Honikel et al., 1983). According to Davey (1983), rigor mortis is brought about by ATP disappearance and is a consequence of the cross-bridging of the heads of the myosin molecules of the thick filaments with the g-actin monomers of the thin filaments during physiological contraction as rigor mortis is developing. These cross-bridges are part of the myosin molecule, and during contraction, they cyclically extend outward to attach to the thin or actin filament, and then swivel or rotate so that the top of each crossbridge undergoes approximately a 10 nm translocation, pushing the actin filament toward the centre of the sarcomere (Goll et al., 1974). The relationships of toughness to the degree of contraction of muscle rigor mortis and to thaw shortening have been reviewed by Locker et al. (1975). The present review will be mainly concerned with the methods to prevent cold shortening and its effects on meat quality.

2-3-4-3-1 Quality Characteristics Affected by Degree of Contraction

Early work of Locker (1959) revealed that there was a wide variation in the degree of contraction of different muscles and of fibres within muscles when set in rigor mortis. Further studies using M. psoas from beef showed that at chiller temperatures excised muscles shortened and were tougher than muscles left on the carcass. It was therefore postulated that contractions of muscles induced toughness in meat (Locker, 1960)

Values for sarcomere length are used as a measure of myofibrillar contraction state, and have been shown to be positively related to the tenderness of ovine meat (Smith and Carpenter, 1970; Smith et al., 1970a, b; Bouton et al., 1973c; Smith et al., 1976; Purchas, 1979; Solomon et al., 1981), pork (Dransfield and Lockyer, 1985; Petaja et al., 1985) and beef (Cooper et al., 1968; Lee and Ashmore, 1985). It is known that myofibrillar contraction to sarcomere lengths below 1.8 to 2.0 μm increases toughness in the cooked post-rigor meat until, at

sarcomere lengths of 1.2 to 1.3 μm and below, the meat becomes more tender, eventually becoming as tender as that at sarcomere lengths greater than 1.8 to 2.0 μm (Harris, 1976). The increased tenderness of very severely cold-shortened muscle (sarcomere lengths < 1.2 to 1.3 μm) has been explained as due to the severe structural disruption which produces zones of stretched and zones of highly contracted myofibrils (Marsh et al., 1974). However, such localized changes in the myofibrillar contraction would also produce changes in the surrounding connective tissue network (Harris, 1976). The inability of the connective tissue network to accommodate to further changes in the diameter of myofibrils as sarcomeres contracted to below 1.2 to 1.3 μm could well be a factor in causing the myofibrillar disruption. Rowe (1974) has shown that in heavily-contracted muscles, the collagen fibres are under strain since the crimp has been removed from the connective tissue network and this probably limits the cross-sectional expansion in the myofibrils. On the other hand, the finding that adhesion between the meat fibres increases significantly with myofibrillar contraction (Bouton and Harris, 1972; Bouton et al., 1973b, 1974, 1975a) indicates that connective tissue may also play a part in cold-shortening toughness. Shear force values decreased exponentially as sarcomere length increased for mutton muscles (Bouton et al., 1973c), with increase in sarcomere length of 0.23, 0.13 and 0.16 μm for M. longissimus, M. biceps femoris and M. semimembranosus respectively, being associated with decreases of 104, 93 and 135% in shear force values. Smith et al. (1976) reported that decreases in sarcomere length of 0.00 and 0.08 μm for M. longissimus or 0.03 and 0.08 μm for M. biceps femoris as fat thickness decreased from 7.1 mm to 3.3 mm and 1.1 mm, were associated with increases of 33 to 63% in the first muscle, or 2 to 22% in the second muscle in shear force requirement. However, Solomon et al. (1981) did not find significant relationships between sarcomere length and tenderness for ovine M. longissimus and M. semimembranosus, incubated at 3⁰C for 48 h. Voyle (1969) suggested that the toughening effect of cold-shortening is due to the accumulative effect of physical changes at fibre level and macromolecular changes in the myofilaments. Temperature (Locker and Hagyard, 1963; Purchas and Barton, 1976; Purchas, 1979; Dransfield and Lockyer, 1985), physical restraint (Locker, 1960; Marsh and Leet, 1966; McCrae et al., 1971; Buege and Stouffer, 1974; Jeremiah et al., 1984) and

rate of postmortem pH drop (Dutson, 1983; Marsh, 1983) are the main determinants affecting the extent of shortening.

2-3-4-3-2 Methods of Controlling Degree of Contraction

Since it has become widely accepted that cold and thaw shortening are major causes of meat toughness, considerable research has been directed towards their alleviation (Locker et al., 1975). The capacity for cold-shortening can be greatly reduced by temperature control, electrical stimulation and by hanging posture. According to Davey and Garnett (1980), cold-shortening in pre-rigor lamb can also be prevented by freezing carcasses very rapidly in less than four hours. The thaw-shortening and toughening that can follow such a treatment can be prevented by storing the carcasses for a period greater than 10 days in the frozen state not below -12°C .

2-3-4-3-2-1 Temperature

Low temperatures can cause pre-rigor muscle with high ATP levels to contract with an accompanying two- or three-fold increase in toughness (Marsh et al., 1974; Marsh and Carse, 1974; Cliplef and Strain, 1976; Locker and Daines, 1976; Dransfield and Lockyer, 1985). Several researchers have reported that conditioning at elevated temperature of 13° to 16°C , or a delay in chilling through increasing thickness of fat can result in improved tenderness, the mechanisms being attributed to the prevention of cold-shortening and accelerated ageing (Locker et al., 1975; Olson et al., 1976a; Smith et al., 1976; Dutson et al., 1977; Moeller et al., 1977; Lochner et al., 1980).

Early post-mortem temperature has a large effect on the rate of rigor development with rigor onset taking about 1.6 times longer at 21°C and 2.3 times longer at 10°C than at 37°C in pig muscle (Briskey et al., 1962). In lamb, rigor development takes about 3.5 times longer at 5°C than at 37°C (Attrey et al., 1982). Excised pork M. longissimus from six Large White cross pigs were subjected by Dransfield and Lockyer (1985) to a range of chilling rates using temperatures between 20°C and -20°C . Onset of rigor at 20°C varied from 3 to 7.5 h, and rigor was complete in 6.5 to 15 h. They

concluded that cold-shortening was induced when samples were chilled at 3°C or below but not at 5°C or at ambient temperatures. A positive correlation between tenderness and very early (2 to 5 h) post-mortem temperature has been reported (Lochner et al., 1980; Marsh et al., 1980/1981; Martin et al., 1983; Petaja et al., 1985), under conditions where muscle temperature was maintained at about 37°C during this time by heavy fat cover or by an appropriate ambient temperature. According to Olsen et al. (1976a) and Moeller et al. (1977) delayed chilling by 12 h, or a short period (3 h) at elevated temperatures (25 to 37°C) prior to chilling, increased myofibrillar fragmentation. Stromer and Goll (1967), using M. semitendinosus and M. psoas major muscles from 7 heifers, reported that muscle stored at 16°C was significantly less contracted than that held at 2°C for a similar time period, which showed that at 16°C samples exhibited a marked thickening of the A-band, a shortening of the I-band and a replacement of the H-zone by a dark line or band, but the 2°C samples showed only alternating light and dark bands of nearly equal width. Jeremiah et al. (1984) found that muscle fibre diameter was not affected in pig M. semimembranosus by delayed chilling, but that carcasses held at either 13 or 22°C for 24 h had significantly smaller M. longissimus fibre diameters for the aitchbone hanging positions (sides were suspended by the os coxae from hooks inserted through the obturator foramen [aitchbone] with the limbs hanging free) than for the Achilles tendon hanging position, and carcasses held at 22°C for either 12 or 24 h had significantly larger M. psoas major fibre diameters for aitchbone than for Achilles tendon hanging positions. However, muscle can also shorten at higher temperatures, especially above 30°C. Honikel et al. (1983) called this phenomenon "rigor shortening". They suggested that rigor shortening started at pH 6.3 to 6.0 and at ATP content of 50% of the concentration in living muscle. Recently, Honikel et al. (1986) reported that the sarcomere lengths in unrestrained, excised beef M. sternomandibularis shortened less than 10% in the pre-rigor state between 6° and 18°C. Below 6°, sarcomeres contracted up to 70%, between 20° and 38°C sarcomere shortening of 40% was observed. The same authors also reported that the minimum shortening in pork M. cleidooccipitalis was measured at about 10°C, a higher degree of shortening up to 50% being obtained above and below this temperature. In contrast, cold-shortening can begin at pH 7.0 and at the full ATP content in living muscle (Petaja et al., 1985). Davey and Gilbert

(1973) examined conditioning of lamb at 45°C and reported a greater extent of rigor shortening at this high temperature, resulting in greater toughness. Bowling et al. (1978) also reported that lambs subjected to 49°C and 32°C environmental temperatures after slaughter showed the most pronounced sarcomere shortening and tougher muscles than those subjected to +16°C, 0°C, -16°C and -32°C. Lee and Ashmore (1985) reached similar conclusions from work with beef at 35°C. Dransfield and Lockyer (1985) found that pork held at 20°C tended to be tougher than that held at 5°C which could indicate that higher temperatures during rigor may also give rise to tougher meat.

The degree of contraction depends on the type of muscle fibres (Marsh et al., 1974; Bendall, 1975; Locker et al., 1975), with contraction usually being more extensive in muscles with a greater proportion of red muscle fibres than white muscle fibres because degree of contraction is directly associated with the relative number of mitochondria and inversely with the amount of sarcoplasmic reticulum (Cornforth et al., 1980). Cornforth et al. (1980) suggested that the mitochondria release an overload of Ca ions at low temperature and flood the saturated sarcoplasmic reticulum and initiate shortening. However, mitochondria play no role in Ca ions re-accumulation and relaxation upon re-warming, unlike the sarcoplasmic reticulum (Berman et al., 1977; Kanda et al., 1977; Cornforth et al., 1980).

2-3-4-3-2-2 Electrical Stimulation

Asghar and Pearson (1980) indicated that Ca ions and ATP content are the major factors which govern the degree of muscle contraction. The post-mortem release of Ca ions from the sarcoplasmic reticulum (Tume, 1979, 1980) and/or from the mitochondria (Cornforth et al., 1980) at the time when the ATP level in muscle is still high results in a significant level of shortening. However, if the Ca ions are released after some depletion of ATP from muscle has taken place, only a minor amount of shortening will occur (Asghar and Pearson, 1980). This suggests that depletion of ATP to minimum levels by increasing the rate of post-mortem glycolysis so as to exhaust the glycogen while the temperature of the carcass is still high would minimise cold-shortening. Electrical stimulation was found to

increase the rate of post-mortem glycolysis (Chrystall and Hagyard, 1976; Davey et al., 1976; Chrystall and Devine, 1978; Nichols and Cross, 1980; Chrystall, 1982; Crouse et al., 1983; Rashid et al., 1983a, b; Solomon et al., 1986; Kondos and Taylor, 1987), and to reduce the time for the onset of rigor mortis (Davey et al., 1976). Bendall and Rhodes (1976) reported that with electrical stimulation at pH 6.0, 50% of the initial resting content of ATP had disappeared and at pH 5.7 more than 90% of the ATP had disappeared, thus minimising the chances of cold-shortening. Similar results were reported by Will et al. (1979) and Valin et al. (1981). Kondos and Taylor (1987) showed that electrical stimulation accelerated the glycolytic processes resulting in an immediate increase in muscle lactate and a reduction of about 30% in ATP. Therefore, these mechanisms have encouraged researchers to use electrical stimulation as another way of improving meat tenderness by avoidance of cold-shortening (Asghar and Pearson, 1980; Valine et al., 1981; Rashid et al., 1983b; Chrystall and Devine, 1983). According to Sorinmade et al. (1978), carcasses from stressed animals do not respond to electrical stimulation probably because of the low levels of ATP. Rashid et al. (1983b) studied the effectiveness of electrical stimulation in reducing the incidence of cold-shortening. They showed that rapid chilling of excised M. semitendinosus from electrically-stimulated lamb carcasses shortened about 7.3% less in 24 h than muscles from unstimulated sides.

2-3-4-3-2-3 Physical Restraint

Changing the method of carcass suspension has been reported to alter sarcomere lengths, muscle fibre diameter and increase tenderness (Jeremiah et al., 1984). A number of investigations have indicated that by hanging the carcass in a special way certain muscles are stretched, thus reducing contraction and making the meat more tender (Bouton et al., 1973c; Hosteller et al., 1976; Solomon, 1986). The degree of muscle contraction has been observed to be more pronounced in excised pre-rigor muscle than in intact muscle on the carcass (Locker, 1960; Marsh and Leet, 1966; McCrae et al., 1971). However, stretching of excised muscle resulted in more tender meat (Krugger and Field, 1971; Lewis et al., 1973; Buege and Stouffer, 1974). Because the extent of shortening has been shown to be largely dependent on the amount of tension exerted on a muscle in the carcass,

hanging carcasses from the aitch-bone, which stretches several major muscles, also increases the tenderness of those muscles (Asghar and Pearson, 1980; Jeremiah et al., 1984).

Hostetler et al. (1972) used sides from 40 young steers in five postures (vertical, horizontal, neck-tied, hip-free and hip-tied) to show that the greatest improvement in the unconventional positions was in the M. longissimus, but that most of the major muscles of the leg were significantly improved. Some suspensions favoured one muscle and some another. In a similar study Bouton et al. (1973c) compared carcasses hung from the hock, but stretched with metal splints, hung from the pelvis, and hung from both pelvis and hock. The tenderness data showed that M. longissimus derived the greatest benefit from pelvis suspension, but major leg muscles also improved substantially. They concluded that hanging from the aitch-bone so improved the quality of several important muscles that their tenderness at 1 to 2 days was equal to that of muscles from normally-hung carcasses aged for 2 to 3 weeks at 0°C. Davey and Gilbert (1973) used a stick to support a lamb carcass in a normal standing position and showed improved tenderness of M. longissimus, M. biceps femoris, M. semimembranosus and M. gluteus medius. Similar results were reported by Davey and Curson (1971) for lamb hung from the aitch-bone by an anal hook. Quarrier et al. (1972) also reported improved tenderness, associated with longer sarcomere lengths, in the leg and loin muscles of lambs on pelvic suspension. Buege and Stouffer (1974) compared either weighted or mechanical means with non-tensioned controls using 31 lamb carcasses. The tension treatment had a very highly significant beneficial effect upon shear force of M. longissimus when rapidly chilled at 2°C. Abban et al. (1975) tried tensioning of the muscle by rotating the femur of lamb carcasses, and found some improvement in tenderness of certain muscles. Hostetler et al. (1975) showed increases in tenderness, when they combined hip-free suspension with high-temperature (15 to 16°C) ageing. Locker et al. (1975) pointed out that the effect of posture alone can be distinguished only under post-mortem conditions which prevent cold-shortening. Moller et al. (1983) used 16 lamb carcasses to compare Achilles tendon-hung with pelvic-hung treatments for 24 h at 0° to 1°C. The data showed several muscles of the pelvic-hung carcasses which had significantly lower shear force values than those from the Achilles tendon-hung carcasses. In pork, Jeremiah et al.

(1984) indicated that hip-free suspension as opposed to conventional carcass suspension, significantly increased the length of sarcomeres, and reduced muscle fibre diameters in M. longissimus and M. semi-membranosus while significantly shortening sarcomeres, and increasing muscle fibre diameter in the M. psoas major.

2-3-4-3-3 Relationships Between Fatness and Degree of Muscle Contraction

A cooling rate that is adequate for well-insulated carcasses will obviously be more than adequate for those that are leaner, with the extent of this "overchill" increasing markedly with decreasing carcass fatness (Lochner et al., 1980). This statement has been substantiated by a number of investigations (Smith et al., 1976; Bowling et al., 1977; Tatum et al., 1982). They all indicated that increasing subcutaneous fat thickness improved tenderness through its effect on the rate of post-mortem chilling. The mechanism by which fatness increases tenderness through an insulating effect has been reviewed previously (Section 2-3-3-1).

2-3-4-4 Degree of Protein Breakdown

The biochemical aspects of the ageing process of meat have been reviewed by Asghar and Yeates (1978). Goll et al. (1974) proposed that the increased tenderness which results from the ageing of meat arises from transverse breaks or cracks in the myofibrils and weakening of the actin-myosin complex. Several studies have documented the changes occurring in or near the Z-disks during conditioning of meat (Davey and Dickson, 1970; Hay et al., 1973; Parrish et al., 1973; Penny, 1974; Johnson and Bowers, 1976; Olson et al., 1977; Gann and Merkel, 1978; Goll et al., 1983; Koochmaraie et al., 1984, 1986; Robson et al., 1984; Zeece et al., 1986). Bush et al. (1972) described a Ca-activated proteolytic enzyme which destroys the Z-disk structure of myofibrils. The importance of Ca^{+2} ions had previously been shown by Davey and Gilbert (1969) by demonstrating that the weakening of lateral attachments and the disappearance of Z-disks during ageing were inhibited by ethylene diamine tetraacetic acid (EDTA). According to Etherington (1984), the free Ca^{+2} concentration regulates the Ca-activated neutral proteinases (CANP) which are

located at the Z-disk and which have been found to release the Z-line protein alpha-actinin and also to degrade troponins T and I and C-protein. Nagainis and Wolfe (1982) suggested that Z-disks are attached to thin filaments by an actin that differs subtly from thin-filament actin in that it is rapidly cleaved by calcium-activated factors. The principal degradative changes detectable in electron microscopy of post-mortem myofibrils are a weakening of the junction between the I-filaments and the Z-disk (Davey and Gilbert, 1969; Penny, 1980) and a reduction in Z-disk integrity (Henderson et al., 1970). Either of these changes could cause increased tenderness (Goll et al., 1983). Recently, Zeece et al. (1986) demonstrated that Ca-activated factor (CAF) is effective in releasing soluble protein from myofibrils in vitro and that it is effective over a fairly wide range of pH and temperature conditions. However, the rates of degradation of Z-disks and the appearance of gaps at I-Z junction are not the same for all types of fibre. White fibres which have narrow Z-disks are degraded at a faster rate than red fibres, which have Z-disks twice as thick as those of white fibres (Gann and Merkel, 1978). The degree of fragmentation has been used as a measure of the extent of conditioning (Moller et al., 1973; Olsen et al., 1976a; Culler et al., 1978). The higher proportion of smaller fragments in conditioned meat than in unconditioned meats is used as an indicator of structural changes in the myofibrils, which correlate with increased tenderness of meat cooked after conditioning (Moller et al., 1973; Culler et al., 1978; Jeremiah and Martin, 1978, 1985; Koohmaraie et al., 1987). Jeremiah and Martin (1985) reported that muscle fibre diameters were generally smaller for aged samples than unaged and sarcomere lengths became progressively longer with ageing. The same authors also found that the proportion of wavy fibres increased with the ageing time and Covington et al. (1970) showed that the proportion of wavy fibres increased as shear force values increased. They suggested that if the wavy fibres indicate the degree of muscle contraction, then, as the relation indicates, the greater the state of contraction the less tender the muscle.

Several studies have reported the occurrence of acidic proteases that have activity against myofibrillar proteins, in particular the relationship between cathepsins B and D with post-mortem changes including the degradation of myosin, actin and troponin-T during the

first 24 to 48 h of muscle storage as the pH drops below the initial physiological value to a range of 5.3 to 5.8 (Penny et al., 1974; Penny, 1976; Schwartz and Bird, 1977; Penny and Dransfield, 1979). The ability of cathepsin D to hydrolyse myofibrillar protein under different conditions of pH and temperature was investigated by Zeece et al. (1986). SDS-PAGE analysis of myofibrils treated at pH 5.5 and 37°C and then sedimented, showed degradation of myosin heavy chains and titin, also a small amount of actin, tropomyosin, troponins T and I, and myosin light chains were degraded. They concluded that cathepsin D does not play a principal role in the tenderization process occurring in muscle post-mortem because raising the pH and/or lowering the temperature greatly reduced the effectiveness of the enzyme. Takahashi and Saito (1979) demonstrated that proteolysis of connectin takes place during post-mortem ageing of muscle. This is strong evidence suggesting cathpeptic-proteolysis of gap filaments during conventional ageing. These results were supported by Orcutt and Dutson (1985) who found that connectin undergoes proteolysis during post-mortem conditioning. The latter authors concluded that endogenous acid proteases may be responsible for the majority of gap filament degradation which occurs during post-mortem conditioning. However, Suzuki et al. (1985) showed no changes in the electrophoretic characteristics of connectin in chicken myofibrils isolated by gel permeation chromatography from fresh and stored muscle. According to Locker et al. (1977) and Locker (1982), gap filaments may be an important muscle component that influences muscle tenderness. They showed that gap filaments maintain their structure after heating to 200°C. Therefore, the protein (or proteins) comprising gap filaments were thought to be responsible for much of the structural integrity and tensile strength of cooked and raw unaged muscle. However, Locker et al. (1977) and Davies et al. (1978) demonstrated that gap filaments were sensitive to proteolytic enzymes of the calcium-activated-factor system (CAF).

Other structural changes during ageing of meat include the degradation of the M-line protein (Henderson et al., 1970; Hay et al., 1973), the loss of minor proteins associated with actin (Hay et al., 1973, and in particular, loss of troponin-T (Cheng and Parrish, 1977, 1978a, b; Locker et al., 1977; MacBride and Parrish, 1977; Olson et al., 1977; Yamamoto et al., 1977, 1979; Jeremiah and Martin, 1978;

Penny and Ferguson-Prye, 1979; Penney and Dransfield, 1979; Yates et al., 1983; Babiker, 1985).

2-3-4-4-1 Quality Characteristics Affected by Protein Breakdown

As reviewed in previous section, post-mortem ageing of muscles produces an improvement in meat tenderness. The effects of ageing on other meat quality aspects have also been reported, including an improvement in flavour (Sink and Smith, 1972; Jennings et al., 1976), and reducing cooking loss (Savell et al., 1978b; Hopkinson et al., 1985). However, other studies have found little change in palatability during meat ageing (Harrison et al., 1970; Lyon et al., 1983). Also there is evidence that changes associated with post-mortem ageing may be dependent on the type of muscle, with red muscle fibres tending to undergo the tenderizing changes of ageing to a much lesser extent than white muscle fibres (Hay et al., 1972, 1973; Semlek and Riley, 1974; Moller et al., 1983), and with the extent of ageing changes varying with sex (Purchas, 1972; Hopkinson et al., 1985).

2-3-4-4-2 Post-mortem Factors Affecting Protein Breakdown

2-3-4-4-2-1 Time and Temperature

Davey and Gilbert (1976) suggested that ageing periods could be reduced by subjecting the carcasses to higher temperatures (14-44⁰C). A number of other studies have shown that rapid tenderization of meat occurs by ageing at elevated temperatures (Newbold and Harris, 1972; Bouton et al., 1973c; Parrish et al., 1973; Follett et al., 1974; Locker and Daines, 1975; Pierson and Fox, 1976; Kasther et al., 1976; Olson et al., 1976a; Moller et al., 1977; Cheng and Parrish, 1978a; Bowling et al., 1978). According to Dutson and Pearson (1985), the incubation of carcasses at an elevated temperature (15 to 22⁰C) caused an increase in the free activity of lysosomal enzymes, allowing them to be available to act on the muscle proteins at a higher temperature and a lower pH. The same authors reviewed other studies and concluded that elevated temperatures enhanced the degradation of troponin-T, myosin and gap filaments.

Several investigators have shown that the extent of protein breakdown during post-mortem ageing is determined by the duration of the process (Jergenson et al., 1974; Davey and Gilbert, 1976; Davey, 1983). At normal ageing temperatures (1 to 2°C), 6 days of ageing has been shown to produce satisfactory tenderness in young beef carcasses of different degrees of fatness (Martin et al., 1971). According to Culp et al. (1973), after 11 days of post-mortem ageing no further tenderization occurs.

Smith et al. (1971) demonstrated an increase in tenderness of more than 40% when carcasses were held at 16°C for 10 to 16 h as compared with carcasses held at normal chill room temperature. Bouton et al. (1973c) reported greater than 50% increased tenderness when carcasses held at 15°C to 16°C for 2 days were compared with those held at 0°C for the same period of time. According to Locker and Daines (1975, 1976), conditioning carcasses at 35°C to 37°C causes greater tenderness improvement than conditioning at 15°C. Shear force values of unshortened M. sternomandibularis, held at 15°C, fall by 60% over a period of 2.5 days with a slight additional decline on prolonging storage to 8 days (Davey, 1983). Moller et al. (1983) studied the effects of ageing for 1, 2, 3 and 4 weeks at 0 to 1°C on shear force values obtained for mutton M. longissimus and M. semimembranosus cooked at 80°C for 1 h. The shear force decreased rapidly during the first week for both muscles, and from the first to the fourth weeks the improvement was very slow. The activity of the acidic (pH 4.9), neutral (pH 7.0) and alkaline (pH 9.2) proteinases was measured by Babiker and Merkel (1985) for beef M. longissimus extracts at 1, 4, 8, 16, 24, 48 and 168 h post-mortem. They concluded that while post-mortem storage time was more important than ageing temperature on acidic and neutral proteinase activity, ageing temperature was the most important determinant of alkaline proteinase activity. The conclusion from the review of Dutson and Pearson (1985) was that increased temperatures during pre-rigor and post-rigor conditioning definitely improved meat tenderness.

2-3-4-4-2-2 Electrical Stimulation

The possibility that electrical stimulation increases the rate of ageing tenderization has been the subject of a number of investigations (Savell et al., 1981, 1982; Mckeith et al., 1981; Babiker and Lawrie, 1983; Davey, 1983; Bowles et al., 1983; Lyon et al., 1983; Martin et al., 1983; Moller et al., 1983; Hopkinson et al., 1985; Taylor and Cornell, 1985). The results are variable with some studies showing that electrically-stimulated samples have lower shear force values than unstimulated samples up to about 14 days of ageing (George et al., 1980), 8 days of ageing (Savell et al., 1981), or 6 days of ageing (Martin et al., 1983). The results of Bowles et al. (1983) showed no significant difference in tenderness of M. longissimus and M. semimembranosus beef samples which received either electrical stimulation or 6 days' ageing treatment. Similar results were reported by Lyon et al. (1983), but in different muscles. Moller et al. (1983) found that sheep M. longissimus and M. semimembranosus stimulation did not appear to accelerate ageing tenderization at the low storage temperature (0 to 1°C). Taylor and Cornell (1985) found no significant difference in tenderness of beef M. longissimus when electrically-stimulated or aged for 28 days, but samples receiving both the electrical stimulation and ageing treatments were significantly more tender than those receiving the electrical stimulation alone. There were no significant differences between ageing plus electrical stimulation treatment and ageing alone. Valin et al. (1981) concluded that electrical stimulation per se has no significant effect on meat ageing, but that it could perhaps be used to improve the efficiency of meat ageing by reducing its duration. It has been shown that electrical stimulation shortens the period of rigor and thus allows tenderization to begin at higher temperatures (George et al., 1980; Martin et al., 1983; Babiker and Lawrie, 1983).

Devine et al. (1979) found that the mitochondria of electrically-stimulated muscle appeared to be swollen and in some cases ruptured, which may have enhanced the activity of autolytic enzymes. It has been suggested that the combination of low pH and high temperature caused by electrical stimulation promotes the rupture of lysosomal membranes and releases those enzymes which act on muscle components (Moeller et al., 1977; Dutson et al., 1980; George et al., 1980;

Chrystall, 1982; Crouse et al., 1983; Dutson, 1983; Marsh, 1983; Rashid et al., 1983a, b; Newbold and Small, 1985; Orcutt and Dutson, 1985; Wu et al., 1985; Eikelenboom and Smulders, 1986; Solomon et al., 1986). Dutson et al. (1980) found that the activity of lysosomal enzymes is increased by the rapid pH decline caused by electrical stimulation. Thus, the activity of β -glucuronidase and cathepsin-C have been shown to be increased by 24% and 30% respectively following electrical stimulation (Dutson et al., 1980). These results have been substantiated by Wu et al. (1985).

2-3-4-4-2-3 Cooking Temperature

The myofibrillar proteins along with the connective tissue proteins are the main proteins responsible for the ultimate tenderness of meat (Seideman and Durland, 1984). Seideman and Durland (1984) stated that initial changes that take place in muscle tissue when it is exposed to heat are electrostatic and/or involve hydrogen cross-linkages. Further heating causes aggregations of peptide chains which are responsible for the observed phenomena of gelatin formation and hardening. According to Bramblett et al. (1959), temperatures between 57^o and 75^oC will result in protein coagulation, but there is probably no specific coagulation temperature because muscle fibres consist of several proteins, each with different properties. Hamm and Deatherage (1960) found that myofibrillar proteins start to coagulate between 30^o to 40^oC and are markedly coagulated at 55^oC. Heat-induced changes in myofibrillar protein solubility were investigated by Cheng and Parrish (1979) in beef M. longissimus at death and after heating at 45, 50, 55, 60, 70 and 80^oC. They found that alpha-actinin was the most heat-labile protein and became insoluble at 50^oC, heavy and light chains of myosin became insoluble at 55^oC, while actin, tropomyosin and troponin were more heat resistant. Actin was insoluble between 70^o and 80^oC and tropomyosin and troponin became insoluble above 80^oC (Cheng and Parrish, 1979). Hartshorne et al. (1972) suggested that at temperatures above 40^oC, the conformation of myosin may no longer recognise troponin, while above 50^oC the conformation of myosin may be further altered and the activation by actin lost (Hartshorne et al., 1972). During cooking the toughness is known to change in at least three successive steps as demonstrated by Davey and Gilbert (1974). Heating meat to around 50^oC yields an increased toughness, which in

general coincides with increased myofibrillar denaturation and large changes in water-holding capacity (Hamm and Deatherage, 1960; Bouton and Harris, 1972). Between 50^o and 60^oC, the toughness then decreases, a change which is usually interpreted in terms of collagen denaturation (Laakkonen et al., 1970; Bouton and Harris, 1981; Beilken et al., 1986). Also during cooking, an effect of increased proteolytic activity in the muscle on meat tenderness has also been postulated (Laakkonen et al., 1970; Penfield and Meyer, 1975; King et al., 1981; Beilken et al., 1986). All these findings suggested that several proteolytic enzymes are active in meat between 50^o and 60^oC but that they were denatured at 70^oC. Fluorescence and microcalorimetric studies of cured meat during heating (Oreshkin et al., 1986) indicated that meat proteins heat-denature within the temperature range from 20^o to 90^oC in two stages. The protein structure is loosened and hydrated between 20^o to 61^oC and complicated by a reverse process of coagulation during which the protein chains adhere to one another between 62^o and 90^oC. This process causes tightening of the protein structure and reduces its water-holding capacity.

2-3-4-4-3 Relationships Between Fatness and Muscle Protein Breakdown

According to the review of Asghar and Pearson (1980), the rate of biophysical and biochemical reactions of the cellular systems of muscle depend on temperature, so it is not surprising that a thick layer of fat acts as an insulating barrier and allows for a very gradual decline in muscle temperature during chilling. This permits increases in the natural breakdown of the tissue (Jennings et al., 1978). These relationships between fatness and temperature are more important at an early post-mortem period of chilling which cause breakdown of muscle protein (Section 2-3-4-4-2-1). However, these relationships will decline with increasing post-mortem time, thereby minimising the relationship between fatness and ageing (Parrish, 1974).

2-3-4-5 Rate of Glycolysis and Ultimate pH

Glycogen contained within the muscle at death is metabolized through an anaerobic process leading to the formation of lactic acid and consequently to a lowering of the pH (Petersen, 1984). Meat from

normal animals will usually achieve ultimate pH values of around 5.5 but high ultimate pH values (6.0 or above) may be found if muscle glycogen stores have been depleted prior to slaughter.

2-3-4-5-1 Quality Characteristics Affected by pH

The rate of glycolysis and therefore of pH drop in postmortem muscle, and the ultimate pH reached may affect many meat quality factors (Dutson, 1983). Several studies have reported the effects of pH at specific times during conversion of muscle to meat, as well as the ultimate pH of meat, on the quality of ovine meat (Bouton et al., 1971, 1972a, 1982a,b; Smith et al., 1976; Furnival et al., 1977). The relationships between postmortem pH decline and muscle tenderness have been reviewed by Dutson (1983) and Marsh (1983). They concluded that a high ultimate muscle pH (6.2 or greater) is associated with more tender meat.

The relationship between rate of pH fall and ultimate pH in postmortem muscle and the quality of meat have been studied (Khan and Nakamura, 1970; Johnson and Henrickson, 1970; Lockett et al., 1975a,b; Dransfield and Rhodes, 1975; Smith et al., 1976; Asghar and Yeates, 1977; Honikel and Fischer, 1977; Izumi et al., 1977). All these reports suggest that a relatively slow rate of glycolysis and a moderately low ultimate pH are characteristics of normal, usually tender meat. Others have shown that higher ultimate pH values are associated with more tender meat (Kauffman et al., 1964; Walter et al., 1965; Bouton and Shorthose, 1969; Bouton et al., 1971, 1972a,b, 1973a,b; Khan and Lentz, 1973; Fredeen et al., 1974; Martin et al., 1975; McDougall et al., 1979; Dransfield, 1981; Dutson et al., 1981; Fjelkner-Modig and Ruderus, 1983; Yu and Lee, 1986). Still other researchers have found no significant relationships between ultimate pH and meat quality (Husaini et al., 1950). Bouton et al. (1973b) found bovine M. longissimus was maximally tough in the pH range from 5.8 to 6.0. Miles and Lawrie (1970) identified a relationship between pH and meat tenderness using cooked rabbit muscle, whereby tenderness increased linearly with increasing pH over the range from 5.5 to 7.1. Dransfield (1977) demonstrated that some of the observed variability in cooked meat tenderness between 18 beef muscles was associated with differences in their ultimate pH, with improved tenderness being

correlated with higher ultimate pH. Yu and Lee (1986) compared the effect of three postmortem pH ranges (high > 6.3, intermediate 5.8 to 6.3 and low < 5.8) on bovine M. longissimus tenderness and found that the high pH meat was most tender, followed by the low and then the intermediate pH meats. They attributed the tenderization of high pH meat to the removal of Z-lines, whereas the tenderization of low pH meat was due to the degradation of myosin heavy chains and M-lines, while the intermediate pH meat showed very limited degradation of M-lines and myosin with well preserved Z-lines (Yu and Lee, 1986).

2-3-4-5-2 Factors Affecting Muscle pH

The pH of a postmortem muscle is largely influenced by the activity of the animal just before its slaughter and during the death struggle (Hallund and Bendall, 1965; Bendall, 1973; Devine et al., 1979). It is also influenced by the stimulation of glycolysis during excision and sampling of the muscle (Bendall, 1973). The latter is evidenced by the strong contraction that takes place when muscle is cut soon after slaughter. Electrical stimulation soon after slaughter has a significant stimulatory effect on the rate of pH fall (Bendall, 1976; Chrystall and Hagyard, 1976; Davey et al., 1976; Bendall et al., 1976; Chrystall and Devine, 1978; Nichols and Cross, 1980; Chrystall, 1982; Crouse et al., 1983; Rashid et al., 1983b; Newbold and Small, 1985; Eikelenboom and Smulders, 1986; Solomon et al., 1986).

According to Chrystall and Devine (1978), Houllier et al. (1984) and Newbold and Small (1985), in stimulated muscle, pH fall occurs in two stages: a very fast drop during the brief period of stimulation (ΔpH) and a further significant drop at a rate (dpH/dt) still about twice as fast as that which occurs in unstimulated muscle. If stimulation is undertaken within minutes after slaughter, low voltages and currents are sufficient to achieve a large increase in rate of rigor onset, mainly through the triggering of a more rapid dpH/dt . Rashid et al. (1983b) demonstrated that electrical stimulation and chilling methods had marked influences on muscle postmortem glycolysis rates of sheep carcasses. Walter (1975) showed that a rapid antemortem or rapid postmortem decline in pH, while the carcass temperature remained high may cause a denaturation of sarcoplasmic and myofibrillar proteins. Laborde et al. (1985) postulated that the pH

of pig muscle was affected by muscle fibre type, with the red muscle fibres having the highest ultimate pH. Further information on relationships between muscle fibre types and susceptibility of the animal to stress was reviewed by Ashmore (1974). He postulated that the conversion of glycogen stores to lactic acid was affected by the proportion of muscle fibres adapted for glycogenolytic metabolism, because this type of metabolism responds most dramatically to epinephrine, the hormone released in proportion to the level of stress imposed upon the animal. This pattern of glycogen depletion results from the fact that red fibres have a more copious blood supply than white fibres, and would therefore "see" the epinephrine at a faster rate (Ashmore, 1974). Lawrie (1978) stated that red muscles resist oxidative rancidity and discolouration on storage to a markedly greater degree than white fibres during frozen storage at -10°C . This has been shown to be due to the fact that the ultimate pH attained in red muscle was usually higher than that in white muscle. The rate of fall of pH decreases with decreasing muscle temperature (Newbold and Harris, 1972), but pH falls more rapidly at 1°C than at 5°C during the first few hours postmortem (Cassens and Newbold, 1967). Similar observations were made by Dransfield and Lockyer (1985). They showed that pig samples cooled in air at 3°C had the lowest rate of pH drop and on average took 7 h to reach pH 6.0, while, an increase or decrease in cooling temperature caused an increase in rate of pH fall. On average pH 6.0 was reached in about 4 h at 20°C in air and 5.5 h at -1°C in liquid.

2-3-4-5-3 Relationships Between Fatness and Muscle pH

Smith et al. (1976) studied the effect of fat thickness on muscle pH of lamb, and found that carcasses with thin back fat had significantly higher pH values than lambs with thick back fat. However, there was no relation between pH values and back fat thickness for pig M. longissimus and M. semimembranosus, in the study of Vos and Sybesma (1971). In pork, Martin and Fredeen (1974b) found no relationship between initial pH (40 min postmortem) and back fat thickness but ultimate pH (48 h) was significantly higher for the high fat group. The reason for these conflicting results was not clear.

2-3-4-6 Water-Holding Capacity

The water-holding capacity of meat is its ability to absorb and retain water during the application of some external force or treatment (Hamm, 1960). The importance and chemical basis of this characteristic has been extensively reviewed (Hamm, 1960, 1975; Lawrie, 1985; Offer and Trinick, 1983). According to Jeffrey (1983) the myofibrillar proteins are the main water binders in meat, with the quantity bound being proportional to the space between the filaments. Therefore water-holding capacity has received more attention than most biophysical properties of muscle because it is a sensitive indicator of changes in the charge and structure of muscle proteins (Hamm, 1960, 1975). Moreover, it is known that the interfilament spacing is by no means constant, but varies with pH, sarcomere length, ionic strength, osmotic pressure and whether the muscle is relaxed or in rigor (Elliott, 1968; April et al., 1972; Goldman et al., 1979; Millman and Nickel, 1980; Millman et al., 1981). It has been suggested that changes in the water-holding capacity of meat are caused by changes in the volume of the myofibrils resulting from changes in the interfilament spacing (Offer and Trinick, 1983).

2-3-4-6-1 Quality Characteristics Affected by Water-Holding Capacity

Several studies have reported positive correlations between water-holding capacity and tenderness (Tuma et al., 1967; Webb et al., 1967; Bouton et al., 1971; Berry et al., 1974). Bouton et al. (1972a) studied the effect of pH on some properties of ovine muscle and showed that an increase in shear values which are usually associated with cold-shortening. Martin and Fredeen (1974a) found a negative correlation between water-holding capacity and shear force value of beef. The importance of intrafibre water to meat tenderness has been emphasized by Currie and Wolfe (1980) who correlated changes in the mechanical properties of uncooked beef muscle undergoing rigor mortis with changes in the water-holding capacity of muscle fibres as influenced by pH, and the rate of fall of pH and showed that intrafibre water was affected by the osmotic pressure within the fibre.

2-3-4-6-2 Factors Affecting Water-Holding Capacity

The water-holding capacity of meat has been shown by Bouton et al. (1971, 1972a) to be closely related to pH, and to be a sensitive indication of variation in the charges and structure of muscle proteins. In the work of Hamm (1960), pH was clearly identified as a major factor influencing the water-holding capacity (WHC) of a homogenized meat system, with a minimal water-holding capacity occurring at the isoelectric point of the major proteins in muscle (pH 5.0 to 5.5). It then increased markedly with changing pH on either side of that point. Penny et al. (1963) demonstrated a similar phenomenon with purified beef myofibrils over the pH range 4.5 to 7.5. Then used the increase in water-holding capacity to explain myofibrillar swelling and increased fibre diameter. Furthermore, Gault (1985) showed that minimum swelling of the raw meat occurred within the range of pH 5.2 to 4.5. Below this pH there was a marked increase in swelling to the maximum value achieved around pH 3.5, corresponding to an approximate doubling of the volume of the meat discs. The data showed a decline in swelling with further decreases in the pH of the meat. According to Yasui et al. (1980) the maximum binding strength of myosin and actomyosin occurs at pH 6.0, and is reduced at lower pH. Miller et al. (1980b) and Solomon and Schmidt (1980) have shown that the amount of extractable protein is related to the binding strength of processed meats and that it is higher in pre-rigor meat which has a high pH. Matyniak and Ziolecki (1983) showed that the changes in the amount of expressible water and in cooking loss of duck meat occurred in parallel with changes in the pH values of the meat. Increases in meat acidity below pH 5.9 were associated with higher cooking losses, which gradually declined with an increase in pH. The lowest pH value (6.0) was associated with almost the highest level of expressible water. Offer and Trinick (1983) observed an increased swelling of individual myofibrils over the pH range 5.0 to 9.0 and this led to the first structural hypothesis of water-holding in meat based on the swelling or shrinkage of myofibrils caused by expansion or shrinkage of the myofilament lattices.

Recently, relationships between water-holding capacity and muscle fibre characteristics (Laborde et al., 1985) have revealed that the red muscle had a slightly higher water-holding capacity and pH than

the white muscle fibre. Hamm (1975) showed that two thirds of the decrease in water-holding capacity of post-mortem meat was associated with the reduction in ATP content. Honikel et al. (1981) demonstrated that as much as two thirds of the decrease in water-holding capacity of salted meat occurred due to rigor development and the remaining third was caused by the decrease in pH. Electrical stimulation did not affect the amount of free water (drip) in the package during retail display (Morgan, 1979; Jeremiah and Martin, 1980), while a number of reports in the literature have shown that electrical stimulation either decreases (Elgasim et al., 1981), has no effect on drip loss (Griffin et al., 1981; Babiker and Lawrei, 1983; Bowles Axe et al., 1983; Wood and Froehich, 1983; Dikeman et al., 1985) or brings about an increase in water-holding capacity (Greathouse et al., 1983; Lewis and Babiker, 1983; Eikelenboom and Smulders, 1986). Inconsistent findings have also been reported on the effect of electrical stimulation on the juiciness (Bouton et al., 1980; Elgasim et al., 1981; Salm et al., 1981; Riley et al., 1983a,b; Fabiansson and Buchter, 1984), but some other workers have reported that meat from electrically-stimulated carcass sides is less juicy than that from unstimulated sides (Savell et al., 1978a,b,c; Sorinmade et al., 1978; Bouton et al., 1980; Crouse et al., 1983).

2-3-4-6-3 Relationships between Fatness and Water-holding Capacity

The relation of water-holding capacity of meat to fat is a very complicated problem because results are different with different muscles and different animals (Hamm, 1960). Saffle and Bratzler (1959) found no significant correlation between fat content and defrosting drip in certain muscles of swine. Lin et al. (1985) found significant differences in fat content among M. semitendinosus, M. semimembranosus and M. biceps femoris from the same ham, but expressible juice levels for three of these muscles was not statistically different. They concluded that expressible juice was a measure of bound moisture in muscle and it was not affected by differences in fat content. Hawrysh et al. (1975), however, found that expressible juice levels for mature, marbled beef samples were higher than those of similar samples from regular beef. They explained the results of their study on the basis of greater amounts

of fat in the cooked meat from mature animals, and by the fact that in mature, marbled samples the fat which was very soft may have permitted the expressed muscle to slide out and cover a larger area on the filter paper, thus enabling the paper to absorb larger amounts of fat. The higher expressed fluid yield for mature, marbled samples probably reflected the increase in percent fat expressed rather than actual amount of juice expressed. In contrast, a direct curvilinear relationship between percent of fat in expressible juice and scores for quantity and quality of juice was reported by Gaddis et al. (1950), who found that the percent of expressible juice tended to decrease with increase in its fat content in beef, lamb, and mutton. The data of Swift and Berman (1959) showed that the increasing water retention of beef muscle relative to protein, was accompanied by an increasing fat content.

2-3-4-7 Muscle Pigment Content

Fresh muscle colour is determined mainly by the quantity of myoglobin and the relative proportions of the three pigments: purple reduced myoglobin (Mb), red oxymyoglobin (MbO₂) and brown metmyoglobin (MetMb) (Strange et al., 1974).

2-3-4-7-1 Quality Characteristics Affected by Muscle Pigment Content

Meat colour is considered by retailers to be of prime importance to consumers when choosing meat (Truscott et al., 1984). According to Franke and Solberg, (1971) the consumer considers the bright red colour of oxymyoglobin in fresh meat desirable, while the brown colour of metmyoglobin is considered undesirable. Pirko and Ayres (1957) and Adams and Huffman, (1972) showed that the consumer uses the colour of the meat to assess freshness and as a criterion of quality. Jeremiah et al. (1972), studied the palatability ratings of steaks assigned to various colour scores, and showed that mean scores of flavour, juiciness and tenderness did not differ among the groups. However, Fredeen et al. (1974) showed that the highest colour scores, both subjective and objective, related to the lowest initial shear force values.

2-3-4-7-2 Factors Affecting Muscle Pigment Content

The colour intensity of meat is determined by the total concentration of Mb and will be affected by such antemortem factors as species, sex, and age of animal, and postmortem factors such as anatomical location, temperature, and pH (Seideman et al., 1984). Thus, muscles of the beef carcass have more myoglobin per gram than those of lamb, and lamb has more than pork (Walters, 1975). Male animals have muscles with higher myoglobin concentrations than female animals, and the concentration of bovine myoglobin increases with increasing chronological age, so a light colour is indicative of youthful, high quality meat (Urbain, 1952). According to Seideman et al. (1984) muscles used in locomotion will usually contain a higher concentration of myoglobin than a support muscle due to the increased amount of oxygen required for the production of energy. Similar conclusions were made by Ledward, (1985) when he compared three muscles (M. biceps femoris, M. semimembranosus and M. longissimus) for metmyoglobin concentration and found highly significant differences between muscles. Hood (1980) showed that the degree of discolouration after 96 h at 10⁰C was two to five times that at 0⁰C, depending on the muscle with the effect being most pronounced in the stable M. longissimus and least in the unstable M. psoas major.

According to Ledward (1985) the rate of change of temperature and pH of the muscle during postmortem glycolysis can modify the perceived colour independently of met Mb formation. A rapid fall in pH at high temperatures produces a pale and watery appearance because the proteins in the meat matrix are unable to bind the water effectively, while a slow rate of pH fall at low temperatures gives rise to a compacted (cold-shortened) matrix and a dark appearance (Ledward, 1985). In addition, the oxygen consumption rate is likely to be greater in rapidly, as opposed to slowly chilled meat, (Atkinson and Follett, 1973) and this will inhibit the formation of the bright red oxymyoglobin, giving a darker overall appearance. Lawrie (1985) stated that at high ultimate pH values the dark colour is present without a compacted structure because the fibres have high water-holding capacity and the oxygen consumption rate of the meat increases with increase in pH.

Obvious differences in terms of pigment concentration exist between muscles containing predominantly red or white muscle fibre types (Cassens and Cooper, 1971). According to Seideman et al. (1984), red muscle fibres generally tend to have a higher concentration of myoglobin than white muscle fibres because of their predominantly aerobic metabolism, which requires more oxygen, and therefore more myoglobin, than white muscle fibres that are predominantly anaerobic. This was illustrated by Lawrie (1950), who reported concentrations of 0.465% myoglobin (wet weight) in horse M. longissimus and 0.705% in M. psoas. Corresponding figures for pig were 0.280% and 0.435% respectively. According to Gauthier (1970), the relationship of muscle fibre types to colour of meat can also be demonstrated between the ultrastructural and cytochemical features of the three fibre types and the colour of a muscle. Chemical as well as histochemical data suggest that red and intermediate fibres contribute to the redness of a muscle and in both cases, mitochondrial content is a measure of redness (Gauthier, 1970).

Panel evaluation studies have shown that meat from electrically-stimulated carcasses is generally brighter (Asghar and Henrickson, 1982; Babiker and Lawrie, 1983; Crouse et al., 1983; Moody et al., 1984; Cross et al., 1984; Claus et al., 1985), than that from unstimulated carcasses. These differences have been identified when the carcasses are evaluated within 24 h postmortem (Savell et al., 1978b). Beyond that time the difference in colour of stimulated and unstimulated meat disappeared (Calkins et al., 1980). That is probably why several other studies have not found any improvement in lean colour associated with electrical stimulation (Nichols and Cross, 1980; Dutson et al., 1982; Greathouse et al., 1983; Rashid et al., 1983a; McIntyre and Ryan, 1984). According to Orcutt et al. (1984), electrical stimulation can improve the initial colour of beef M. longissimus by eliminating the "heat ring", a dark discolouration. The improvement in lean colour associated with electrical stimulation may be due to accelerated postmortem glycolysis causing rapid pH reduction in the muscle while the carcass temperature is still high (Calkins et al., 1980; Claus et al., 1985; Buts et al., 1986). Savell et al. (1978a) observed more structural damage in electrical stimulation than in non-stimulated beef muscle. According to Slepser et al. (1983), this tissue disruption may result in a looser muscle

structure that permits deeper oxygen penetration, thus resulting in a thicker MbO₂ layer and a deeper MMb layer. The looser structure may also cause more light scatter and consequently a lighter muscle appearance without changing the percent of surface MbO₂ (Sleper et al., 1983). Similar conclusions were reached by Claus et al. (1985). They reported that the association of electrical stimulation with a more open muscle structure may result in greater reflective properties of the muscle causing it to appear lighter. These factors could also be related to greater oxygen incorporation by the muscle. Contreras and Harrison (1981) evaluated the colour stability of ground beef from electrically-stimulated and control carcasses. The data on reflectance, Hunter Lab spectrophotometer data and Hunter a/b ratios, suggested that ground beef from electrically-stimulated carcasses was more sensitive to metmyoglobin formation than that from the control, when both were exposed to radiant energy for 4 h.

The colour intensity of meat is also influenced by pH and the morphology of the muscle structure. A low ultimate pH will cause the muscle structure (fibrils) to be more open and to scatter light (Walters, 1975). In addition, a low ultimate pH will also cause the myoglobin fraction to be more readily oxidized to metmyoglobin which has a lower colour intensity (Walter, 1975). On the other hand, the muscle fibres of meat with a high ultimate pH are swollen and tightly packed together forming a barrier to the diffusion of oxygen and the absorption of light (Walters, 1975). Furthermore, the high-pH muscle does not brighten upon exposure to oxygen because the high pH does not permit oxygen to combine with myoglobin to form red oxymyoglobin (Urbain, 1952). The high pH of the meat will also accelerate respiratory activity of the meat tissue (Walters, 1975). As a result, there is only a very thin layer of red oxymyoglobin over the underlying purple reduced myoglobin (Walters, 1975).

2-3-4-7-3 Relationship between Fatness and Colour

Martin and Fredeen (1974b) showed that the electronic colour recordings of meat samples were not influenced by fatness. Van Den Oord and Wesdorp, (1971) used minced beef containing 0%, 15% and 30% fat and showed that the higher fat content samples had higher oxymyoglobin proportions. Similar results were obtained by Elliott (1967)

in an experiment with meat slices containing cores of fat of varying diameter. Szocs et al. (1982) showed that the meat surface reflectance percent was positively associated with fat percent in the muscle sample of beef.

CHAPTER 3

MATERIALS AND METHODS

3-1 ANIMALS AND EXPERIMENTAL DESIGN

Experimental animals came from flocks of Southdown and Romney sheep located on the Sheep and Beef Cattle Research Unit at Massey University (Table 3-1).

The initial population of Southdown ewes was established in 1976 with ewes being allocated to either the fat or meaty line on the basis of weight-corrected fat depth measurements (Barton, 1981; Purchas, 1981; Purchas *et al.*, 1982). Selection of replacement animals has been from within the flocks based on weight-corrected fat depth measurements made during the first 15 months of life. Two 15-month sires per line were used each year. In Experiments 1 and 2, offspring from selected sires crossed with Romney ewes were used, while in Experiments 3, 4, 5 and 6, purebred offspring of selected sires were used.

3-1-1 EXPERIMENT 1

This experiment was performed in the years 1982-1983. Southdown-Romney cross lambs (rams from selection lines; ewes selected at random) were born within a four-week period in August-September 1982. They were identified and weighed at birth, and were tailed and the rams castrated with rubber rings at 3 to 4 weeks of age. All lambs were weaned on 30 November (10 to 12 weeks of age).

On 16 December 1982, 64 lambs (31 ewes and 33 wethers) were selected from the 82 lambs available (selection of the lines as described in Section 3-1-3). Where possible selected lambs were between 21 kg and 33 kg live weight with equal numbers in each sex by sire classification. On the day of selection, the lambs were randomly allocated within sex and sire groups to four pastures: white clover (Trifolium repens), lucerne (Medicago sativa), lotus (Lotus pedunculatus) and perennial ryegrass (Lolium perenne). The lambs were rotationally grazed ad libitum under similar management conditions for an 84-day period, and were individually weighed at 7 to 14 day intervals. On 7 March 1983, the live weights (full) were recorded, and on 9 March

Table 3-1. Descriptions of experimental designs and measurements.

Experiment	Year of slaughter	Breed and sex	Age at slaughter (months)	No. animals		Nutritional treatments	Treatments		Measurements
				Fat	Meaty		Post-mortem treatments	Whole carcass	
1	1983	Southdown X Romney wether and ewe lambs	6 to 7	32	32	White clover (16) ^a Lucerne (16) ^a Lotus (16) ^a Perennial ryegrass (16) ^a	-	-	1. Meat quality 2. Certain individual muscle weights 3. Linear measurements
2	1984	Southdown X Romney wether and ewe lambs	6 to 7	32	32	The same four pastures as for Experiment 1	-	-	As for Experiment 1
3	1981	Southdown rams	16 to 17	12	18	-	-	-	1. Side dissection 2. Carcass and linear measurements
4	1982	Southdown rams	16 to 17	10	8	-	-	-	1. Leg and rack dissection 2. Carcass and linear measurements 3. Histology and meat quality
5	1984	Southdown rams	16 to 17	12	12	-	Electrical stimulation of 12 carcasses	1. Fat trimming 2. Cold shortening 3. Ageing treatment	1. Side dissection 2. Carcass and linear measurements 3. Histology and meat quality
6	1985	Southdown rams	16 to 17	12	12	White clover (12) ^a Lotus (12) ^a	As for Experiment 5	As for Experiment 5	As for Experiment 5

^a The number of animals allocated to each pasture type.

the lambs were slaughtered at the plant of Borthwick C.W.S. Ltd., Feilding (Section 3-2-1-1).

The following measurements were taken:

1. Linear and area measurements on the cross-section at the 12th rib (Section 3-2-2-1);
2. Muscle pH (Section 3-2-5-1);
3. Warner-Bratzler Shear values (Section 3-2-7-2).

3-1-2 EXPERIMENT 2

This experiment was carried out in the years 1983 and 1984 with the Southdown-Romney cross lambs (rams from selection lines; ewes selected at random) within the four sire groups being born in 1983, and managed as for Experiment 1 (Section 3-1-1).

A total of 100 ewe and wether lambs was available for selection. On 11 November 1983, 64 lambs (31 ewes and 33 wethers) were selected from the 100 lambs by randomly allocating lambs within sex and sire groups to the same four pasture treatments used in Experiment 1 (Section 3-1-1). The experimental period was 145 days. On 4 April 1984, the live weights (full) of the lambs were recorded and they were transported to Takapau, where they were slaughtered on 6 April at the plant of Hawke's Bay Farmers' Meat Co. Ltd. (Section 3-2-1-1).

The same measurements were taken as for Experiment 1 (Section 3-1-1).

3-1-3 EXPERIMENT 3

Southdown lambs born in 1979 were managed as for Experiment 1 (Section 3-1-1). On 14 April 1980 the 62 ram lambs available for selection were reduced to 40 lambs based on a weight-corrected ultrasonic fat depth measurement (Purchas and Beach, 1981).

In November 1979 four rams were selected as sires (two fat and two meaty) based on six weight-corrected fat depth measurements. These measurements were taken approximately between 8 and 16 months of age. The 30 Southdown rams used in this experiment (12 fat and 18 meaty)

were the heaviest of the remaining animals. All the rams were individually weighed at intervals of about 4 weeks and were run together under the same management.

On 9 December 1980, the animals were allocated to one of ten slaughter lots, each lot being slaughtered on different days. The heaviest animals were slaughtered first to minimize the range of carcass weights. All animals intended for slaughter were weighed at 4.00 p.m. the day before slaughter. They were allowed water, but not feed overnight, prior to slaughter at about 8.00 a.m. the next day.

The following measurements were taken:

1. Side and rack dissection (Section 3-2-2-2 and 3-2-3);
2. Linear and area measurements (Section 3-2-2-1).

3-1-4 EXPERIMENT 4

Fifty-eight Southdown rams born in the spring of 1981 were available for selection, which took place on 26 May 1982. Thirty-seven rams were selected from the 58 rams, based on a weight-corrected ultrasonic fat depth measurement.

Eighteen rams (10 fat and 8 meaty) were used in this experiment. Selection of the animals and the sires for the next generation were made following the procedures outlined for Experiment 3 (Section 3-1-3).

On 14 January 1983, the animals were allocated to one of three slaughter lots, which were slaughtered on different days with the heaviest lot first to minimize the range of carcass weights. The day before slaughter, the animals were fasted as for Experiment 3 (Section 3-1-3).

The following measurements were taken:

1. Dissection of rack and leg cuts (Sections 3-2-2-2 and 3-2-3);
2. Linear and area measurements (Section 3-2-2-1);
3. Adipose tissue measurements (Section 3-2-6);
4. Muscle pH (Section 3-2-5-1);
5. Meat quality measurements (Section 3-2-7).

3-1-5 EXPERIMENT 5

The animals of this experiment were born in the spring of 1982 and were managed as for Experiment 1 (Section 3-1-1). On 16 May 1983, 40 Southdown rams were selected from the 107 rams available, based on a weight-corrected ultrasonic fat depth measurement.

Twenty-four rams (12 fat and 12 meaty) were used in this experiment. Selection of the 24 rams and the sires for the next generation were made following the procedures outlined in Experiment 3 (Section 3-1-3). All rams were run together under the same management and weighed regularly.

On 4 January 1984, the animals within each line were allocated to one of eight slaughter lots of three depending on their live weights, each lot being slaughtered on different days. In order to minimize the range of carcass weights, the heaviest animals within a group were slaughtered first. Lot composition alternated between being two fat and one meaty, and being two meaty and one fat. Prior to slaughter the animals were fasted as in Experiment 3 (Section 3-1-3).

The following measurements were taken:

1. Side and cuts dissection (Sections 3-2-2-2 and 3-2-3);
2. Linear and area measurements (Section 3-2-2-1);
3. Muscle fibre parameters (Section 3-2-4);
4. Muscle characteristics (Section 3-2-5);
5. Adipose tissue measurements (Section 3-2-6);
6. Meat quality measurements (Section 3-2-7).

3-1-6 EXPERIMENT 6

Seventy Southdown rams born in the spring of 1983 were available for selection. On 1 October 1984, 40 rams were selected from the 70 rams based on a weight-corrected ultrasonic fat depth measurement.

Selection of the 24 rams (12 fat and 12 meaty) for use in this experiment and the selection of sires for the next generation, and the general management, were as described for Experiment 3 (Section 3-1-3).

On the day of selection, the rams were randomly allocated to either a white clover (Trifolium repens) group or a lotus (Lotus pedunculatus) group. The rams were rotationally grazed ad libitum on pure swards of these two species for 80 days.

On 30 November 1984, the animals within each line were allocated to one of eight slaughter lots of three depending on their live weights, each lot being slaughtered on different days as described in Experiment 5 (Section 3-1-5).

The same measurements were taken as in Experiment 5.

3-2. TECHNIQUES AND PROCEDURES

3-2-1 SLAUGHTER PROCEDURES

3-2-1-1 Preparation and Weighing of Non-carcass Components

3-2-1-1-1 Experiments 1 and 2

Lambs were dispatched for slaughter as their age reached approximately 6 to 7 months (Table 3-1). This is within the range in which lambs would normally be slaughtered in New Zealand.

All lambs were transported to the Borthwick C.W.S. Ltd., Feilding and Hawke's Bay Farmers' Meat Co. Ltd., Takapau, meat plants for Experiments 1 and 2 respectively, where they were stunned, bled and dressed using normal procedures. Accelerated conditioning was used with Experiment 2 (Chrystall, 1978) and carcasses of Experiment 1 were conditioned and aged (Locker et al., 1975; Table III) and then frozen.

3-2-1-1-2 Experiments 3, 4, 5 and 6

Animals were dispatched for slaughter as their age reached approximately 16 to 17 months (Table 3-1). The animals were kept to that age because it was easier to get large samples of tissue for evaluation, and to obtain more information from the animals to select the sires for the next generation.

Slaughter and dressing methods followed normal commercial procedures with a captive bolt pistol being used to stun the animals. The organs were removed according to normal dressing procedures, always in the same order. The foregut and oesophagus were cleaned and washed under cold running water and allowed to drip before weighing. Preparation and weighing of the organs and parts were recorded as illustrated in Table 3-2.

3-2-1-2 Electrical Stimulation

Half of the carcasses (12 whole carcasses) were electrically stimulated at 25 and 30 minutes post-mortem for Experiments 5 and 6 respectively.

Table 3-2. Measurements that were taken at the time of slaughter and 24 h post-mortem in Experiments 3, 4, 5 and 6.

Measurements	Experiment No.			
	3	4	5	6
Carcass weight ¹ (kg)	+	+	+	+
Time of slaughter			+	+
Time of electrical stimulation			+	+
Omental fat weight (kg)	+	+	+	+
Mesenteric fat weight (kg)				+
Kidney fat weight (kg)	+	+	+	+
Foregut empty weight (kg)	+	+	+	+
Intestines full weight ² (kg)	+	+	+	+
Small intestine weight (kg)				+
Large intestine weight (kg)				+
Liver weight (kg)	+	+	+	+
Heart weight (kg)	+	+	+	+
Kidney weight (kg)	+	+	+	+
Thyroid gland weight (g)	+	+	+	+
Adrenal gland weight (g)	+	+	+	+
Spleen weight (g)			+	+
Metacarpal bone weight ³ (g)	+	+	+	+
Metacarpal bone length ³ (mm)	+	+	+	+
Metacarpal bone circumference ³ (mm)	+	+	+	+

¹ Carcass weight was the weight of the carcass 24 h post-mortem

² Intestines included the mesentery and the mesenteric fat

³ These measurements were made on both metacarpal bones

During electrical stimulation the carcasses were suspended on a gambrel by a hook which was insulated from the rail by a nylon cord (Figure 3-1).

The electrical current was applied by 4 wires each terminating with a spring-loaded jaw-type clamp. Three clamps were attached to muscles of the neck (positive charge) and the other clamp was attached to the gambrel (earth). The electrical stimulation parameters were 800 volts RMS (1130 V peak), 10 MS pulse width, 14.28 Hz, for 90 sec. continuously (Chrystall, 1978).

3-2-1-3 Subcutaneous Fat Trimming and Temperature Measurement

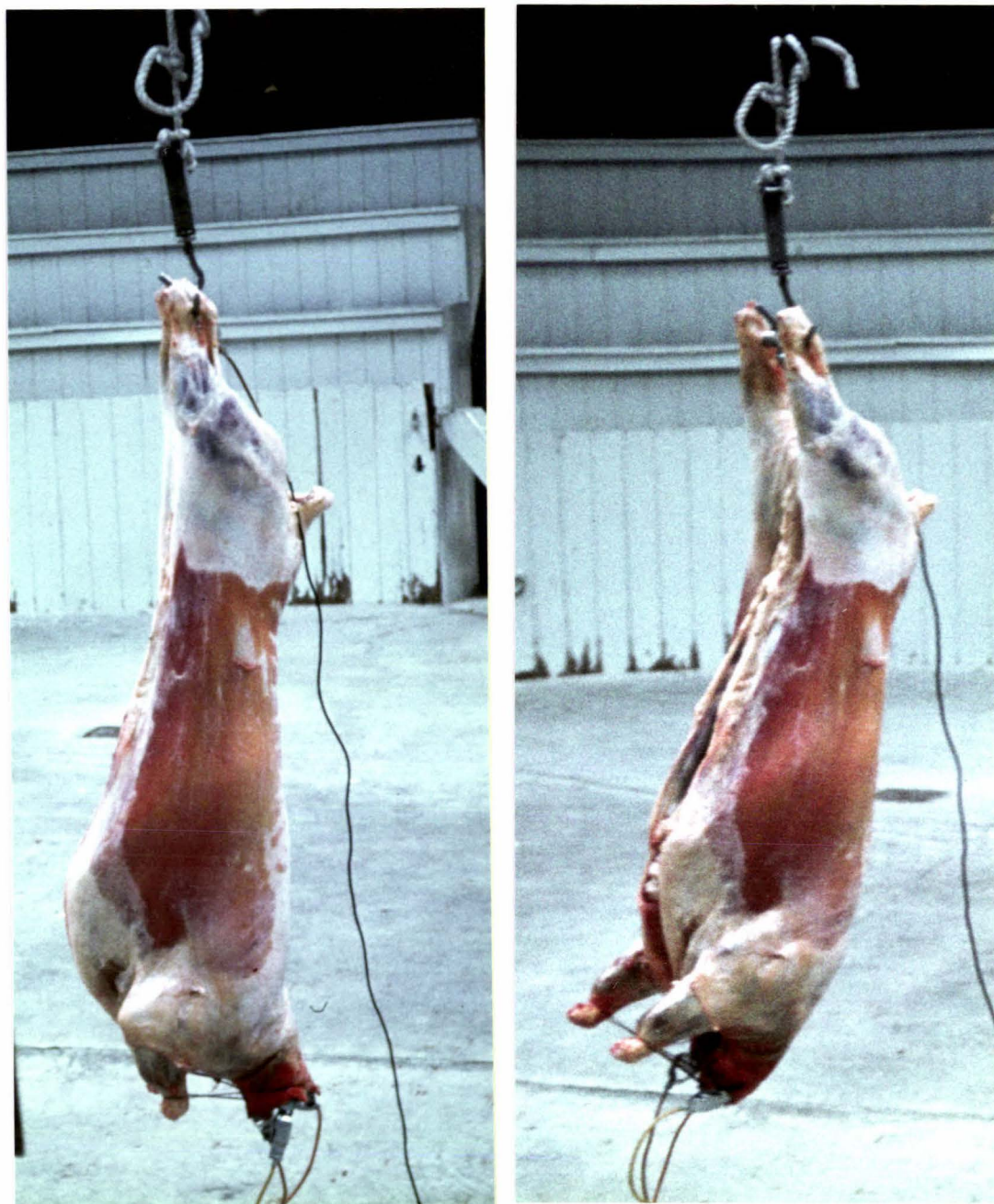
At about 36 ± 2 min post-mortem, the subcutaneous fat over the loin of the right side of each carcass was carefully separated from the underlying muscle and dissected away from the dorsal midline to a point approximately 100 mm lateral to the midline. Fat cover was removed from one side only to permit comparisons on a within-carcass basis. In this way each animal served as its own control.

Temperatures of M. longissimus on both sides were recorded at 2-h intervals starting at approximately 40 min post-mortem for 12 h. This was done by inserting a thermometer (Model 1001, Type NiCr/NiAl thermocouple) in the middle of M. longissimus to a point 30 mm lateral to the midline, approximately 15 mm from the dorsal surface of the muscle.

Each carcass was transferred to a cooler (0 to 3°C) at 100 ± 5 min post-mortem.

3-2-1-4 Temperature Treatment

At 38 ± 2 min post-mortem, M. biceps femoris was removed from the right side of each carcass, cleaned of fat and placed in a polythene bag and on ice. The left side muscle was removed at about 110 min post-mortem and kept at room temperature (16 to 20°C). Twenty-four h post-mortem, both muscles were frozen for subsequent assessments.



(a)

(b)

Figure 3-1 Photographs illustrating the response of a ram carcass in Experiment 6 to electrical stimulation at 30 min post-mortem. (a) Before stimulation with the earth electrode attached to the gambrel and 3 live electrodes attached to neck muscle; (b) at the start of the 90-sec stimulation period (800 V RMS, 14.28 Hz)

3-2-1-5 Ageing Treatment

At 26 \pm 2 h post-mortem, the left and right Mm. semimembranosus were removed from the carcass. Triplicate 25 mm thick slices were cut from the centre of each muscle, dipped in an antibacterial solution (100 mg streptomycin sulphate and 100 mg procaine penicillin, both Glaxo Laboratories [N.Z.] Ltd., per litre) and placed in plastic bags. The left side samples were cooked immediately (1 day ageing) and the right side samples were cooked after being stored at 3 \pm 1°C for 15 day.

3-2-2 CARCASS MEASUREMENTS

3-2-2-1 Linear and Area Measurements

At approximately 24 h post-mortem, carcasses were weighed and the linear measurements illustrated in Figures 3-2 and 3-3, and defined in Table 3-3, were made. Those in Figure 3-3 were taken after the cutting was completed (Section 3-2-2-2). Calipers and a metal rule were used to make the measurements (mm).

After the dissection was completed for each cut (Section 3-2-3), the weight, length and circumference of the following bones was recorded (Figure 3-4):

- I Humerus bone
- II Radius bone
- III Femur bone
- IV Tibia and fibula bones

The circumference of each bone was measured with a fine cotton string at the narrowest point on the shaft. The length was measured by calipers from the distal to the proximal extremities (Figure 3-4).

3-2-2-2 Cutting Procedures

3-2-2-2-1 Experiments 1 and 2

The frozen carcasses were cut into four commercial units according to DEVCO specifications (The Meat Export Development Company [N.Z.] Ltd.) (Figure 3-5).

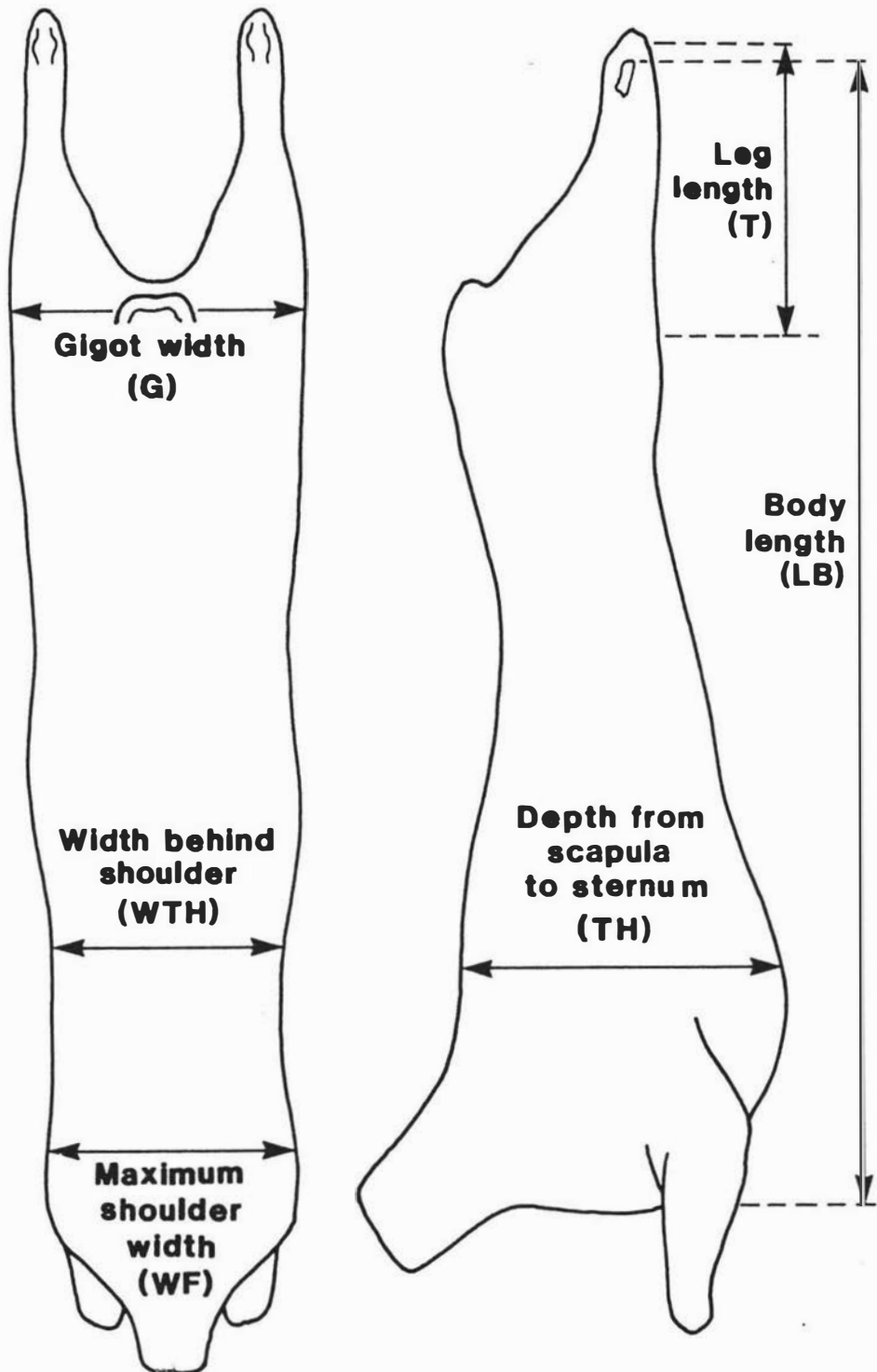


Figure 3-2. A diagram indicating where measurements were taken on the hanging carcass.

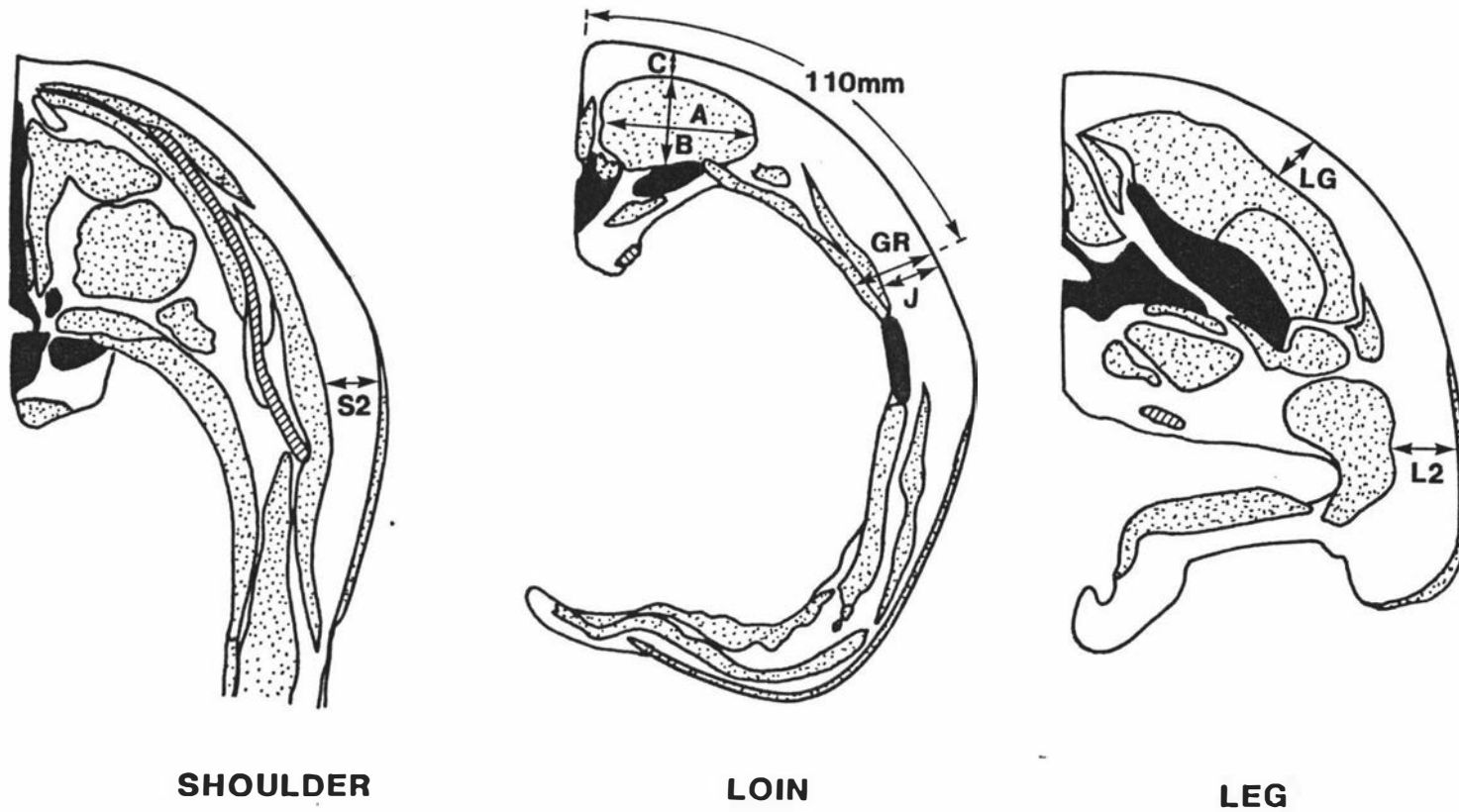


Figure 3-3. Diagrams indicating where measurements were taken on some cut surfaces of the carcasses. The shoulder cut was made between ribs 7 and 8, the loin cut was between the 12th and 13th ribs, and the leg cut was between the last lumbar and the first sacral vertebrae.

Table 3-3. Definitions of the carcass linear measurements

Measurement	Definition
1. Body length (LB)	From the point where the gambrel is inserted through the Achilles tendon to a point just anterior to the point of the humerus (Moxham and Brownlie, 1976).
2. Leg length (L)	From the distal end of the tarsals to the centre of the tuberosity of the tibia, which is visible on the ventral aspect of the hanging carcasses (Palsson, 1939).
3. Gigot width (G)	Maximum width of the gigots, with the carcass suspended from a gambrel. The measurement was taken at right angles to the length of the carcass at a line level with the femoral trochanter (Palsson, 1939).
4. Maximum shoulder width (WF)	Maximum width of the shoulder, measured at the level of the scapula from one lateral surface to the other, using a caliper (Palsson, 1939).
5. Depth from scapula to sternum (Th)	Maximum depth of chest was taken behind the shoulders at a line cutting the posterior angles of the scapula and at right angles to the length of the carcass (Palsson, 1939).
6. Width behind shoulders (WTH)	Minimum width behind the scapula (Palsson, 1939).
7 ^a . Fat thickness (C)	The depth of subcutaneous fat over 8 at right angles to the skin (Palsson, 1939).
8 ^a . Fat thickness (J)	The depth of subcutaneous fat over the <u>M. obliquus externus abdominis</u> (Palsson, 1939).

(Continued)

Table 3-3 (continued)

Measurement	Definition
9 ^a . Fat thickness (S2)	The depth of subcutaneous fat over the <u>M. latissimus dorsi</u> at a point at right angles to the mid-line bone (Kirton <u>et al.</u> , 1967a).
10 ^a . Tissue thickness (GR)	The depth of tissue over the surface of the rib at a point 110 mm from the mid-line (Frazer, 1976).
11 ^a . <u>M. longissimus</u> width (A)	The maximum width across the surface of the <u>M. longissimus</u> .
12 ^a . <u>M. longissimus</u> depth (B)	The maximum depth at right angles to the width measurement.
13 ^a . Area of <u>M. longissimus</u>	Area of the cut surface was traced on a tracing paper and the area was determined by using a digitising tablet attached to an Hitachi personal computer (Model MB-16003[E]).
14 ^b . Fat thickness (LG)	Fat thickness over the ventral edge of <u>M. gluteus medius</u> (Kirton and Johnson, 1979).
15 ^b . Fat thickness (L2)	Fat thickness over the ventral edge of <u>M. obliquus internus abdominis</u> (Kirton <u>et al.</u> , 1967a).

^a Measurements were taken on the cut surface between ribs 12 and 13 (Figure 3-3).

^b Measurements were taken on the cross-section of the leg cut (Figure 3-3).

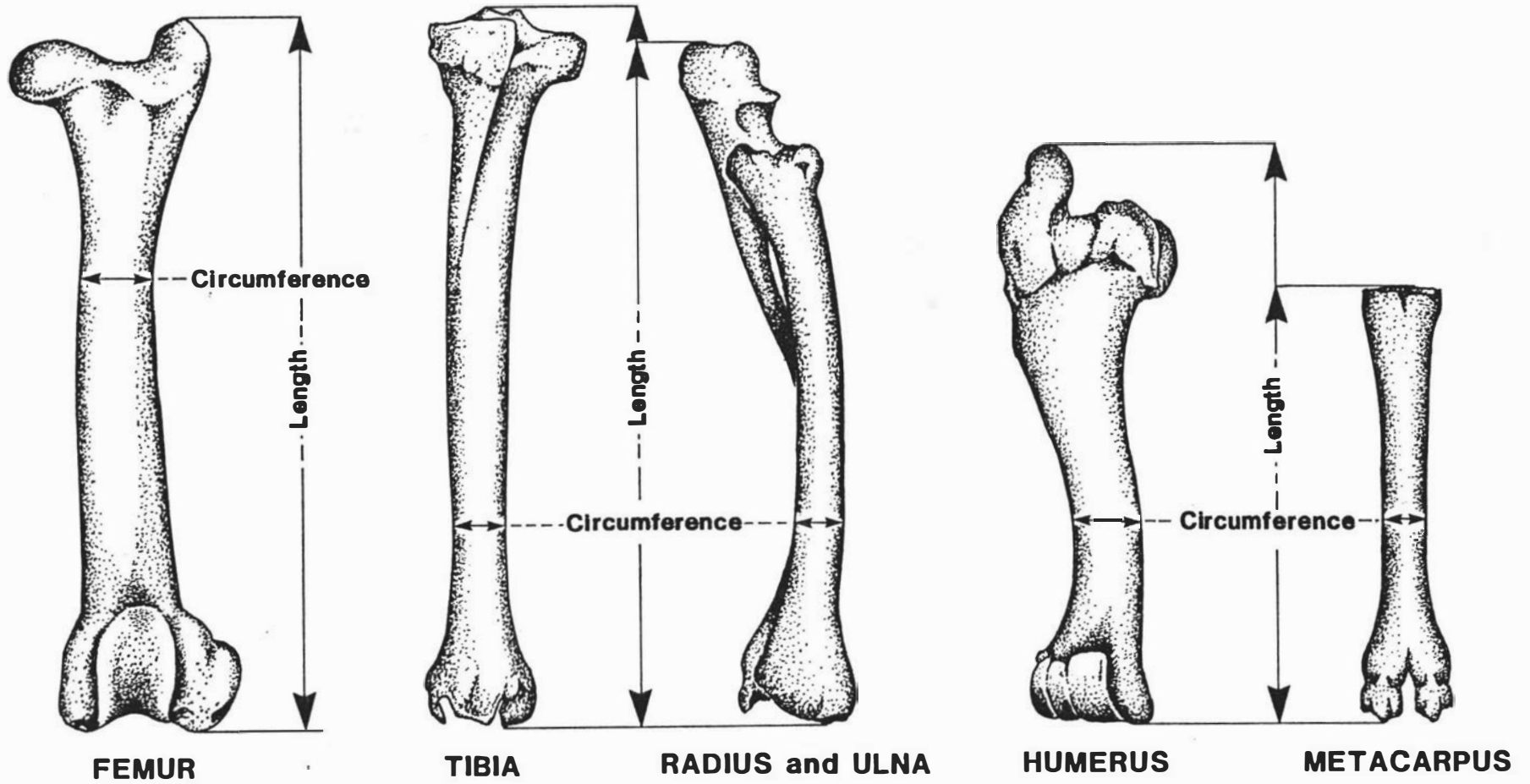


Figure 3-4. Diagrams indicating where measurements were taken from five bones.

3-2-2-2 Experiments 3, 4, 5 and 6

Each carcass was cut into four anatomical cuts: shoulder, rack, loin and leg (Figure 3-5).

The shoulder was separated from the rack by first cutting with a knife along a line against the caudal edge of the 7th rib on each side, and then the vertebra was sawn through. The rack was separated from the loin by cuts against the caudal edge of the 12th rib, the ventral edge of the costal cartilages, and through the cartilage disc separating the 12th and 13th thoracic vertebrae. The leg was separated by cutting through between the last and second to last lumbar vertebrae.

The cuts were either dissected within 24 h or sealed in a plastic bag and frozen at approximately -20°C for periods ranging from 4 to 22 weeks.

3-2-3 DISSECTION PROCEDURES

The method was based on the sheep carcass evaluation as described by Brown and Williams (1979). The whole vertebral column was left with the left side of the carcass to avoid errors due to splitting. This was done by carefully dissecting the soft tissue and bone of the right side away from the vertebral column. The weight of the half-vertebral column was subtracted from the side weight which included the whole vertebral column.

Prior to dissection, each cut was thawed in a cooler at 1 to 2°C overnight, while still in its plastic bag.

To reduce moisture losses, the dissection was done as quickly as possible using knives, forceps, scalpels and scissors. The cut and its parts were kept covered with towels which had been soaked in cold water and wrung dry. As soon as a muscle or a bone was cleaned, it was weighed.

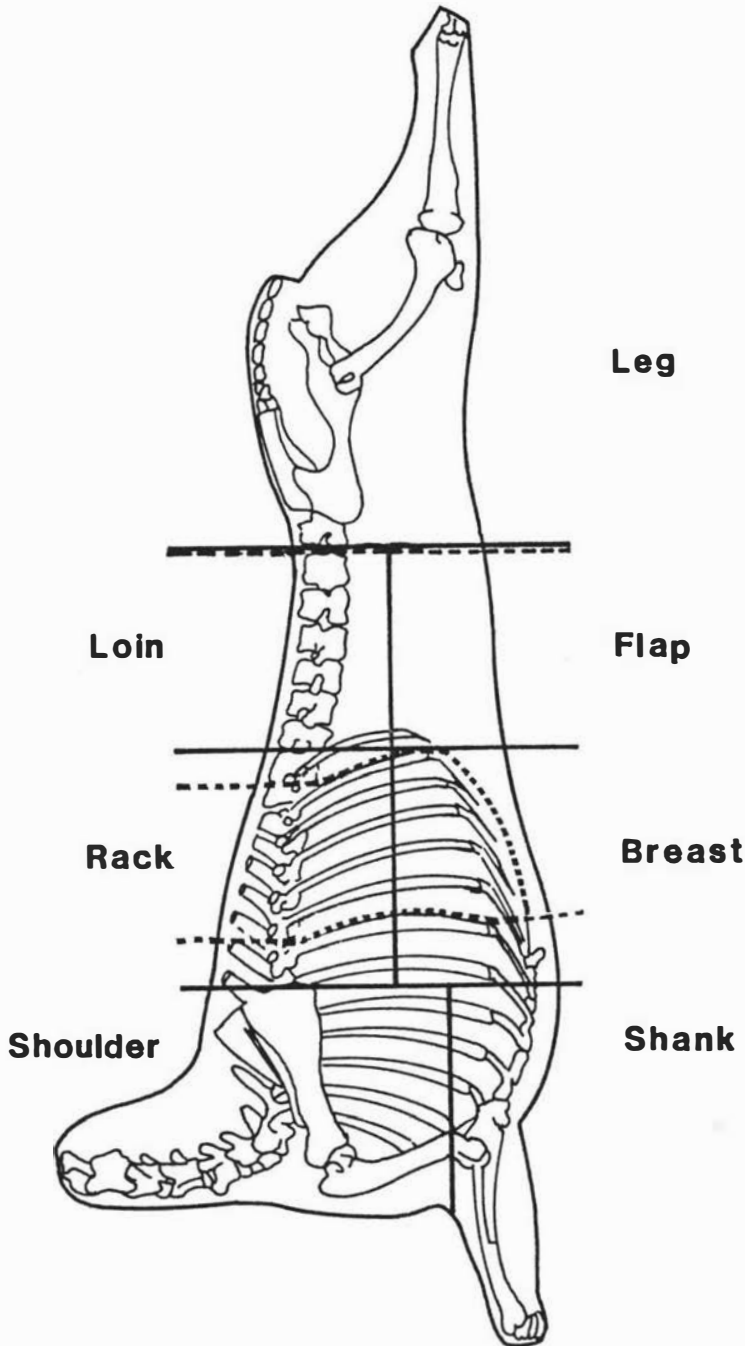


Figure 3-5. A side of carcass showing the position of the standardised cuts using dotted lines for Experiments 3, 4, 5 and 6 and solid lines for Experiments 1 and 2 (Devco).

Each cut was then dissected into the following tissue groups:

- I Subcutaneous fat: this comprised all the fat on the external surface, i.e. the fat that lies directly under the skin or under M. cutaneus trunci. This fat was removed by a knife without excavating the grooves between muscles.
- II Intermuscular fat: all the fat beneath the deep fascia associated with muscles and cuts (except intramuscular fat, which was determined chemically).
- III Muscle: this was the total weight of dissected muscle in each joint, weighed after the complete removal of all adherent intermuscular fat. The muscle inevitably contained a little fat and tendon. Also certain muscles were removed and weighed individually from each cut. The dissection of individual muscles was based on the description of Fourie (1962).
- IV Bone: this was the total weight of trimmed bone in each cut which included cartilages, as at the dorsal edge of the scapula, and costal cartilages. Also certain individual bones were removed and weighed from each cut.
- V Scrap: this included all tissues not readily identifiable as muscle, fat or bone. The weight of this tissue included:
 - a. Tendons
 - b. Glands, nerves and blood vessels.

3-2-4 MUSCLE FIBRE TYPES

3-2-4-1 Collection of Samples

At approximately 35 ± 2 min post-mortem the right M. semi-tendinosus was separated from its neighbouring muscles and its cranio-dorsal attachment to the M. biceps femoris severed. It was cleaned of fat, placed in a plastic bag and kept on ice prior to further processing.

3-2-4-2 Sectioning and Staining Procedure

Approximately 60 to 90 min post-mortem (depending on the rank of slaughter), a longitudinal strip with an average size of 7 mm in length along the muscle and 4 mm in diameter was removed. The sample was wrapped in aluminium foil and immediately frozen in approximately 100 ml of isopentane cooled to -160°C in approximately 50 ml of liquid nitrogen for 10 to 15 min. The frozen sample was mounted on a cryostat chuck with a few drops of Tissue-Tek II O.C.T. compound, such that the orientations of muscle fibres were perpendicular to the cutting blade and was allowed to equilibrate to -20°C in a cryostat (LIDSHAW CRYO TOME Model 1500). Serial transverse, 10 μm thick, sections were cut, and mounted on clean glass slides. The unstained, mounted sections were left in a refrigerator for at least 30 min before staining to prevent the sections separating from the slides at later stages in the staining procedure, and then either stained for alkali-stable myosin ATPase by the method of Padykula and Herman (1955) as modified by Davies and Gunn (1972), or stained for succinate dehydrogenase (SDH) using the Nitro Blue Tetrazolium method (Nachlas *et al.*, 1957), or with PAS haematoxylin according to the procedure of Lillie (1965). A cover slip was then placed over the tissue section using glycerol jelly to fix it in place.

3-2-4-3 Muscle Fibre Diameter and Proportion

At 400X magnification the sections were examined using a projection microscope (ERNST LEITZ WETZLAR Type 31.047-500). Four hundred fibres of each muscle fibre type were traced onto tracing paper for each animal. The cross-sectional area of each traced fibre was measured using a digitising tablet attached to an Hitachi personal computer (Model MB-16003[E]). The diameter for each traced fibre was taken to be that of a circle with the same area.

The proportion of fibres of each of the muscle fibre types was calculated by counting all the fibres of each type in an area containing at least 1500 fibres, and dividing the total number of each type by the total number of fibres counted, and then multiplying the quotient by 100.

3-2-5 MUSCLE CHARACTERISTICS

3-2-5-1 Muscle pH

Sample cores (approximately 20 mm in diameter) were taken from the inside of a selected muscle and a 1-g sub-sample from the centre of the core was dropped into 10 ml of 5 mM iodoacetate and chopped finely with scissors (Bendall, 1973). The mixture was homogenised to a fine slurry using a glass homogeniser.

Measurements of pH were taken with a pH meter (Radiometer pH meter 29), calibrated against a buffer of pH 7.0 and then checked against a second buffer of pH 4.0 at room temperature.

The pH was measured by inserting the combined glass electrode in the homogenate. The electrode was washed well with distilled water between measurements and frequently with acetone as well in order to remove lipid.

3-2-5-2 Sarcomere Length

3-2-5-2-1 Sample selection and preparation

Three muscles (M. semitendinosus; M. biceps femoris; M. longissimus) from the left and right sides of each carcass were assessed for sarcomere length at approximately 12 h post-thawing. A 5 mm section was removed from the centre of M. semitendinosus and M. biceps femoris and at the 5th lumbar region of M. longissimus, and each section was subdivided into four equal-sized pieces. Then one piece from each section was randomly chosen. Small bundles of fibres were dissected from the meat piece, laid out on a glass slide and covered with a drop of buffered (0.05M Tris, pH 7.6) 0.25M sucrose solution (Stromer and Goll, 1967). Care was taken to ensure that single bundles were teased out and covered with a coverslip.

3-2-5-2-2 Measurement procedures

3-2-5-2-2-1 Oil immersion microscopy: Sarcomere lengths of M. biceps femoris in Experiment 5 were measured using a conventional microscope. The slide (see Section 3-2-5-2-1) was examined under the microscope with an oil immersion objective

(magnification X1250) (Ruddick and Richards, 1975). Sarcomere length was calculated using a calibrated objective lens and the values were converted using the calculated calibration factor. The mean of 12 measurements per sample was calculated.

3-2-5-2-2-2 Laser diffraction method: Sarcomere length by laser diffraction was determined by procedures similar to those described by Cross et al. (1980/1981).

The apparatus consisted of a helium-neon laser, with a wavelength of 632.8 nm (Spectra-physics model 102 2 mW laser head with the Model 212 power supply), which was mounted on a retort stand with a specimen-holding device and screen (Figure 3-6). The slide (Section 3-2-5-2-1) was then placed horizontally in the path of a vertically-orientated laser beam to give an array of diffraction bands on the screen. The bands were perpendicular to the long axis of the fibres. The distance from the specimen to the screen had a constant value of 100 mm. A ruler was used to make 10 measurements for each sample and the results averaged. Sarcomere lengths were calculated using a conversion table based on the following formula:

$$n\lambda = S \sin \theta \quad (\text{Bouton } \underline{\text{et al.}}, 1973d)$$

where $\lambda = 632.8 \text{ nm}$
 $S =$ distance from sample to screen
 $n =$ nth order of the diffraction pattern
 and $\theta =$ as defined in Figure 3-6

3-2-5-3 Intramuscular Fat

M. longissimus from the left rack cut was trimmed of subcutaneous fat, connective tissue, intermuscular fat and epimysium and chopped finely with scissors. Fat was measured by extracting triplicate 10 to 12 g samples with petroleum ether (B.P. 40 to 60°C) for 8 to 9 h in a soxhlet apparatus (A.O.A.C., 1980) after these samples had been dried by a freeze-drying unit for 3 to 4 days.

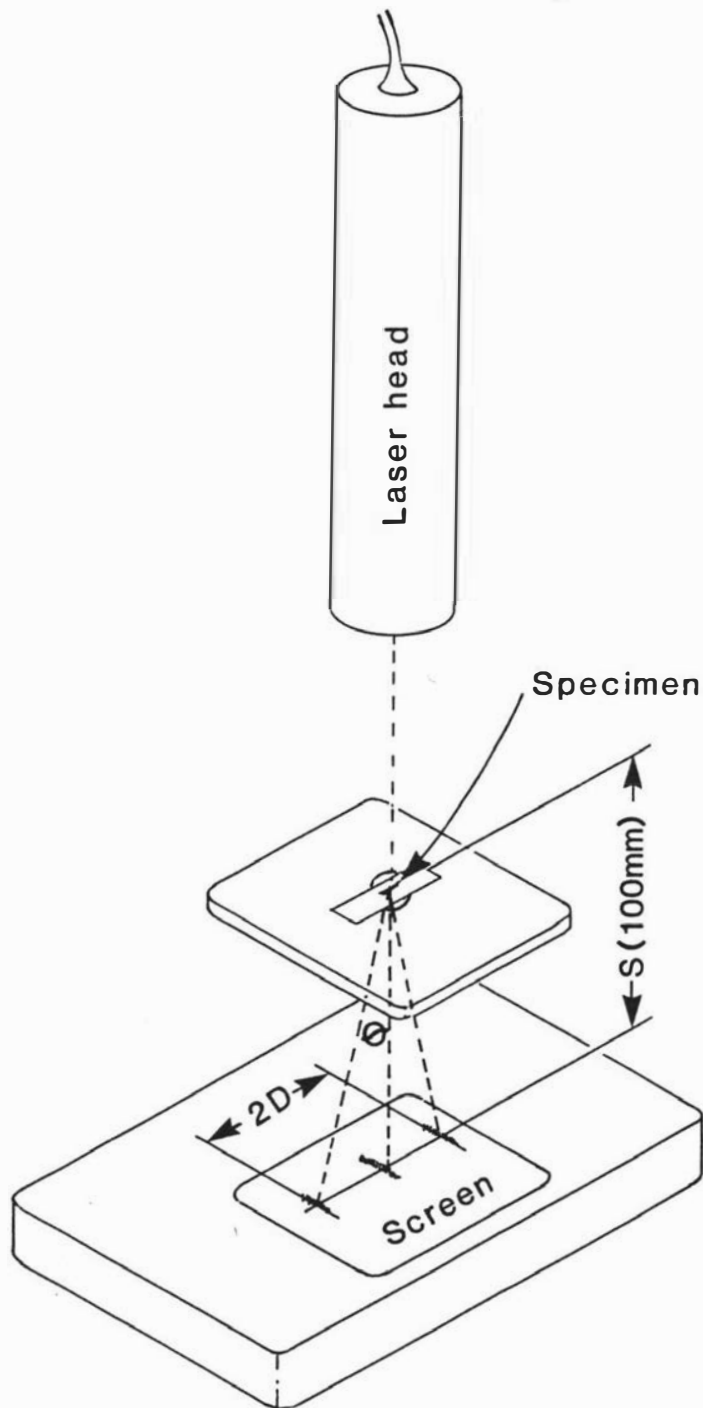


Figure 3-6. Diagram showing the equipment used to measure sarcomere length by laser diffraction.

3-2-6 ADIPOSE TISSUE MEASUREMENTS

3-2-6-1 Adipose Tissue Sampling Sites

Approximately 10 mm cubes of adipose tissue, representing subcutaneous, intermuscular, perirenal, omental and mesenteric depots, were taken from the following 5 sites:

- I Subcutaneous fat: fat over M. iliocostalis from the rack cut
- II Intermuscular fat: fat beneath M. latissimus dorsi from the rack cut
- III Perirenal fat: from a thick portion of the depot
- IV Omental fat: from a thick portion of the depot
- V Mesenteric fat: from a thick portion of the depot.

3-2-6-2 Fat Histology

The fat samples after being stored in 4% formaldehyde at 1 to 2⁰C for up to 3 months were attached to chucks with a few drops of Tissue-Tek II O.C.T. compound, frozen (-25⁰C) and then sectioned on a cryostatic microtome (Sjostrom et al., 1971). The sections were transferred to slides, where they were mounted in a water-based mountant and covered with a coverslip. The thicknesses of the sections were 100, 150 or 200 μm , depending on the size of the fat cells, with thicker sections being used when larger fat cells were expected.

3-2-6-3 Fat Cell Volume

A projection microscope (REICHERT WIEN VISOPAN) was used to measure the diameter of over 200 randomly-selected adipocytes, at a magnification of 125X. Care was taken to ensure that the same region was viewed only once. The mean diameter (\bar{d}) of the adipocytes and its standard deviation (s) were calculated and the mean adipocyte volume (V) was obtained using the formula of Goldrick (1967):

$$V = (\pi/6) (3s^2 + \bar{d}^2)\bar{d}$$

3-2-6-4 Fat Cell Number

The number of cells (N) was estimated from the formula of Truscott et al. (1983a):

$$N = \frac{\text{fat weight of dissected depot} \times \text{proportion lipid in the depot}}{\text{mean cell volume} \times 0.91 \times 0.9}$$

where it was assumed that the density of lipid was 0.91 g/cm³ and that 90% of the cell volume was lipid.

3-2-6-5 Chemical Analysis of Fat

Fat samples representing the depots were analysed for lipid content by Soxhlet extraction procedure (A.O.A.C., 1980). Duplicate samples, each weighing about 5 to 6 g were freeze-dried for 3 to 4 days, and then the lipid was extracted with petroleum ether (B.P., 40 to 60°C) for 8 to 9 h in a Soxhlet apparatus.

3-2-7 MEAT QUALITY MEASUREMENTS

3-2-7-1 General

Measurements of aspects of meat quality made on major leg muscles (M. semitendinosus, M. semimembranosus and M. biceps femoris) and the main back muscle (M. longissimus) included Warner-Bratzler shear values on cooked samples, water-holding capacity and reflectance spectrophotometry. After being dissected from their respective cuts and weighed, the muscles were kept chilled (1 to 3°C) in plastic bags for not more than 12 h prior to the above measurements being made.

3-2-7-2 Warner-Bratzler Shear Values

Triplicate 25 mm thick slices were cut from the M. longissimus (LD) (1st to 4th lumbar vertebrae in the loin cut, and 9th to 12th thoracic vertebrae in the rack cut), M. semimembranosus (SM) and M. biceps femoris (BF) and 4 slices were cut from the M. semitendinosus (ST) at the time of muscle preparation. The slices were weighed and stored at chiller temperature (1 to 2°C) in plastic bags until cooked

by immersing the bags in a water bath at 70°C for 90 min (Purchas, 1972). The cooked meat was kept at 1 to 3°C overnight in the cooler. After cooling, 3 cores (13 mm x 13 mm cross-section) were cut parallel to the orientation of the muscle fibres for each LD, SM and BF slice, and 2 cores were cut for each ST slice. Each core was then sheared perpendicularly to the fibres in 2 places, with a Warner-Bratzler shear device. This machine measured the maximum force required to cut across the muscle fibres (Pearson, 1963).

After cooking and prior to cutting the cores, the cooked samples were carefully dried with tissues to remove excess surface moisture and re-weighed to determine cooking losses.

3-2-7-3 Water-holding Capacity

Determinations of the water-holding capacity (in terms of expressed juice values) were based on measuring the loose water liberated by applying pressure to the muscle tissue.

Two preliminary investigations were carried out to compare the normal press method involving tightening screws by hand (Hanning *et al.*, 1957) with a method which used a 10 kg weight for 5 min (Matyniak and Zirolecki, 1983). The investigations also compared 3 different calculations as follows:

- I. Expressed juice = $\frac{\text{Loose water area (outer-inner area)}}{\text{Meat film area}}$
- II. Expressed juice = $\frac{\text{Loose water area (outer-inner area)}}{\text{Sample weight}}$
- III. Expressed juice = $\frac{\text{Sample weight before - sample weight after}}{\text{Sample weight}}$

The first experiment involved muscles from 10 animals with 3 measurements being made on each muscle. Repeatability between triplicates was measured as intraclass correlations (Snedecor and Cochran, 1980). The results (Table 3-4) showed no significant differences between the two methods, but the 10 kg-method was more

Table 3-4. Comparisons of means, standard errors and intraclass correlations (repeatabilities) between two methods (10 kg and hand-tightened) and between three methods of calculating expressed juice values for M. biceps femoris and M. semimembranosus from 10 animals.

Definition of expressed juice	M. biceps femoris				M. semimembranosus				
	10 kg method		Hand-tightened		10 kg method		Hand-tightened		
	Mean + SE	Repeatability	Mean + SE	Repeatability	Mean + SE	Repeatability	Mean + SE	Repeatability	
I.									
<u>Loose water area</u> <u>meat film area</u>	4.48+0.19	0.42 *	5.13+0.19	0.28 NS	4.47+0.19	0.77 ***	4.82+0.19	0.43 *	
II.									
<u>Loose water area</u> <u>sample weight</u>	34.9+0.5	0.60 **	35.7+0.5	0.55*	34.3+0.5	0.71**	35.1+0.5	0.59 **	
III.									
<u>Sample wt. before - sample wt. after</u> <u>Sample weight before</u>	0.47+0.05	0.50 *	0.48+0.05	0.40 S	0.46+0.05	0.55 *	0.47+0.05	0.33 S	

*, **, *** See Table 3-1

Table 3-5. Comparisons of means, standard errors and intraclass correlations (repeatability) among three methods of calculation for measuring expressed juice values of three muscles (M. longissimus[LD], M. biceps femoris [BF] and M. semimembranosus [SM]) from six animals

Definition of expressed juice	Muscle	Mean	S.E.	Repeatability	Significance
I.					
<u>Loose water area</u>	LD	3.76	0.08	0.47	*
<u>meat film area</u>	BF	4.76	0.12	0.60	**
	SM	3.98	0.19	0.70	**
II.					
<u>Loose water area</u>	LD	30.9	0.49	0.65	**
<u>sample weight</u>	BF	33.5	0.40	0.53	**
	SM	33.2	0.53	0.69	**
III.					
<u>Sample wt. before - sample wt. after</u>	LD	0.43	0.01	0.77	**
<u>Sample weight before</u>	BF	0.46	0.01	0.15	NS
	SM	0.44	0.01	0.49	*

repeatable for all 3 muscles and was adopted for routine use. The repeatability values were most consistent for definition II across the two methods and two muscles. The results of the second experiment (Table 3-5), which involved three muscles from 6 animals confirmed that definition II was most consistent.

Based on the results of these investigations, the following procedure was adopted.

Samples of about 500 mg were weighed to the nearest mg, placed on a tarred filter paper (Whatman No. 1, 11.0 cm diameter Qualitative, stored previously in a desiccator over saturated KCl) between plexi-glass plates and a weight of 10 kg was applied to the top plate (weight = 111.4 g) for exactly 5 min. The perimeter of the pressed meat and the total wetted area of the filter paper were then pencilled, and expressed juice values were calculated as:

$$\text{Expressed juice (cm}^2\text{/g)} = \frac{\text{Total area (cm}^2\text{)} - \text{Meat film area (cm}^2\text{)}}{\text{weight of sample (g)}}$$

The areas were calculated as described in Section 3-2-4-3.

3-2-7-4 Reflectance Spectrophotometry

The percentage reflectance of light at four wavelengths was measured on freshly-cut surfaces of M. longissimus, M. semimembranosus, M. biceps femoris and M. semitendinosus at approximately 12 h post-thawing as a measure of meat colour. Samples free from connective tissue and external fatty tissue were exposed to the atmosphere at cooler temperature (1 to 3°C) for 1 h before measurement.

Reflectance was measured using a spectrophotometer (Bausch and Lomb Spectronic 20) with an integrating sphere reflectance attachment. A porcelain reference standard supplied with the instrument was used as a standard and its reflectance was considered as 90. Duplicate 15 mm thick slices were cut perpendicular to the fibres. Evaluation time averaged approximately 20 sec per wavelength used. All samples were evaluated for percent reflectance at wavelengths of 474, 525, 572 and 630 nm. Three reflectance ratios 474/525, 572/525 and 630/525 were calculated. The instrument was zeroed frequently during measurement using the reference standard supplied by the manufacturer.

2. Carcass Quality Data Model

Least squares means for two selected lines (Fat and Meaty), two sexes (ewe and wether) and four pastures for the various variables measured, were computed after being adjusted by covariance analysis for differences in the appropriate covariate. The interactions between the covariate and the main effects were used to test for the significance of differences between slopes of the regression lines within the different main effects (i.e. to test for the homogeneity of the regression coefficients within main effects).

The model used to describe carcass quality characteristics was:

$$Y_{ijkl} = \mu + A_i + B_j + C_k + (AB)_{ij} + (AC)_{ik} + (BC)_{jk} + b(x_{ijkl}) + e_{ijkl} \dots \dots \dots (2)$$

where

Y_{ijkl} , μ , A_i , B_j , C_k , $(AB)_{ij}$, $(AC)_{ik}$, $(BC)_{jk}$ and e_{ijkl} are as defined for Model 1,

b is the regression coefficient of Y_{ijkl} on the covariate X_{ijkl} and

x_{ijkl} is equal $(X_{ijkl} - \bar{X})$, \bar{X} being the overall mean of the covariate X_{ijkl} .

3-2-8-2 Experiments 3 and 4

1. Meat Quality Data Model

The general form of the linear model used to analyse meat quality data in Experiment 4 only was:

$$Y_{ij} = \mu + A_i + e_{ij} \dots \dots \dots (3)$$

where Y_{ij} , μ , A_i and e_{ij} are as defined for Model 1.

2. Carcass Quality Data Model

This model was:

$$Y_{ij} = \mu + A_i + b(x_{ij}) + e_{ij} \dots \dots \dots (4)$$

where Y_{ij} , μ , A_i , b , (x_{ij}) and e_{ij} are as defined in Model 2.

3-2-8-3 Experiment 5

1. Meat Quality Data Model

The linear model used to analyse meat quality data in this experiment was:

$$Y_{ijk} = \mu + A_i + D_j + (AD)_{ij} + e_{ijk} \dots\dots\dots (5)$$

where Y_{ijk} , μ , A_i and e_{ijk} are as defined previously,
 D_j is the effect of electrical stimulation and
 $(AD)_{ij}$ is the sire x electrical stimulation interaction.

2. Carcass Quality Data Model

Model 3 as described previously was used for analysing the carcass quality data in this experiment.

3-2-8-4 Experiment 6

For the carcass and meat quality data in this experiment, two models were considered to be satisfactory for the analysis:

1. Meat Quality Data Model

$$Y_{ijkl} = \mu + A_i + C_j + D_k + (AC)_{ij} + (AD)_{ik} + (CD)_{jk} + e_{ijkl} \dots\dots\dots (6)$$

where Y_{ijkl} , μ , A_i , C_j , D_k , $(AC)_{ij}$, $(AD)_{ik}$ and e_{ijkl} are as defined previously,

$(CD)_{jk}$ is the pasture x electrical stimulation interaction.

2. Carcass Quality Data Model

$$Y_{ijk} = \mu + A_i + C_j + b(x_{ijk}) + (AC)_{ij} + e_{ijk} \dots\dots\dots (7)$$

where Y_{ijk} , μ , A_i , C_j , b , x_{ijk} , $(AC)_{ij}$ and e_{ijk} are as defined previously.

The growth of various body parts relative to each other (Experiments 3, 5 and 6) was examined using the allometric equation

$Y = ax^b$, described by Huxley (1932). Growth Coefficients (b-values) for a part (Y) relative to the whole (X) were calculated by using double logarithmic regression equations $\log_{10}Y = \log_{10}a + b(\log_{10}x)$, where a and b are constants.

The hypothesis that the growth coefficient (b) equals 1.0 was tested in each case (Steel and Torrie, 1981). This test assessed whether the part was becoming an increasing or a decreasing proportion of the whole as the whole itself increased (Butterfield and Berg, 1966).

CHAPTER 4

RESULTS

4-1 SELECTION LINE EFFECTS ON CARCASS CHARACTERISTICS

4-1-1 GROWTH RATE

Growth rate information for the animals in each experiment is presented in this Section as background to the main purpose of these experiments, which was to explore the effect of selection for and against fatness on meat and carcass quality.

Average daily gains for different periods of time for the six experiments are given in Table 4-2, while Figures 4-1 and 4-2 show the growth curves for the two selection lines in Experiments 5 and 6 from birth to slaughter. The model used for analysis of Experiments 1 and 2 included sex, pasture, and selection line effects, while for Experiment 6 it included pasture, and selection line effects and for Experiments 3, 4 and 5 it included only the selection line effect. Generally, the analyses indicated that selection for or against fatness had not influenced growth rate in a statistically significant way.

Average daily gains for the Southdown ram hoggets of Experiments 3, 4, 5 and 6 were calculated for a period from the time of making the first fat depth measurement (at about 8 to 9 months old) up to slaughter, while those of the Southdown x Romney cross ewe and wether lambs of Experiments 1 and 2 were calculated for a period from weaning to slaughter.

Table 4-1. Definitions of abbreviations used in other Tables.

Abbreviation	Definition
FLW	Final live weight
CW	Carcass weight
SW	Side weight
TSM	Total side muscle
TSF	Total side fat
TSB	Total side bone
SHW	Shoulder weight
RW	Rack weight
LW	Loin weight
LGW	Leg weight
SCF	Subcutaneous fat
IMF	Intermuscular fat
RSD	Residual standard deviation
r^2	Coefficient of determination
Level of statistical significance	
NS	($P > 0.1$)
S	($P < 0.1$)
*	($P < 0.05$)
**	($P < 0.01$)
***	($P < 0.001$)

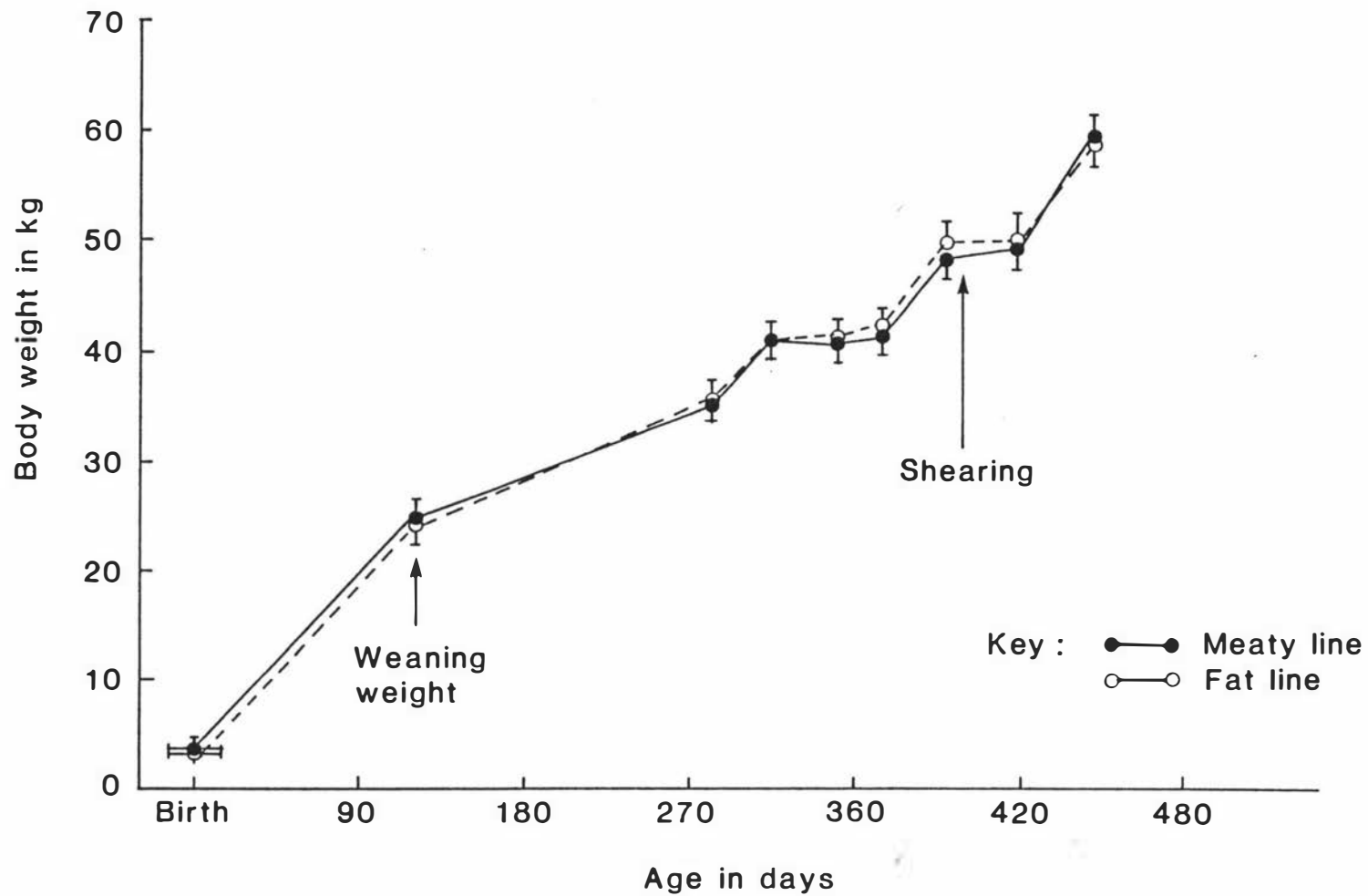


Figure 4-1. Mean body weights for the two selection lines of Southdown rams from birth to just prior to the slaughter of the first lot in Experiment 5. Vertical and horizontal bars show the standard errors for body weight and date of birth, respectively.

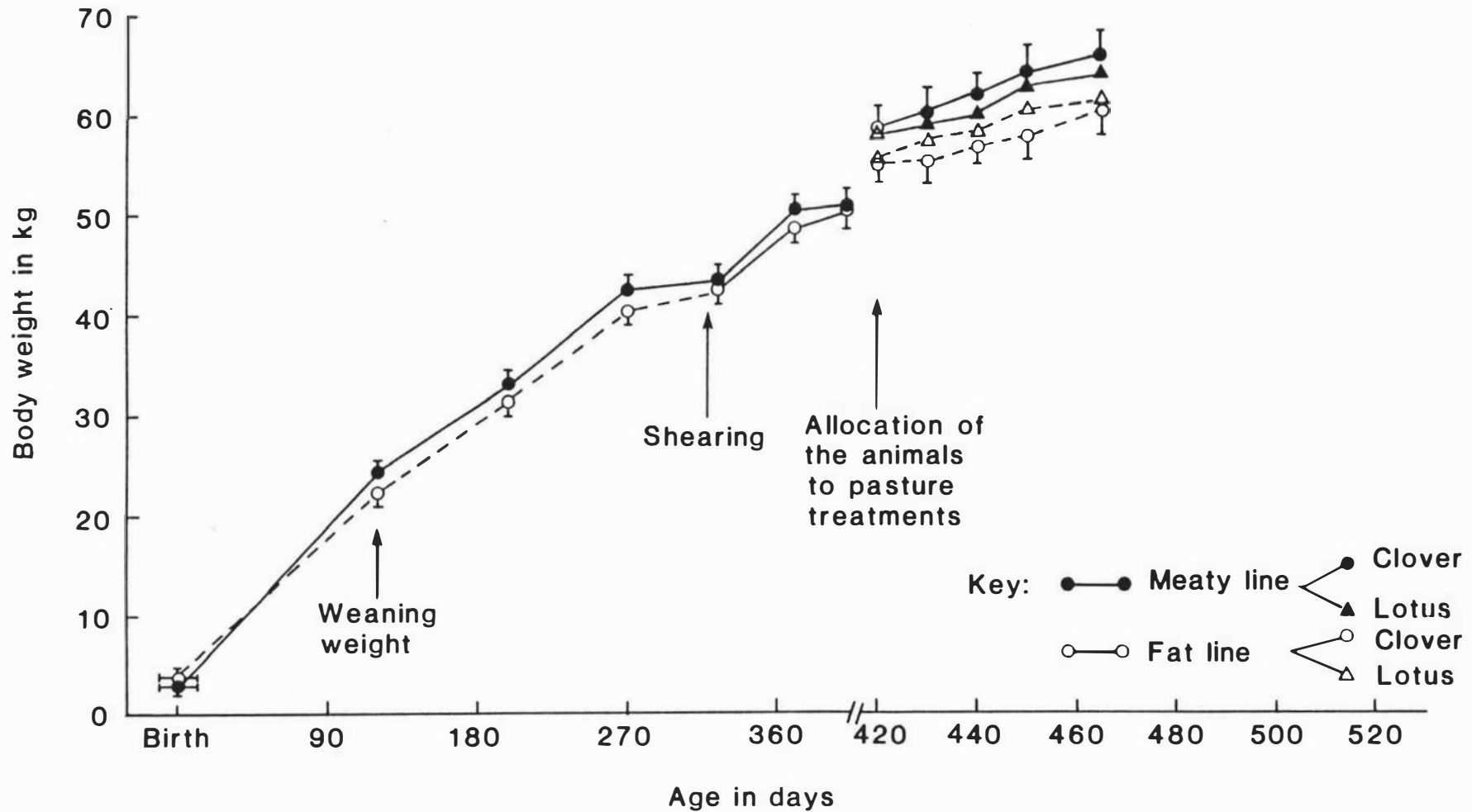


Figure 4-2. Mean body weights for the two selection lines of Southdown rams from birth to just prior to the slaughter of the first lot in Experiment 6. Vertical and horizontal bars show the standard errors for body weight and date of birth, respectively.

Table 4-2. Least squares means for the average daily gain (g/day) over the periods indicated for the two selection lines (fat and meaty) of Southdown sheep (Experiments 3 to 6) and for their crossbred progeny out of unselected Romney ewes (Experiments 1 and 2)

Experiment No.	Period of growth	Selection line		RSD (g)	Level of significance
		Fat	Meaty		
<u>Southdown x Romney cross lambs</u>					
1	30 Nov. 1982 to 7 Mar. 1983	145.0	141.0	17	NS
2	21 Oct. 1983 to 4 Apr. 1984	83.2	86.8	14	NS
<u>Southdown ram hoggets</u>					
3	14 Apr. 1980 to 9 Dec. 1980	69.3	72.0	11	NS
4	26 May 1982 to 14 Jan. 1983	78.8	81.4	10	NS
5	16 May 1983 to 5 Dec. 1983	112.0	120.0	16	NS
6	8 Mar. 1984 to 27 Nov. 1984	117.0	113.0	16	NS

4-1-2 NON-CARCASS BODY COMPONENTS

Least squares means of the weights of certain non-carcass body components for Experiments 3, 4, 5 and 6 are given in Tables 4-3, 4-4, 4-5 and 4-6, respectively. When comparisons between lines were made at the same carcass weight (carcass weight as a covariate), significant differences between the two selection lines existed for non-carcass fat weights. Rams from the fat line had approximately 27% and 30% more omental fat in Experiments 3 and 5, respectively and 32% more kidney fat in Experiment 5 than those from the meaty line. These tables also show the effects of selection for or against fatness on the weight of empty foregut and intestines (small and large intestines) of rams. There were no significant differences between lines in weight of empty foregut except in Experiment 3 in which instance

Table 4-3. Least squares means of live weight, carcass weight, dressing-out percent, and non-carcass component weights for two selection lines (fat and meaty) of Southdown rams in Experiment 3.

Item	Selection line (L)		Significance		r^2	RSD	Covariate	
	Fat (F)	Meaty (M)	F vs M	L x covariate			Variable	Significance
No. of animals	12	18						
Final live weight (kg)	58.07	59.89	S	-	0.11	2.66	-	-
Carcass weight (kg)	29.05	28.55	***	NS	0.55	1.17	FLW	***
Dressing-out %	49.51	48.21	*	NS	0.44	1.58	CW	***
Omental fat weight (kg)	1.14	0.896	*	NS	0.36	0.195	CW	*
Kidney fat weight (kg)	0.749	0.649	NS	NS	0.26	0.157	CW	*
Foregut empty weight (kg)	1.66	1.84	***	NS	0.52	0.13	CW	***
Intestines weight (kg)	3.66	4.18	**	NS	0.47	0.39	CW	**
Liver weight (kg)	0.840	0.880	NS	NS	0.27	0.08	CW	**
Heart weight (kg)	0.239	0.239	NS	NS	0.04	0.029	CW	NS
Kidneys weight (kg)	0.135	0.145	*	NS	0.27	0.013	CW	NS
Thyroid gland weight (g)	4.72	4.93	NS	S	0.18	0.96	CW	NS
Adrenal gland weight (g)	3.11	2.72	NS	NS	0.10	0.67	CW	NS

For definitions of abbreviations see Table 4-1.

Table 4-4. Least squares means of live weight, carcass weight, dressing-out percent, and non-carcass component weights for two selection lines (fat and meaty) of Southdown rams of Experiment 4.

Item	Selection line (L)		Significance		r ²	RSD	Covariate	
	Fat (F)	Meaty (M)	F vs M	L x covariate			Variable	Significance
No. of animals	10	8						
Final live weight (kg)	61.03	62.13	**	-	0.33	0.831	-	-
Carcass weight (kg)	30.59	29.47	NS	NS	0.29	1.191	FLW	NS
Dressing-out %	49.67	48.70	**	NS	0.93	0.575	CW	***
Omental fat weight (kg)	1.48	1.30	NS	NS	0.25	0.358	CW	S
Kidney fat weight (kg)	0.902	0.834	NS	NS	0.16	0.168	CW	NS
Liver weight (kg)	0.940	0.955	NS	NS	0.08	0.075	CW	NS
Heart weight (kg)	0.239	0.264	S	NS	0.33	0.026	CW	NS
Kidneys weight (kg)	0.160	0.165	NS	NS	0.14	0.012	CW	NS
Thyroid gland weight (g)	6.79	6.68	NS	S	0.21	1.596	CW	NS
Adrenal gland weight (g)	3.01	2.75	NS	S	0.28	0.509	CW	NS

For definitions of abbreviations see Table 4-1.

Table 4-5. Least squares means of live weight, carcass weight, dressing-out percent, and non-carcass component weights for two selection lines (fat and meaty) of Southdown rams of Experiment 5.

Item	Selection line (L)		Significance		r ²	RSD	Covariate	
	Fat (F)	Meaty (M)	F vs M	L x covariate			Variable	Significance
No. of animals	12	12						
Final live weight (kg)	60.6	61.0	NS	-	0.80	4.4	-	-
Carcass weight (kg)	30.4	28.2	**	NS	0.82	1.1	FLW	***
Dressing-out %	49.7	47.2	**	NS	0.67	1.7	CW	***
Omental fat weight (kg)	1.17	0.90	*	NS	0.63	0.23	CW	***
Kidney fat weight (kg)	0.805	0.606	*	NS	0.67	0.165	CW	***
Foregut empty weight (kg)	0.88	0.98	NS	NS	0.10	0.29	CW	NS
Intestines ^a weight (kg)	4.18	4.84	***	NS	0.37	0.46	CW	NS
Liver weight (kg)	0.835	0.846	ns	NS	0.09	0.569	CW	NS
Heart weight (kg)	0.226	0.253	**	NS	0.52	0.016	CW	*
Kidneys weight (kg)	0.139	0.149	*	NS	0.42	0.094	CW	**
Thyroid gland weight (g)	4.55	4.70	NS	NS	0.04	0.99	CW	NS
Adrenal gland weight (g)	3.06	2.91	NS	NS	0.07	0.41	CW	NS
Spleen weight (g)	65.7	65.2	NS	NS	0.06	8.87	CW	NS

a Intestines weight included the full small and large intestines and mesenteric fat.
For definitions of abbreviations see Table 4-1.

Table 4-6. Least squares means of live weight, carcass weight, dressing-out percent, and non-carcass components for two selection lines (fat and meaty) and two pastures (White clover and Lotus) of Southdown rams of Experiment 6.

Item	Selection line		Significance F vs M	Pasture		Significance CL vs LO	r ²	RSD	Covariate	
	Fat (F)	Meaty (M)		Clover (CL)	Lotus (LO)				Variable	Significance
No. of animals	12	12		12	12				-	-
Final live weight (kg)	60.5	63.8	*	63.4	60.8	NS	0.43	4.02	-	-
Carcass weight (kg)	31.3	30.1	*	31.4	30.0	*	0.82	1.26	FLW	***
Dressing-out %	49.85	47.63	**	49.36	48.13	NS	0.53	1.94	CW	*
Omental fat weight (kg)	1.31	1.25	NS	1.34	1.22	S	0.71	0.168	CW	***
Kidney fat weight (kg)	0.954	0.890	NS	0.907	0.938	NS	0.61	0.189	CW	**
Mesenteric fat weight (kg)	0.528	0.500	NS	0.547	0.480	S	0.51	0.070	CW	**
Foregut empty weight (kg)	1.90	2.04	S	1.99	1.94	NS	0.53	0.182	CW	**
Intestines ^a weight (kg)	3.41	3.64	NS	3.46	3.59	NS	0.40	0.393	CW	*
Small intestine weight (kg)	1.40	1.54	NS	1.46	1.47	NS	0.26	0.302	CW	S
Large intestine weight (kg)	2.02	2.10	NS	1.99	2.12	NS	0.16	0.381	CW	NS
Liver weight (kg)	0.980	1.02	NS	1.05	0.941	NS	0.65	0.065	CW	***
Heart weight (kg)	0.220	0.252	**	0.240	0.232	NS	0.74	0.023	CW	***
Kidneys weight (kg)	0.168	0.183	S	0.176	0.175	NS	0.55	0.018	CW	**
Thyroid gland weight (g)	7.91	7.08	NS	7.87	7.12	NS	0.40	39.7	CW	NS
Adrenal gland weight (g)	2.94	2.99	NS	2.85	3.07	NS	0.33	0.35	CW	NS
Spleen weight (g)	70.0	75.9	*	74.1	77.7	NS	0.62	7.24	CW	NS

For definitions of abbreviations see Table 4-1.

rams from the meaty line had significantly heavier empty foregut weights than those from the fat line. The apparent effects of selection on the weight of empty intestines were consistent across Experiments 3 and 5, with the rams from the fat line having significantly lighter intestines for the same carcass weight than those from the fat line. Furthermore, rams from the meaty line in Experiment 6 had approximately 7% greater intestinal weights (10% and 4% more of the small and large intestine weights, respectively) than rams from the fat line, but these differences were not statistically significant (Table 4-6). Data on non-carcass components also showed differences between lines for heart, kidney, and spleen weights. Meaty rams had significantly heavier kidney weights in Experiments 3 and 5, heart weights in Experiments 5 and 6 and spleen weights in Experiment 6 than fat rams. Statistical analyses did not reveal any significant line effects on the slopes of the regression lines of non-carcass components on carcass weight.

Appendix 1 gives the allometric growth coefficients of the non-carcass components relative to live weights in Experiments 3, 4, 5 and 6. Inconsistent results within and between experiments and also high standard errors are shown, probably because there was little variation in the age and weight of animals within experiments. The only significant results obtained were in Experiment 6, where the allometric growth coefficients for omental fat, kidney fat, and liver weight were higher than 1.0, indicating that their proportion increased with increasing liveweight.

4-1-3 CARCASS DIMENSIONS

4-1-3-1 Southdown X Romney Lambs (Experiments 1 and 2)

The data on liveweight, carcass weight and dimensions of the carcasses representing four sires from two selection lines, four pastures and two sexes in Experiments 1 and 2 are given in Table 4-7 and 4-8, respectively. In general, the data showed no significant differences between the two sires within each line for all carcass characteristics considered in this study. Interactions between all factors studied were omitted from the Tables because statistical analyses showed none of these to be significant.

Table 4-7. Least squares means showing the effect of selection line, sex, and pasture on carcass characteristics of Southdown X Romney cross lambs in Experiment 1.

	Selection line				Significance	Pasture				Significance	Sex		Significance	r ²	RSD	Covariate	Significance
	Fat		Meaty			Clover	Lucerne	Lotus	Perennial ryegrass		Wether	Ewe					
	Sire 1	Sire 2	Sire 3	Sire 4													
No. of animals	18	14	16	16		16	16	16	16		31	33					
Final live weight (kg)	40.7	41.0	40.8	40.1	NS	42.3	43.2	41.2	37.0	**	42.2	39.6	NS	0.61	3.7	-	-
Carcass weight (kg)	18.2	18.5	17.7	17.7	*	18.7	18.0	17.7	17.7	**	18.1	18.0	NS	0.93	0.9	FLW	***
Dressing-out %	43.6	44.2	43.0	43.3	NS	44.3	42.8	42.7	44.2	NS	43.2	43.8	NS	0.70	1.9	CW	***
<u>M. semitendinosus</u> weight (g)	94.7	91.3	99.1	95.0	NS	95.0	95.0	99.9	95.2	S	98.6	93.9	**	0.72	8.5	CW	***
<u>M. semimembranosus</u> weight (g)	271.7	261.4	266.2	259.8	NS	258.5	268.4	269.8	262.3	S	266.1	263.4	NS	0.78	17.6	CW	***
<u>M. biceps femoris</u> weight (g)	275.3	272.3	279.3	258.4	*	263.1	273.3	285.4	263.4	**	269.7	272.9	NS	0.85	16.9	CW	***
Femur weight (g)	117.9	116.9	122.8	131.1	**	113.9	123.7	127.7	123.5	NS	124.2	123.5	S	0.62	11.4	CW	***
Femur length (mm)	153.4	152.1	156.4	159.1	**	153.1	154.6	156.6	156.9	NS	156.2	156.9	S	0.57	4.99	CW	*
Ultrasonic fat depth (mm)	4.92	5.77	3.96	3.72	***	6.72	4.33	3.35	3.97	***	4.60	4.58	NS	0.85	1.08	FLW	***
Fat depth C (mm)	4.91	5.37	4.29	3.58	*	6.27	4.35	3.22	4.31	***	4.69	4.38	NS	0.82	1.32	CW	***
Fat depth J (mm)	14.0	16.4	13.9	12.9	S	16.4	14.3	12.8	13.8	**	13.7	14.9	**	0.85	2.31	CW	***
Fat depth S ₂ (mm)	11.6	12.9	11.1	10.2	*	13.3	11.4	10.0	11.1	**	11.1	11.8	*	0.85	1.78	CW	***
Tissue depth GR (mm)	15.3	17.9	15.3	13.9	*	18.3	15.7	13.7	14.7	**	15.3	15.9	***	0.89	2.27	CW	***
Fat depth LG (mm)	11.9	11.9	10.3	10.4	***	13.2	10.3	9.6	11.3	NS	11.3	11.0	S	0.74	2.27	CW	***
<u>M. longissimus</u> width (A)	55.4	54.0	55.5	55.0	NS	54.4	54.8	55.9	54.8	NS	55.7	54.2	**	0.67	2.09	CW	***
<u>M. longissimus</u> depth (B)	34.1	33.9	34.3	33.2	S	32.9	34.0	34.9	33.5	*	33.5	34.3	NS	0.79	1.57	CW	***
<u>M. longissimus</u> area (cm ²)	13.9	13.6	14.1	13.1	S	13.4	13.9	14.1	13.3	S	13.8	13.6	NS	0.79	1.04	CW	***

For definitions of abbreviations see Table 4-1.

Table 4-8. Least squares means showing the effect of selection line, sex, and pasture on carcass characteristics of Southdown X Romney cross lambs in Experiment 2.

	Selection line				Significance	Pasture				Significance	Sex		Significance	r ²	RSD	Covariate	Significance
	Fat		Meaty			Clover	Lucerne	Lotus	Perennial ryegrass		Wether	Ewe					
	Sire 1	Sire 2	Sire 3	Sire 4													
No. of animals	16	16	16	16		16	16	16	16		31	33					
Final live weight (kg)	37.50	36.00	35.42	37.22	NS	40.09	34.94	36.55	34.56	*	37.82	35.20	**	0.43	4.56	-	-
Carcass weight (kg)	16.20	16.26	15.68	15.92	S	16.64	16.52	15.40	15.53	***	16.01	16.01	NS	0.98	0.61	FLW	***
Dressing-out %	44.01	44.13	42.98	43.37	NS	44.87	44.60	42.31	42.71	***	43.65	43.59	NS	0.88	1.34	CW	***
<u>M. semimembranosus</u>																	
weight (g)	203.4	211.8	216.8	219.0	*	203.0	211.3	223.5	212.9	NS	215.3	210.2	NS	0.89	15.3	CW	***
<u>M. biceps femoris</u>																	
weight (g)	209.6	213.5	214.8	222.3	NS	214.0	211.3	222.8	212.1	NS	212.9	217.1	NS	0.90	17.2	CW	***
Femur weight (g)	101.2	111.6	113.5	114.8	S	101.8	108.3	121.7	109.3	*	113.1	107.4	*	0.68	14.4	CW	***
Femur length (mm)	144.9	144.7	148.8	151.9	*	145.6	147.5	147.7	149.5	NS	149.2	145.9	NS	0.74	5.49	CW	***
Ultrasonic fat depth (mm)	5.8	5.7	3.7	4.1	**	6.1	5.0	4.0	4.2	**	4.6	5.0	*	0.89	1.06	FLW	***
Fat depth C (mm)	6.6	5.5	3.4	3.5	***	6.5	4.6	4.1	3.8	**	4.6	4.9	*	0.91	1.08	CW	***
Fat depth J (mm)	12.8	11.7	11.0	10.1	*	13.8	12.0	9.5	10.2	***	11.3	11.5	NS	0.87	1.98	CW	***
Fat depth S2 (mm)	12.4	11.3	9.6	9.9	*	13.3	10.6	9.2	10.3	*	10.5	11.1	S	0.85	1.93	CW	***
Tissue depth GR (mm)	15.0	13.8	12.2	12.0	**	15.8	13.9	11.5	11.8	***	13.0	13.5	S	0.90	2.13	CW	***
Fat depth LG (mm)	11.15	10.7	8.3	8.8	NS	11.6	9.7	7.6	10.1	NS	9.6	9.8	NS	0.68	2.96	CW	***
<u>M. longissimus</u> width (A)	50.6	51.2	52.1	52.0	S	50.6	50.1	53.0	52.1	S	51.5	51.5	NS	0.74	2.43	CW	***
<u>M. longissimus</u> depth (B)	29.0	30.8	30.4	30.31	S	30.6	30.3	30.4	29.8	NS	29.8	30.7	NS	0.80	2.15	CW	***
<u>M. longissimus</u> area (cm ²)	10.76	11.72	12.14	11.42	NS	11.27	11.20	11.70	11.49	NS	11.19	11.66	NS	0.83	1.09	CW	***

For definitions of abbreviations see Table 4-1.

Table 4-7 shows that the overall difference of 0.65 kg in the carcass weight between fat and meaty lines was significant, with the carcasses from the fat line being always greater than those from the meaty line at a constant liveweight. The carcasses in the fat line tended to have shorter femur bones in Experiments 1 and 2, and lighter femur bones in Experiment 2. When adjusted to the same carcass weight there were significant differences in fat depth measurements due to selection effects (Tables 4-7 and 4-8). On average the lamb carcasses from the fat line had 1.5 mm and 1.9 mm greater depth of back fat as measured ultrasonically at fat depth C position than those from the meaty line in Experiments 1 and 2, respectively. The lambs in the fat sire line also had significantly greater fat depth measurements at C, S2 and GR in both experiments and for LG fat depth measurements in Experiment 1, and J fat depth measurements in Experiment 2.

The effects of pastures and sexes on carcass characteristics will be discussed briefly because those treatments were a part of the model which was used in the analyses. By using orthogonal contrasts (a method for making comparisons among treatment means), the effects of pasture treatments were found to be significant for liveweight and carcass weight of lambs in Experiments 1 and 2 (Tables 4-7 and 4-8) and dressing-out percent in Experiment 2. Also the fat depth measurements were significantly different between pasture groups.

4-1-3-2 Southdown Rams (Experiments 3, 4, 5 and 6)

The selection effects on liveweight, carcass weight and dressing-out percent of rams in Experiments 3, 4, 5 and 6 are given in Tables 4-3, 4-4, 4-5 and 4-6, respectively. Carcass weight and dressing-out percent were consistently higher for rams from the fat line across all experiments, when carcass weight was adjusted to a constant liveweight. Tables 4-9, 4-10, 4-11 and 4-12 show that the carcasses from the meaty line were significantly longer by 56 mm, 43 mm, 26 mm and 39 mm than those in the fat line for Experiments 3, 4, 5 and 6, respectively. For the length of hind leg, the carcasses of the meaty line were also longer by 4 mm, 4 mm, 7 mm and 5 mm than those from the fat line for the same sequence of experiments. Most length and circumference measurements of individual bones also showed similar results to body and leg lengths (Tables 4-9, 4-10, 4-11 and 4-12). Gigot

Table 4-9. Least squares means of carcass and metacarpal bone dimensions (mm) of Southdown rams in Experiment 3 for two selection lines (fat and meaty).

Item	Selection line (L)		Significance		r ²	RSD	Covariate	
	Fat (F)	Meaty (M)	F vs M	L X covariate			Variable	Significance
No. of animals	12	18						
Body length (LB)	1040	1096	*	NS	0.47	40	CW	***
Maximum shoulder width (WF)	238	236	NS	NS	0.45	6	CW	***
Width behind shoulder (WTH)	218	210	**	NS	0.35	7	CW	NS
Gigot width (G)	254	251	NS	NS	0.37	5	CW	***
Leg length (T)	181	185	*	NS	0.37	6	CW	**
Metacarpal bone length	105.0	108.0	**	NS	0.44	3.7	CW	***
Metacarpal bone circumference	53.1	54.0	NS	S	0.17	3.7	CW	NS
Humerus length	133.7	140.7	NS	NS	0.40	5.9	CW	*
Humerus circumference	62.7	66.6	NS	NS	0.51	2.71	CW	**
Radius and ulna length	174.9	178.7	NS	NS	0.46	5.0	CW	*
Radius and ulna circumference	62.2	65.7	S	S	0.46	3.2	CW	**
Femur length	163.9	171.5	NS	NS	0.68	3.6	CW	***
Femur circumference	65.1	68.7	NS	NS	0.53	2.68	CW	*
Tibia length	176.3	180.7	NS	NS	0.44	4.5	CW	**
Tibia circumference	53.8	56.8	NS	NS	0.25	3.40	CW	NS
Ultrasonic fat depth	6.3	5.2	**	NS	0.24	1.1	CW	NS
Fat depth C	7.4	5.5	***	NS	0.37	1.37	CW	NS
Fat depth J	16.7	14.2	**	S	0.39	2.47	CW	NS
<u>M. longissimus</u> depth (B)	35.5	34.7	NS	NS	0.10	2.3	CW	NS
<u>M. longissimus</u> width (A)	59.3	60.5	NS	S	0.17	3.2	CW	NS
<u>M. longissimus</u> area (cm ²)	15.8	16.7	S	S	0.37	1.4	CW	**

For definitions of abbreviations see Table 4-1.

Table 4-10. Least squares means of carcass and metacarpal bone dimensions (mm) of Southdown rams of Experiment 4 for two selection lines (fat and meaty).

Item	Selection line (L)		Significance		r ²	RSD	Covariate	
	Fat (F)	Meaty (M)	F vs M	L X covariate			Variable	Significance
No. of animals	10	8						
Body length (LB)	1039	1082	***	NS	0.57	22	CW	NS
Maximum shoulder width (WF)	245	244	NS	NS	0.48	7	CW	**
Width behind shoulder (WTH)	229	217	***	NS	0.67	6.28	CW	*
Gigot width (G)	258	257	NS	NS	0.31	5	CW	*
Leg length (T)	177	181	NS	NS	0.25	6	CW	NS
Metacarpal bone length	103	106	NS	NS	0.25	10.4	CW	NS
Metacarpal bone circumference	55	54	NS	NS	0.35	0.3	CW	NS
Metacarpal bone weight (g)	36.5	39.1	NS	NS	0.28	3.2	CW	NS
Femur weight (g)	126.9	139.2	**	NS	0.41	9.1	CW	NS
Femur length	159.9	165.6	**	NS	0.42	3.9	CW	NS
Fat depth C	10.8	4.8	***	NS	0.94	0.8	CW	*
Fat depth J	19.5	14.1	***	NS	0.79	1.7	CW	NS
<u>M. longissimus</u> depth (B)	31.6	32.4	NS	S	0.60	2.6	CW	***
<u>M. longissimus</u> width (A)	59.3	62.9	**	NS	0.57	2.4	CW	*
<u>M. longissimus</u> area (cm ²)	15.0	16.0	NS	S	0.61	1.4	CW	**

For definitions of abbreviations see Table 4-1.

Table 4-11. Least squares means of carcass and metacarpal bone dimensions (mm) of Southdown rams of Experiment 5 for two selection lines (fat and meaty).

Item	Selection line (L)		Significance		r ²	RSD	Covariate	
	Fat (F)	Meaty (M)	F vs M	L X covariate			Variable	Significance
No. of animals	12	12						
Body length (LB)	1043	1069	***	S	0.79	16	CW	**
Maximum shoulder width (WF)	244	241	NS	NS	0.69	8	CW	***
Depth from scapula-sternum (Th)	289	293	NS	NS	0.44	13	CW	***
Width behind shoulder (WTH)	224	211	***	**	0.88	5	CW	***
Gigot width (G)	256	258	NS	NS	0.78	5	CW	***
Leg length (T)	179	186	**	NS	0.42	5	CW	S
Metacarpal bone length	104	107	*	NS	0.30	3	CW	NS
Metacarpal bone circumference	53.2	54.7	S	NS	0.31	2.0	CW	S
Humerus length	134	137	*	NS	0.47	3	CW	*
Humerus circumference	63.5	66.5	***	S	0.65	1.4	CW	S
Radius and ulna length	174	179	*	NS	0.45	5	CW	*
Radius and ulna circumference	63.3	66.3	*	NS	0.44	2.2	CW	NS
Femur length	163	169	**	S	0.54	4	CW	NS
Femur circumference	65.5	69.0	*	NS	0.42	2.8	CW	S
Tibia and fibula length	173	179	*	NS	0.28	5	CW	NS
Tibia and fibula circumference	55.3	56.3	NS	S	0.34	2.1	CW	NS
Ultrasonic fat depth	8.5	4.3	***	NS	0.89	0.9	CW	***
Fat depth C	9.0	4.4	***	NS	0.89	1.0	CW	***
Fat depth J	18.2	12.2	***	NS	0.83	1.9	CW	***
Fat depth S2	13.9	9.6	***	S	0.82	1.5	CW	***
Tissue depth GR	25.4	18.3	***	NS	0.89	2.0	CW	***
Fat depth LG	19.2	10.5	***	NS	0.67	4.0	CW	**
Fat depth L2	22.0	15.7	**	NS	0.47	4.5	CW	*
<u>M. longissimus</u> depth (B)	35.1	32.1	**	NS	0.63	1.8	CW	***
<u>M. longissimus</u> width (A)	61.5	63.8	*	NS	0.22	2.7	CW	NS
<u>M. longissimus</u> area (cm ²)	17.9	17.4	NS	NS	0.38	1.4	CW	**

For definitions of abbreviations see Table 4-1.

Table 4-12. Least squares means of carcass and metacarpal bone dimensions (mm) of Southdown rams of Experiment 6 for two selection lines (fat and meaty) and within two pasture treatments (White clover and Lotus).

Item	Selection line		Significance F vs M	Pasture		Significance CL vs LO	r ²	RSD	Covariate	
	Fat (F)	Meaty (M)		Clover (CL)	Lotus (LO)				Variable	Significance
No. of animals	12	12		12	12					
Body length (LB)	1063	1102	**	1081	1084	NS	0.59	25	CW	**
Maximum shoulder width (WF)	249	242	*	246	245	NS	0.66	7	CW	***
Depth from scapula to sternum (Th)	298	296	NS	295	298	NS	0.42	6	CW	*
Width behind shoulder (WTH)	226	218	**	223	220	S	0.79	5	CW	***
Gigot width (G)	258	253	S	253	259	NS	0.61	5	CW	**
Leg length (T)	175	180	**	177	178	NS	0.52	5	CW	*
Metacarpal bone length	102.1	103.9	NS	102.6	103.5	NS	0.30	3.4	CW	NS
Metacarpal circumference	53.5	55.0	S	53.6	54.9	NS	0.34	1.9	CW	NS
Humerus length	129.0	133.3	NS	128.3	133.9	NS	0.31	10.9	CW	*
Humerus circumference	62.0	64.8	**	62.9	64.0	NS	0.57	2.3	CW	**
Radius & ulna length	169.3	162.9	NS	159.6	172.6	NS	0.26	17.3	CW	NS
Radius & ulna circumference	61.9	65.8	**	62.1	65.6	*	0.66	2.7	CW	**
Femur length	161.5	165.9	*	161.8	165.6	*	0.52	4.5	CW	NS
Femur circumference	65.0	66.5	*	65.0	66.5	*	0.65	1.9	CW	S
Tibia & fibula length	171.3	173.7	NS	171.6	173.4	NS	0.38	5.4	CW	S
Tibia & fibula circumference	55.5	55.9	NS	55.5	55.9	NS	0.20	2.0	CW	NS
Ultrasonic fat depth	9.2	5.9	***	7.9	7.1	*	0.86	0.87	CW	**
Fat depth C	9.8	6.0	***	8.2	7.6	S	0.85	1.1	CW	S
Fat depth J	21.4	18.7	**	20.7	19.4	NS	0.70	2.1	CW	***
Fat depth S2	15.4	12.4	***	14.8	13.0	*	0.77	1.8	CW	***
Tissue depth GR	27.1	23.1	***	25.8	24.4	*	0.81	2.0	CW	***
Fat depth LG	23.3	15.9	***	19.7	19.5	NS	0.63	3.7	CW	S
Fat depth L2	22.1	19.6	***	21.3	20.4	NS	0.61	1.7	CW	NS
M. longissimus depth (B)	35.2	34.3	NS	34.8	34.6	NS	0.56	2.2	CW	***
M. longissimus width (A)	59.0	61.5	NS	59.9	60.6	NS	0.15	4.0	CW	NS
M. longissimus area (cm ²)	17.4	17.6	NS	17.7	17.3	NS	0.29	2.1	CW	*

For definitions of abbreviations see Table 4-1.

width measurements were similar for the carcasses from the two selection lines. Maximum shoulder width and width behind the shoulder were greater in the carcasses from the fat line than the meaty line. The regression of width behind shoulder on carcass weight was not homogeneous between the two selection lines, for each 1 kg increase in carcass weight the width behind the shoulder increased 2.33 mm in the fat line and 5.00 mm in the meaty line in Experiment 5. The depth from scapula to sternum was slightly smaller in the fat line. Significant and consistent differences between selection lines existed for all fat depth measurements, with the carcasses from the fat line having almost twice as much backfat thickness as those from the meaty line as shown ultrasonically at fat depth C and by actual fat depth C measurements. The differences between the two lines for other fat depth measurements across the experiments were also high (Tables 4-9, 4-10, 4-11 and 4-12). Fat rams had approximately 17.6%, 38.3%, 49.2% and 14.4% more fat at fat depth J for Experiments 3, 4, 5 and 6, respectively. The differences between the two lines for Experiments 5 and 6 for S2, GR, LG and L2 also existed, with the percent increase in the fat line, relative to the meaty line, being approximately 44.8% and 24.2% for S2, 38.8% and 17.3% for GR, 82.9% and 46.5% for LG and 40.1% and 12.8% for L2. The dimensions of the elliptical transverse section of the M. longissimus at the 12 to 13 rib level were affected slightly by selection. Carcasses from the fat line tended to have deeper (B) and shorter (A) M. longissimus than those from the meaty line, although the differences were not significant in all cases.

4-1-4 SIDE DISSECTIBLE COMPONENTS

4-1-4-1 Weight of Individual Cuts

Means for side weight and the weights of the four anatomical cuts (see Section 3-2-2-2 and Figure 3-5) adjusted to the same side weight are shown in Tables 4-13, 4-14 and 4-15 for Experiments 3, 5 and 6, respectively. The sides from the fat line had significantly heavier racks, but the regression of rack weight on side weight was not homogeneous between the two selection lines in Experiment 5. The analyses revealed that for each increase of one unit in side weight, the rack cut increased by 0.103 and 0.181 units for the fat and meaty rams, respectively. Shoulder weight, however, tended to be heavier from the

Table 4-13. Least squares means for the dissectible components of the side of Southdown rams in Experiment 3 expressed as weights (kg) and as ratios for two selection lines (fat and meaty).

Item	Selection line (L)		Significance		r ²	RSD	Covariate	
	Fat (F)	Meaty (M)	F vs M	L X covariate			Variable	Significance
No. of animals	12	18						
Carcass side weight	13.9	14.0	NS	NS	0.96	0.16	CW	***
Fore-quarter weight	7.62	7.67	NS	NS	0.89	0.16	SW	***
Hind-quarter weight	6.35	6.28	NS	NS	0.88	0.16	SW	***
Rack weight	1.43	1.35	*	S	0.55	0.09	SW	***
<u>Side components:</u>								
Muscle weight	7.99	8.37	***	S	0.80	0.23	SW	***
Fat weight	3.97	3.34	***	NS	0.65	0.33	SW	***
SCF weight	2.34	1.83	***	NS	0.66	0.23	SW	***
IMF weight	1.63	1.51	*	NS	0.44	0.15	SW	***
Bone weight	1.69	1.91	**	NS	0.48	0.17	SW	**
Scrap weight	0.183	0.206	NS	NS	0.27	0.037	SW	*
Muscle:bone ratio	4.74	4.42	*	NS	0.20	0.35	SW	NS
Muscle:fat ratio	2.02	2.56	***	NS	0.51	0.31	SW	NS
SCF:IMF ratio	1.43	1.21	***	NS	0.40	0.14	SW	NS

For definitions of abbreviations see Table 4-1.

Table 4-14. Least squares means for the dissectible components of the side of Southdown rams of Experiment 5 expressed as weights (kg) and as ratios for two selection lines (fat and meaty).

Item	Selection line (L)		Significance		r ²	RSD	Covariate	
	Fat (F)	Meaty (M)	F vs M	L X covariate			Variable	Significance
No. of animals	12	12						
Carcass side weight	14.9	15.0	NS	NS	0.99	0.2	CW	***
Shoulder weight	6.11	6.29	*	NS	0.90	0.17	SW	***
Rack weight	1.48	1.39	*	**	0.88	0.08	SW	***
Loin weight	2.44	2.27	**	NS	0.91	0.12	SW	***
Leg weight	4.89	4.92	NS	NS	0.89	0.15	SW	***
<u>Side components:</u>								
Muscle weight	7.82	8.58	***	NS	0.88	0.26	SW	***
Fat weight	4.89	3.77	***	NS	0.92	0.29	SW	***
SCF weight	2.88	2.00	***	NS	0.91	0.22	SW	***
IMF weight	2.02	1.76	**	NS	0.77	0.17	SW	***
Bone weight	1.95	2.22	***	S	0.81	0.03	SW	***
Scrap weight	0.195	0.201	NS	NS	0.06	0.031	SW	NS
Muscle:bone ratio	4.01	3.86	*	NS	0.46	0.18	SW	*
Muscle:fat ratio	1.61	2.31	***	NS	0.80	0.22	SW	***
SCF:IMF ratio	1.43	1.13	***	NS	0.62	0.14	SW	*

For definitions of abbreviations see Table 4-1.

Table 4-15. Least squares means for the dissectible components of the side of Southdown rams of Experiment 6 expressed as weights (kg) and as ratios for two selection lines (fat and meaty) and two pastures (White clover and Lotus).

Item	Selection line		Significance F vs M	Pasture		Significance CL vs LO	r ²	RSD	Covariate	
	Fat (F)	Meaty (M)		Clover (CL)	Lotus (LO)				Variable	Significance
No. of animals	12	12		12	12					
Carcass side weight	15.37	15.27	NS	15.39	15.25	NS	0.97	0.28	CW	***
Shoulder weight	6.43	6.51	NS	6.46	6.48	NS	0.94	0.15	SW	***
Rack weight	1.56	1.51	*	1.54	1.53	NS	0.91	0.06	SW	***
Loin weight	2.58	2.51	NS	2.57	2.55	NS	0.82	0.14	SW	***
Leg weight	4.78	4.81	NS	4.78	4.80	NS	0.89	0.18	SW	***
<u>Side components:</u>										
Muscle weight	7.96	8.19	**	7.99	8.15	*	0.91	0.22	SW	***
Fat weight	5.37	5.00	**	5.30	5.08	*	0.92	0.24	SW	***
SCF weight	3.20	2.83	***	3.09	2.98	*	0.89	0.19	SW	***
IMF weight	2.17	2.17	NS	2.21	2.14	NS	0.77	0.17	SW	***
Bone weight	1.78	1.92	**	1.81	1.89	*	0.63	0.11	SW	**
Scrap weight	0.164	0.180	NS	0.175	0.169	NS	0.19	0.030	SW	NS
Muscle:bone ratio	4.48	4.29	NS	4.44	4.33	NS	0.36	0.30	SW	S
Muscle:fat ratio	1.48	1.65	***	1.52	1.61	*	0.75	0.13	SW	***
SCF:IMF ratio	1.47	1.30	*	1.41	1.37	NS	0.40	0.14	SW	NS

For definitions of abbreviations see Table 4-1.

meaty line. The meaty sides also had slightly heavier legs and lighter loins than the fat sides.

Allometric growth coefficients between side weight and weights of the four cuts are given in Appendix 3.

4-1-4-2 Dissection Data

4-1-4-2-1 Physical components of sides

Mean weights of the main tissue components in the whole side for fat and meaty lines within Experiments 3, 5 and 6 are given in Tables 4-13, 4-14 and 4-15 and as proportions of side weight for Experiments 5 and 6 in Figures 4-3 and 4-4, respectively.

A clear indication of the effects of selection on body composition can be obtained by a comparison of fat, muscle, and bone weights at the same total side weight (side weight as a covariate).

Selection significantly affected weight of fat, muscle, and bone. The difference in side composition between the two lines was largely accounted for by significantly greater weights of 0.63, 1.12 and 0.37 kg of total fat (subcutaneous plus intermuscular fat weights) in Experiments 3, 5 and 6, respectively. On a fat percent basis, sides from the fat line had 7.0% and 2.9% more total fat than those from the meaty line in Experiments 5 and 6, respectively (Figures 4-3 and 4-4).

There were clear differences between the selection lines for subcutaneous fat weight, with 0.51, 0.88 and 0.37 kg differences between the two lines for the experiments 3, 5 and 6. However, there were smaller differences between the two lines for intermuscular fat weight (0.12 kg, 0.26 kg and 0.00 kg for the three experiments). One of the striking points was the similarity in intermuscular fat weight in the sides from the meaty and fat lines (Table 4-15). This indicated that differences in the physical components between lines had little effect on intermuscular fat. Ratios of subcutaneous fat to intermuscular fat were higher in the fat line as expected from the differences between the lines for both depots. Comparison of least squares means for percent of intramuscular fat of M. longissimus

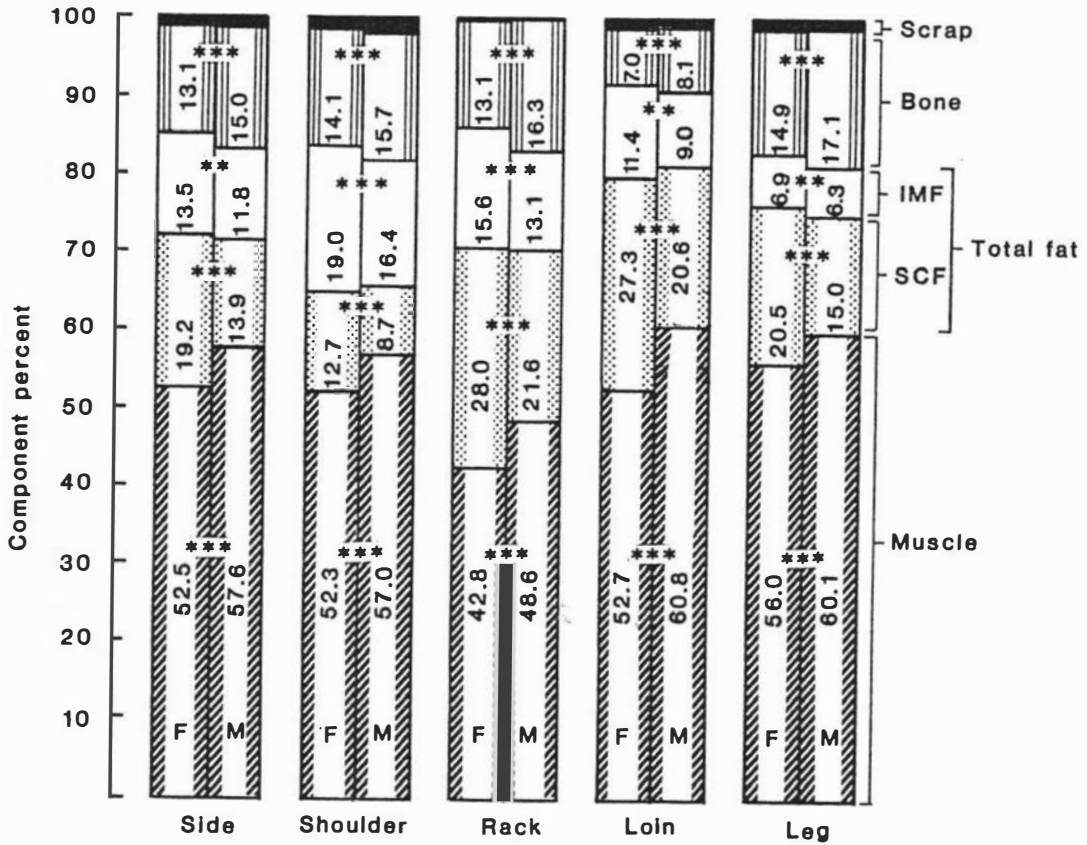


Figure 4-3. The proportion of muscle, subcutaneous fat (SCF), intermuscular fat (IMF), bone, and scrap in the carcass side, shoulder, rack, loin, and leg cuts for Southdown rams within two selection lines (fat [F] and meaty [M]) in Experiment 5. Values were corrected to the same cut weight for each tissue.

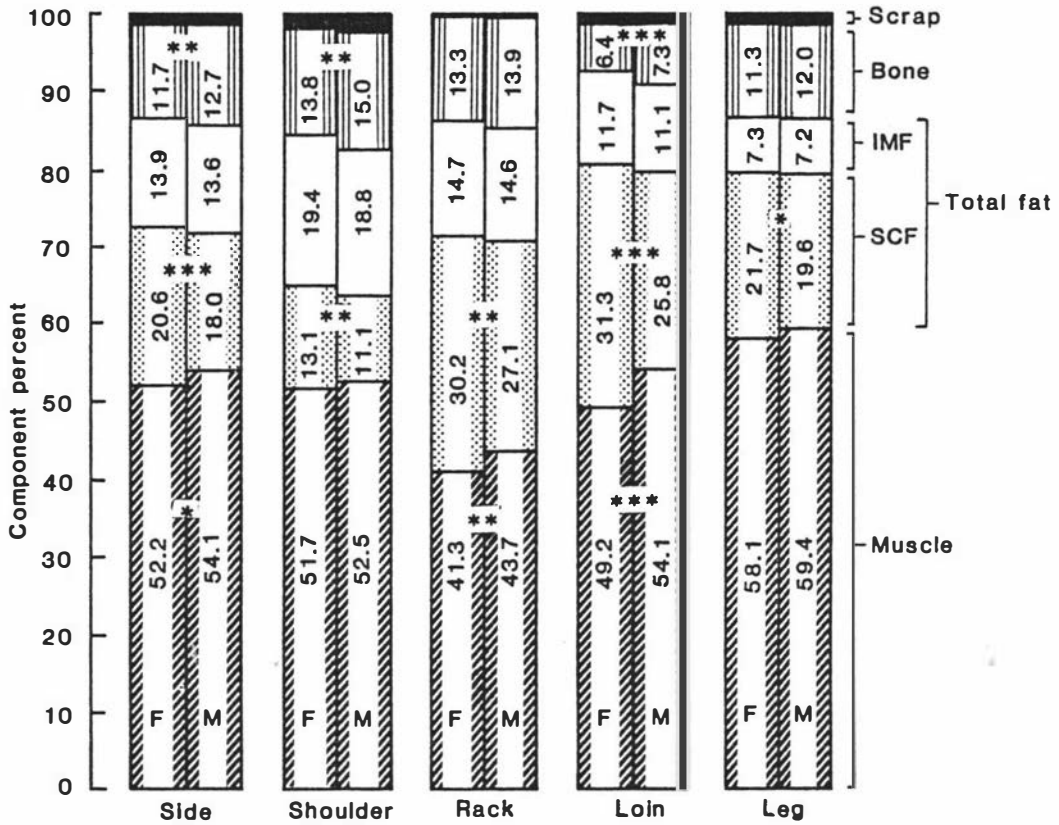


Figure 4-4. The proportion of muscle, subcutaneous fat (SCF), intermuscular fat (IMF), bone, and scrap in the carcass side, shoulder, rack, loin, and leg cuts for Southdown rams within two selection lines (fat [F] and meaty [M]) in Experiment 6. Values were corrected to the same cut weight for each tissue.

adjusted to a constant carcass weight revealed that the meaty line had significantly ($P < 0.01$) less intramuscular fat than did the fat line (4.35% vs 6.89% for Experiment 5, and 5.17% vs 7.21% for Experiment 6).

Carcasses from the meaty line had a significantly greater weight of muscle in the side by 0.38, 0.76 and 0.23 kg in Experiments 3, 5 and 6, respectively. On a percent basis (Figures 4-3 and 4-4) muscle was also higher in the meaty line. The higher ratio of muscle to fat in the meaty line was as expected from the total fat and muscle values.

Differences between lines were clear and consistent for bone weights (Tables 4-13, 4-14 and 4-15), with the leaner sides having 0.22, 0.27 and 0.14 kg more bone for the three experiments. Bone percent in Experiments 5 and 6 was significantly lower in the fat line than the meaty line. Sides from the fat line had slightly higher muscle to bone ratios than did the sides from the meaty line.

Allometric growth coefficients between side weight and weights of muscle, fat, and bone are given in Appendix 3. Although not significantly different from 1.0, the relative size of the coefficients for the three main tissues were consistent across experiments.

4-1-4-2-2 Physical components of the cuts

All the cuts from the left side of each carcass were dissected into fat, muscle, and bone. The least squares means of the components expressed both as weights and percents, are given in Tables 4-16 to 4-22 and Figures 4-3 and 4-4 for Experiments 3, 4, 5 and 6, respectively.

On an adjusted weight basis, the selection lines differed significantly in weights of total fat, subcutaneous fat, and intermuscular fat in all cuts with these differences being more highly significant for subcutaneous fat than for intermuscular fat except for the leg cut in Experiment 6. On a percent basis, Figures 4-3 and 4-4 show that total fat and subcutaneous fat were significantly different between the two lines in all cuts, but that differences were not significant for intermuscular fat. All cuts from the fat line had higher

Table 4-16. Least squares means for the dissectible components of the fore-quarter (FQW) and hind-quarter (HQW) cuts of Southdown rams in Experiment 3 expressed as weights (kg) and as ratios for two selection lines (fat and meaty).

Item	Selection line (L)		Significance		r ²	RSD	Covariate	
	Fat (F)	Meaty (M)	F vs M	L X covariate			Variable	Significance
No. of animals	12	18						
Fore-quarter:								
Total weight	7.62	7.67	NS	NS	0.89	0.16	SW	***
Muscle weight	4.19	4.36	**	S	0.71	0.15	FQW	***
Fat weight	2.25	1.94	***	NS	0.62	0.19	FQW	***
SCF weight	1.07	0.84	***	NS	0.62	0.12	FQW	**
IMF weight	1.18	1.10	S	NS	0.46	0.11	FQW	*
Bone weight	1.09	1.19	**	NS	0.50	0.09	FQW	***
Scrap weight (g)	89.3	99.9	NS	NS	0.23	23.1	FQW	NS
Muscle:bone ratio	3.88	3.70	NS	NS	0.11	0.30	FQW	NS
Muscle:fat ratio	1.87	2.30	***	S	0.51	0.26	FQW	NS
SCF:IMF ratio	0.91	0.76	***	NS	0.37	0.10	FQW	NS
Hind-quarter:								
Total weight	6.35	6.28	NS	NS	0.88	0.16	SQ	***
Muscle weight	3.79	4.01	***	NS	0.80	0.13	HQW	***
Fat weight	1.72	1.40	***	NS	0.67	0.16	HQW	***
SCF weight	1.26	1.00	***	NS	0.67	0.13	HQW	***
IMF weight	0.458	0.403	**	NS	0.38	0.052	HQW	*
Bone weight	0.613	0.688	***	NS	0.75	0.033	HQW	***
Scrap weight (g)	106.0	110.0	NS	NS	0.42	2.49	HQW	***
Muscle:bone ratio	6.19	5.85	*	S	0.31	0.37	HQW	NS
Muscle:fat ratio	2.22	2.95	***	NS	0.48	0.44	HQW	NS
SCF:IMF ratio	2.77	2.49	*	NS	0.23	0.36	HQW	S

For definitions of abbreviations see Table 4-1.

Table 4-17. Least squares means for the dissectible components of the rack cut of Southdown rams of Experiment 3 expressed as weights (kg) and as ratios for two selection lines (fat and meaty).

Item	Selection line (L)		Significance		r ²	RSD	Covariate	
	Fat (F)	Meaty (M)	F vs M	L X covariate			Variable	Significance
No. of animals	12	18						
<u>Rack cut:</u>								
Total weight	1.43	1.35	*	S	0.55	0.09	SW	***
Muscle weight	0.624	0.680	**	NS	0.52	0.045	RW	***
Fat weight	0.534	0.453	***	NS	0.76	0.052	RW	***
SCF weight	0.350	0.285	***	NS	0.72	0.04	RW	***
IMF weight	0.184	0.168	NS	NS	0.51	0.027	RW	***
Bone weight	0.204	0.224	**	NS	0.36	0.017	RW	S
Muscle:bone ratio	3.05	3.05	NS	NS	0.07	0.27	RW	NS
Muscle:fat ratio	1.17	1.58	***	NS	0.57	0.29	RW	**
SCF:IMF ratio	1.92	1.73	NS	NS	0.15	0.33	RW	NS

For definitions of abbreviations see Table 4-1.

Table 4-18. Least squares means for the dissectible components of the rack cut of Southdown rams of Experiment 4 expressed as weights (kg) and as ratios for two selection lines (fat and meaty).

Item	Selection line (L)		Significance		r^2	RSD	Covariate	
	Fat (F)	Meaty (M)	F vs M	L X covariate			Variable	Significance
No. of animals	10	8						
<u>Rack cut:</u>								
Total weight	1.49	1.40	**	NS	0.74	0.05	CW	***
Muscle weight	0.630	0.686	***	NS	0.83	0.027	RW	***
Fat weight	0.685	0.525	***	NS	0.93	0.033	RW	***
SCF weight	0.459	0.340	***	NS	0.86	0.032	RW	***
IMF weight	0.225	0.185	***	NS	0.87	0.016	RW	***
Bone weight	0.171	0.183	**	NS	0.42	0.015	RW	**
Scrap (g)	4.0	6.0	NS	NS	0.15	1.1	RW	NS
Muscle:bone ratio	3.71	3.74	NS	NS	0.15	0.35	RW	NS
Muscle:fat ratio	0.88	1.30	***	NS	0.83	0.13	RW	***
SCF:IMF ratio	2.06	1.84	S	NS	0.13	0.26	RW	NS

For definitions of abbreviations see Table 4-1.

Table 4-19. Least squares means for the dissectible components of the shoulder and rack cuts of Southdown rams of Experiment 5 expressed as weights (kg) and as ratios for two selection lines (fat and meaty).

Item	Selection line (L)		Significance		r ²	RSD	Covariate	
	Fat (F)	Meaty (M)	F vs M	L X covariate			Variable	Significance
No. of animals	12	12						
<u>Shoulder cut:</u>								
Total weight	6.11	6.29	*	NS	0.90	0.17	SW	***
Muscle weight	3.19	3.58	***	NS	0.89	0.10	SHW	***
Fat weight	1.97	1.57	***	NS	0.91	0.10	SHW	***
SCF weight	0.791	0.544	***	NS	0.90	0.057	SHW	***
IMF weight	1.18	1.02	**	NS	0.72	0.10	SHW	**
Bone weight	0.874	0.973	***	S	0.84	0.035	SHW	***
Scrap weight (g)	94.8	101.0	NS	NS	0.14	13	SHW	NS
Muscle:bone ratio	3.72	3.64	NS	NS	0.36	0.18	SHW	NS
Muscle:fat ratio	1.66	2.28	***	S	0.84	0.15	SHW	**
SCF:IMF ratio	0.67	0.54	***	NS	0.53	0.08	SHW	NS
<u>Rack cut:</u>								
Total weight	1.48	1.39	*	**	0.88	0.08	SW	***
Muscle weight	0.606	0.697	***	NS	0.74	0.043	RW	***
Fat weight	0.620	0.485	***	NS	0.95	0.040	RW	***
SCF weight	0.398	0.297	***	NS	0.88	0.042	RW	***
IMF weight	0.222	0.187	***	S	0.900	0.020	RW	***
Bone weight	0.186	0.230	***	NS	0.74	0.070	RW	***
Scrap weight (g)	9.2	8.5	NS	NS	0.12	2.3	RW	NS
Muscle:bone ratio	3.27	3.06	S	NS	0.19	0.25	RW	NS
Muscle:fat ratio	0.99	1.48	***	NS	0.76	0.20	RW	***
SCF:IMF ratio	1.81	1.58	S	NS	0.24	0.26	RW	***

For definitions of abbreviations see Table 4-1.

Table 4-20. Least squares means for the dissectible components of the loin and leg cuts of Southdown rams of Experiment 5 expressed as weights (kg) and as ratios for two selection lines (fat and meaty).

Item	Selection line (L)		Significance		r ²	RSD	Covariate	
	Fat (F)	Meaty (M)	F vs M	L X covariate			Variable	Significance
No. of animals	12	12						
<u>Loin cut:</u>								
Total weight	2.44	2.27	**	NS	0.91	0.12	SW	***
Muscle weight	1.23	1.41	***	NS	0.77	0.08	LW	***
Fat weight	0.917	0.681	***	NS	0.94	0.074	LW	***
SCF weight	0.648	0.470	***	NS	0.94	0.055	LW	***
IMF weight	0.270	0.211	**	NS	0.79	0.038	LW	***
Bone weight	0.165	0.189	***	NS	0.69	0.011	LW	***
Scrap weight (g)	23.1	23.9	NS	NS	0.05	0.8	LW	NS
Muscle:bone ratio	7.51	7.40	NS	NS	0.27	0.42	LW	S
Muscle:fat ratio	1.37	2.13	***	NS	0.79	0.29	LW	***
SCF:IMF ratio	2.42	2.24	NS	NS	0.22	0.36	LW	S
<u>Leg cut:</u>								
Total weight	4.89	4.92	NS	NS	0.89	0.15	SW	***
Muscle weight	2.76	2.95	**	NS	0.85	0.11	LGW	***
Fat weight	1.35	1.05	***	NS	0.79	0.12	LGW	***
SCF weight	1.01	0.74	***	NS	0.82	0.09	LGW	**
IMF weight	0.340	0.310	NS	NS	0.45	0.063	LGW	**
Bone weight	0.731	0.838	***	NS	0.66	0.054	LGW	**
Scrap weight (g)	66.6	76.9	NS	NS	0.12	2.0	LGW	NS
Muscle:bone ratio	3.79	3.53	S	NS	0.20	0.35	LGW	NS
Muscle:fat ratio	2.06	2.89	**	NS	0.56	0.43	LGW	NS
SCF:IMF ratio	3.11	2.41	**	NS	0.42	0.53	LGW	NS

For definitions of abbreviations see Table 4-1.

Table 4-21. Least squares means for the dissectible components of the shoulder and rack cuts of Southdown rams of Experiment 6 expressed as weights (kg) and as ratios for two selection lines (fat and meaty) and two pastures (White clover and Lotus).

Item	Selection line		Significance F vs M	Pasture		Significance CL vs LO	r ²	RSD	Covariate	
	Fat (F)	Meaty (M)		Clover (CL)	Lotus (LO)				Variable	Significance
No. of animals	12	12		12	12					
<u>Shoulder cut:</u>										
Total weight	6.43	6.51	NS	6.46	6.48	NS	0.94	0.15	SW	***
Muscle weight	3.32	3.35	NS	3.30	3.37	*	0.89	0.094	SHW	***
Fat weight	2.13	1.99	*	2.12	2.00	S	0.78	0.164	SHW	***
SCF weight	0.851	0.738	***	0.840	0.748	**	0.83	0.072	SHW	***
IMF weight	1.27	1.25	NS	1.27	1.25	NS	0.59	0.132	SHW	***
Bone weight	0.890	0.960	**	0.894	0.956	*	0.65	0.056	SHW	**
Scrap weight (g)	84.5	96.7	NS	92.1	89.1	NS	0.23	25.6	SHW	NS
Muscle:bone ratio	3.75	3.49	*	3.70	3.54	NS	0.46	0.254	SHW	NS
Muscle:fat ratio	1.57	1.70	*	1.58	1.69	*	0.60	0.181	SHW	*
SCF:IMF ratio	0.668	0.594	*	0.664	0.598	S	0.48	0.077	SHW	NS
<u>Rack cut:</u>										
Total weight	1.56	1.51	*	1.54	1.53	NS	0.91	0.06	SW	***
Muscle weight	0.626	0.657	**	0.630	0.652	S	0.78	0.029	RW	***
Fat weight	0.704	0.652	**	0.705	0.643	**	0.95	0.035	RW	***
SCF weight	0.467	0.421	**	0.466	0.423	*	0.90	0.034	RW	***
IMF weight	0.237	0.231	NS	0.239	0.229	NS	0.90	0.017	RW	***
Bone weight	0.202	0.211	NS	0.201	0.212	NS	0.29	0.013	RW	NS
Scrap weight (g)	5.49	5.42	NS	5.55	5.35	NS	0.22	2.30	RW	NS
Muscle:bone ratio	3.11	3.12	NS	3.14	3.09	NS	0.46	0.21	RW	**
Muscle:fat ratio	0.889	1.01	**	0.894	1.01	S	0.83	0.09	RW	***
SCF:IMF ratio	1.97	1.55	*	1.95	1.85	S	0.37	0.23	RW	NS

For definitions of abbreviations see Table 4-1.

Table 4-22. Least squares means for the dissectible components of the loin and leg cuts of Southdown rams of Experiment 6 expressed as weights (kg) and as ratios for two selection lines (fat and meaty) and two pastures (White clover and Lotus).

Item	Selection line		Significance F vs M	Pasture		Significance CL vs LO	r ²	RSD	Covariate	
	Fat (F)	Meaty (M)		Clover (CL)	Lotus (LO)				Variable	Significance
No. of animals	12	12		12	12					
<u>Loin cut:</u>										
Total weight	2.58	2.51	NS	2.57	2.55	NS	0.82	0.14	SW	***
Muscle weight	1.26	1.37	***	1.29	1.34	*	0.87	0.055	LW	***
Fat weight	1.12	0.978	***	1.08	1.02	*	0.92	0.063	LW	***
SCF weight	0.813	0.681	***	0.764	0.730	NS	0.91	0.049	LW	***
IMF weight	0.304	0.297	NS	0.314	0.287	NS	0.67	0.048	LW	***
Bone weight	0.165	0.187	***	0.171	0.181	NS	0.60	0.013	LW	S
Scrap weight (g)	25.7	27.6	NS	27.6	25.6	NS	0.25	6.7	LW	NS
Muscle:bone ratio	7.96	7.33	NS	7.61	7.41	NS	0.41	0.59	LW	*
Muscle:fat ratio	1.30	1.43	***	1.22	1.34	*	0.82	0.129	LW	***
SCF:IMF ratio	2.69	2.39	NS	2.49	2.59	NS	0.19	0.537	LW	NS
<u>Leg cut:</u>										
Total weight	4.78	4.81	NS	4.78	4.80	NS	0.89	0.18	SW	***
Muscle weight	2.80	2.86	NS	2.80	2.85	NS	0.89	0.115	LGW	***
Fat weight	1.38	1.27	S	1.34	1.31	NS	0.65	0.134	LGW	***
SCF weight	1.03	0.930	S	0.994	0.969	NS	0.64	0.117	LGW	***
IMF weight	0.348	0.343	NS	0.349	0.342	NS	0.29	0.042	LGW	*
Bone weight	0.533	0.562	NS	0.546	0.549	NS	0.47	0.055	LGW	**
Scrap weight (g)	50.9	49.4	NS	53.0	47.3	NS	0.09	16.7	LGW	NS
Muscle:bone ratio	5.27	5.15	NS	5.19	5.23	NS	0.35	0.52	LGW	NS
Muscle:fat ratio	2.03	2.28	S	2.11	2.20	NS	0.27	0.310	LGW	NS
SCF:IMF ratio	3.01	2.70	NS	2.87	2.84	NS	0.31	0.439	LGW	S

For definitions of abbreviations see Table 4-1.

subcutaneous fat to intermuscular fat ratios than those from the meaty line.

The high fat content on an adjusted weight basis was reflected in the weights of muscle and bone, which were lower in all cuts from the fat line. These differences between the lines for the main components were also reflected in the ratios of the components. Cuts from the fat line had slightly higher muscle to bone ratio, but significantly lower muscle to fat ratio than the meaty line.

The allometric growth coefficients between each cut weight and its tissue weights (Appendix 3) revealed few significant results for the rack and loin cuts.

4-1-5 PARTITIONING OF FAT AMONG THE DEPOTS

Line effects on fat partitioning at the same total side fat weight are given in Tables 4-23, 4-24 and 4-25 for Experiments 3, 5 and 6, respectively. Carcass sides from the fat line had more subcutaneous fat, more intramuscular fat in M. longissimus and less intermuscular fat at the same total side fat than those from the meaty line.

There was little difference in the partitioning of the non-carcass fat depots in the body of the animals of the two lines relative to total side fat, with no significant differences between the two lines. The allometric growth coefficients for the fat depots relative to total side fat are presented in Appendix 2. The b values for omental, kidney, subcutaneous, and intermuscular fat depots were not significantly different from 1.0, whereas mesenteric fat was significantly less than 1.0.

4-1-6 WEIGHT DISTRIBUTION WITHIN SUBCUTANEOUS AND INTERMUSCULAR FAT DEPOTS

4-1-6-1 Forequarter and Hindquarter Fat Distribution (Experiment 3)

Subcutaneous fat distribution between the forequarter and hindquarter regions was similar in the two lines (Table 4-23), when

Table 4-23. Least squares means for measures of fat distribution (kg) within total side fat (TSF) of Southdown rams of Experiment 3 from two selection lines (fat and meaty).

Carcass or cut	Fat depot	Selection line (L)		Significance		r ²	RSD	Covariate	
		Fat (F)	Meaty (M)	F vs M	L X covariate			Variable	Significance
Carcass	Omental fat weight	0.930	0.965	NS	NS	0.65	0.14	TSF	***
	Kidney fat weight	0.692	0.687	NS	NS	0.20	0.16	TSF	*
Side	SCF weight	2.05	1.99	*	NS	0.95	0.09	TSF	***
	IMF weight	1.54	1.61	*	NS	0.80	0.09	TSF	***
Forequarter	Fat weight	2.06	2.10	*	NS	0.96	0.06	TSF	***
	SCF weight	0.944	0.919	NS	NS	0.88	0.07	TSF	***
	IMF weight	1.12	1.18	**	NS	0.76	0.07	TSF	***
Hindquarter	Fat weight	1.54	1.50	*	NS	0.95	0.06	TSF	***
	SCF weight	1.11	1.08	S	NS	0.90	0.07	TSF	***
	IMF weight	0.427	0.425	NS	NS	0.66	0.04	TSF	***
Rack	Fat weight	0.483	0.472	NS	NS	0.83	0.05	TSF	***
	SCF weight	0.312	0.295	NS	NS	0.71	0.04	TSF	***
	IMF weight	0.171	0.177	NS	NS	0.74	0.02	TSF	**

For definitions of abbreviations see Table 4-1.

Table 4-24. Least squares means for measures of fat distribution (kg) within total side fat (TSF) of Southdown rams of Experiment 5 from two selection lines (fat and meaty).

Carcass or cut	Fat depot	Selection line (L)		Significance		r^2	RSD	Covariate	
		Fat (F)	Meaty (M)	F vs M	L X covariate			Variable	Significance
Carcass	Omental fat weight	0.98	1.02	NS	NS	0.71	0.20	TSF	***
	Kidney fat weight	0.637	0.655	NS	NS	0.75	0.145	TSF	***
Side	SCF weight	2.54	2.33	*	NS	0.97	0.13	TSF	***
	IMF weight	1.79	1.98	*	NS	0.87	0.13	TSF	***
Shoulder	Fat weight	1.74	1.79	NS	NS	0.92	0.10	TSF	***
	SCF weight	0.680	0.614	NS	NS	0.89	0.061	TSF	***
	IMF weight	1.05	1.15	S	NS	0.75	0.09	TSF	***
Rack	Fat weight	0.570	0.570	NS	NS	0.93	0.046	TSF	***
	SCF weight	0.366	0.358	NS	NS	0.90	0.038	TSF	***
	IMF weight	0.205	0.213	NS	NS	0.81	0.027	TSF	***
	Intramuscular fat ^a weight (g)	24.7	17.0	*	NS	0.59	5.6	TSF	***
Loin	Fat weight	0.816	0.785	NS	NS	0.67	0.012	TSF	***
	SCF weight	0.578	0.544	NS	NS	0.93	0.058	TSF	***
	IMF weight	0.238	0.241	NS	NS	0.86	0.031	TSF	***
Leg	Fat weight	1.21	1.21	NS	NS	0.89	0.09	TSF	***
	SCF weight	0.916	0.855	NS	NS	0.90	0.070	TSF	***
	IMF weight	0.292	0.356	S	NS	0.49	0.061	TSF	**

For definitions of abbreviations see Table 4-1.

^a Intramuscular fat for M. longissimus from the rack cut.

Table 4-25. Least squares means for measures of fat distribution (kg) within total side fat (TSF) of Southdown rams of Experiment 6 for two selection lines (fat and meaty) and two pastures (White clover and Lotus).

Carcass or cut	Fat depot	Selection line		Significance F vs M	Pasture		Significance CL vs LO	r ²	RSD	Covariate	
		Fat (F)	Meaty (M)		Clover (CL)	Lotus (LO)				Variable	Significance
Carcass											
	Omental fat weight	1.32	1.34	NS	1.33	1.33	NS	0.57	0.219	TSF	***
	Kidney fat weight	0.982	0.972	NS	0.910	1.04	NS	0.56	0.244	TSF	**
	Mesenteric fat weight	0.523	0.519	NS	0.535	0.504	NS	0.48	0.071	TSF	**
Side											
	SCF weight	3.01	2.87	*	2.95	2.93	NS	0.95	0.135	TSF	***
	IMF weight	2.09	2.18	S	2.15	2.13	NS	0.84	0.137	TSF	***
Shoulder											
	Fat weight	2.03	2.10	NS	2.10	2.03	NS	0.89	0.114	TSF	***
	SCF weight	0.797	0.786	NS	0.823	0.761	S	0.87	0.067	TSF	***
	IMF weight	1.23	1.31	NS	1.27	1.27	NS	0.67	0.115	TSF	***
Rack											
	Fat weight	0.69	0.64	NS	0.69	0.64	NS	0.93	0.040	TSF	***
	SCF weight	0.454	0.420	S	0.452	0.421	S	0.89	0.034	TSF	***
	IMF weight	0.235	0.223	NS	0.237	0.220	NS	0.85	0.021	TSF	***
	Intramuscular fat ^a (g)	27.1	18.9	***	23.1	22.9	NS	0.90	2.00	TSF	***
Loin											
	Fat weight	1.07	0.989	**	1.03	1.02	NS	0.92	0.063	TSF	***
	SCF weight	0.782	0.688	***	0.735	0.735	NS	0.90	0.053	TSF	***
	IMF weight	0.287	0.301	NS	0.299	0.289	NS	0.70	0.045	TSF	***
Leg											
	Fat weight	1.33	1.33	NS	1.29	1.37	NS	0.84	0.089	TSF	***
	SCF weight	0.981	0.980	NS	0.944	1.02	NS	0.80	0.087	TSF	***
	IMF weight	0.344	0.352	NS	0.344	0.352	NS	0.43	0.037	TSF	**

For definitions of abbreviations see Table 4-1.

^a Intramuscular fat weight for M. longissimus from the rack cut.

compared at the same total side fat. At 3.60 kg total side fat, the intermuscular fat in the forequarter was significantly lower in the fat line (1.12 kg) than in the meaty line (1.18 kg). At the same total side fat, the fat line had more subcutaneous fat and less intermuscular fat. The meaty line had a significantly higher proportion of its total fat (subcutaneous fat, plus intermuscular fat) in the forequarter.

4-1-6-2 Distribution of Subcutaneous Fat (Experiments 5 and 6)

Subcutaneous fat, either after adjustment for total side fat weight (Tables 4-24 and 4-25) or as a percent of the total fat in the side (Figures 4-5 and 4-6), was generally higher in the fat line, but this was significant only for the whole side in Experiment 5 and in the side and loin in Experiment 6. The allometric growth coefficients for subcutaneous fat from these cuts are given in Appendix 2. The b value for subcutaneous fat relative to total fat from the rack cut in Experiment 5 was significantly higher than 1.0, but the b values for subcutaneous fat from the other cuts did not differ significantly from 1.0.

4-1-6-3 Distribution of Intermuscular Fat (Experiments 5 and 6)

The distribution of intermuscular fat between the four anatomical cuts in Experiments 5 and 6 are given in Tables 4-24 and 4-25 and Figures 4-5 and 4-6, respectively. The fat line had slightly lower intermuscular fat relative to total side fat for all cuts, but these differences were not significant. One interesting feature of these results is the close similarity between the two lines for intramuscular fat weight in the M. longissimus at constant total side fat weight. The leg was the only cut where the value of the allometric growth coefficient (b) for intermuscular fat was significantly less than 1.0 for the two lines (Appendix 2).

4-1-7 DISTRIBUTION OF MUSCLE

Least squares means for the weight of muscle between the various cuts, between muscle groups and between individual muscles at the same total side muscle weight are given in Tables 4-26, 4-27 and 4-28 for

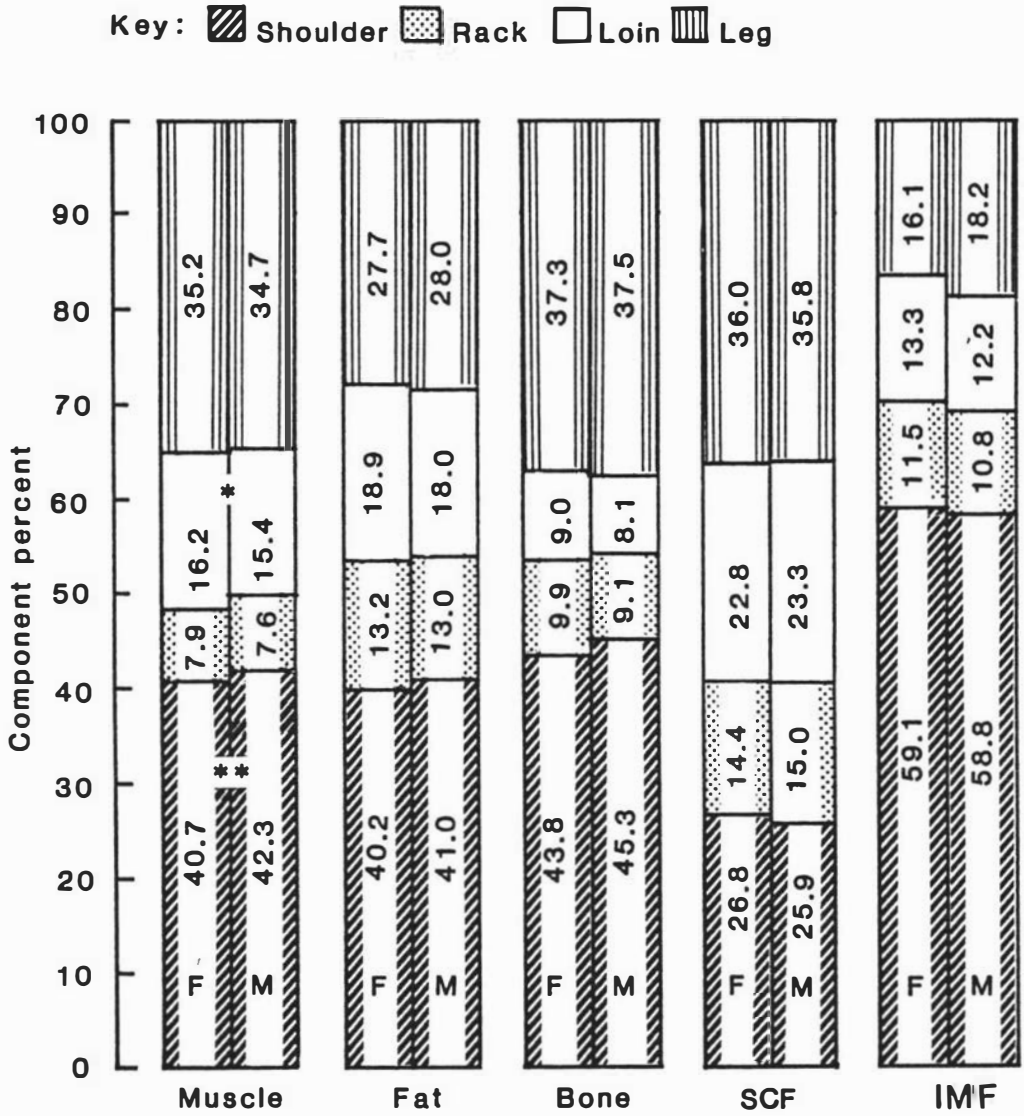


Figure 4-5. The proportion of muscle, fat, bone, subcutaneous (SCF), and intermuscular fat (IMF) in the shoulder, rack, loin, and leg cuts expressed as percentages of the total side components for Southdown rams within two selection lines (fat [F] and meaty [M]) in Experiment 5.

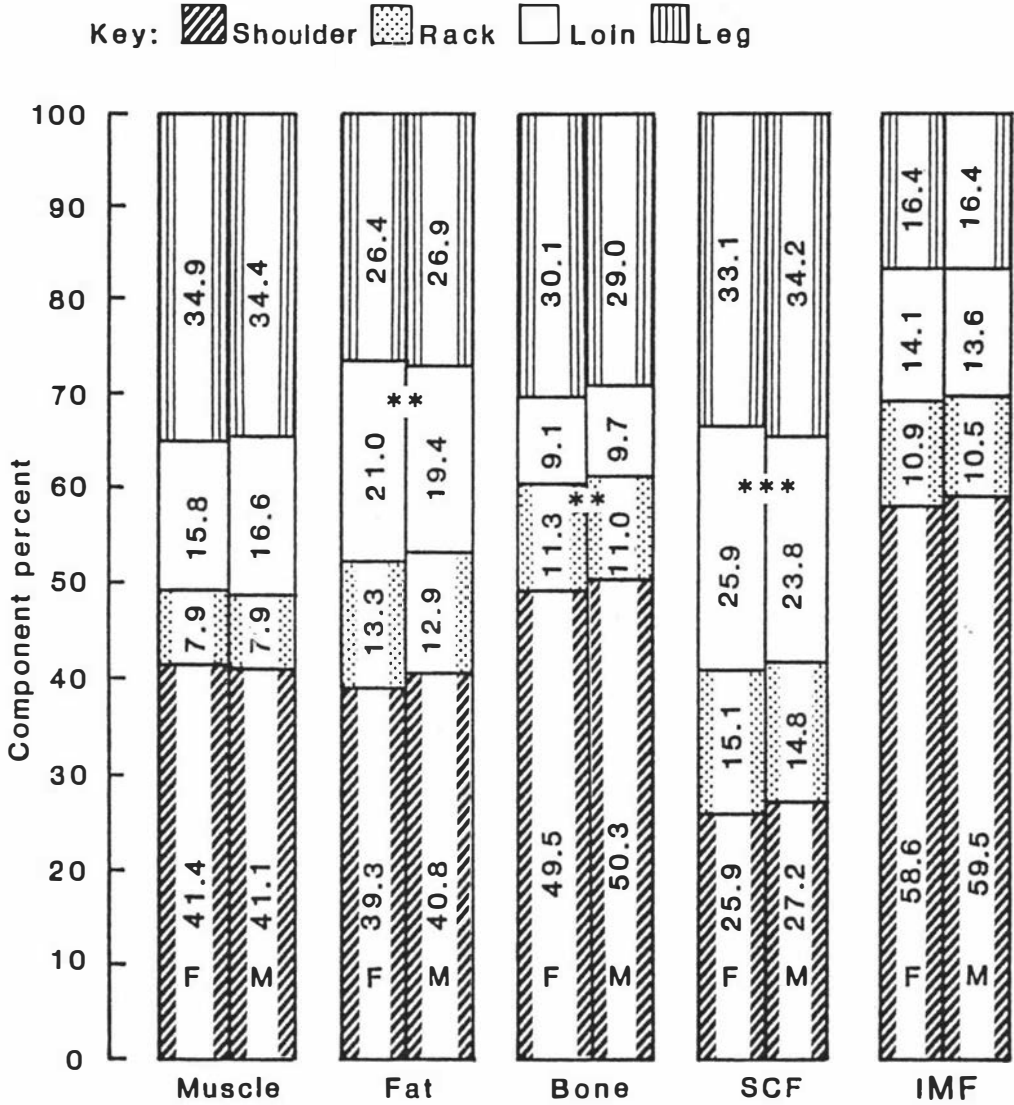


Figure 4-6. The proportion of muscle, fat, bone, subcutaneous (SCF), and intermuscular fat (IMF) in the shoulder, rack, loin, and leg cuts expressed as percentages of the total side components for Southdown rams within two selection lines (fat [F] and meaty [M]) in Experiment 6.

Experiments 3, 5 and 6, respectively. For Experiment 5, rams from the fat line had significantly less muscle in the shoulder by 0.12 kg at the same total side muscle weight, but significantly more muscle by 0.06 kg in the loin cut. However, in Experiment 6, the fat line rams had a lower weight of muscle in the loin. On a percent basis of the total side muscle (Figures 4-5 and 4-6 for Experiments 5 and 6), there were no significant differences between the lines for muscle percents in the cuts except that the meaty line had a significantly higher muscle percent in the shoulder cut (1.6%) and a lower percent in the loin cut (0.8%) than the fat line in Experiment 5.

Appendix 4 shows the allometric growth coefficients for the total muscle in each cut relative to total side muscle. The b values for muscle in the shoulder cut for Experiment 5 and the muscle in the rack cuts for both Experiments 5 and 6 were significantly less than 1.0, whereas the muscle in the loin and leg cuts were not significantly different from 1.0.

Of the 17 individual muscles and 6 muscle groups studied in Experiment 3, only 2 muscles (Mm. trapezius and quadriceps femoris) showed significant differences in their weight distribution relative to total side muscle between the two lines. It would appear that the selection process has had only minor effects on the weights of individual and groups of muscles adjusted to the same total side muscle weight. The weights of these muscles for the two lines at 8.21 kg total side muscle are given in Table 4-26.

The growth of muscles relative to total side muscle are given as allometric growth coefficients in Appendix 6. The b values of M. quadriceps femoris and M. trapezius were significantly lower and higher than 1.0 respectively, whereas the b values for all other muscles were not significantly different from 1.0.

At the same side muscle weight, selection line had no significant effects on muscle weight for five of the seven muscles studied in Experiments 5 and 6 (Tables 4-27 and 4-28). For Experiments 5 and 6, rams from the fat line had significantly heavier M. biceps femoris by 30 g and 27 g, respectively at the same total side muscle weight for Experiment 5. Table 4-27 also shows that the fat line rams had

Table 4-26. Least squares means for the muscle distribution within total side muscle (TSM) for two selection lines (fat and meaty) of Southdown rams of Experiment 3.

Item	Selection line (L)		Significance F vs M	L X Covariate	r ²	RSD	Covariate	
	Fat (F)	Meaty (M)					Variable	Significance
Forequarter:								
Total muscle weight (kg)	4.28	4.30	NS	NS	0.81	0.12	TSM	***
<u>M. rhomboideus</u> (g)	67.1	63.5	NS	NS	0.09	10.1	TSM	NS
<u>M. trapezius</u> (g)	81.8	75.6	**	NS	0.59	6.3	TSM	***
<u>M. brachiocephalicus</u> (g)	172.6	165.7	NS	NS	0.25	23.9	TSM	**
<u>M. latissimus dorsi</u> (g)	143.6	148.4	NS	NS	0.73	8.1	TSM	***
<u>M. serratus ventralis</u> (g)	448.4	458.8	NS	NS	0.50	29.6	TSM	***
<u>M. pectoralis</u> (g)	347.5	347.6	NS	S	0.45	22.8	TSM	**
Abdominal muscles (g)	726.9	734.8	NS	NS	0.52	62.2	TSM	***
<u>M. longissimus</u> (g)	794.0	820.9	NS	NS	0.67	48.0	TSM	***
<u>M. splenius</u> (g)	37.6	38.0	NS	NS	0.14	6.4	TSM	S
<u>M. spinalis</u> (g)	140.8	141.6	NS	NS	0.14	23.9	TSM	NS
Brachial muscles (g)	893.3	894.8	NS	NS	0.37	46.9	TSM	***
Antebrachial muscles (g)	224.6	212.8	*	NS	0.37	15.8	TSM	**
<u>M. cutaneus</u> (g)	197.1	194.1	NS	NS	0.43	21.9	TSM	***
Hindquarter:								
Total muscle weight (kg)	3.92	3.91	NS	NS	0.40	0.84	TSM	***
<u>M. tensor fasciae latae</u> (g)	82.0	90.2	NS	NS	0.66	5.9	TSM	***
<u>M. gracilis</u> (g)	92.2	94.5	NS	NS	0.32	5.9	TSM	**
<u>M. biceps femoris</u> (g)	372.6	349.6	NS	NS	0.52	26.7	TSM	***
<u>M. semitendinosus</u> (g)	155.0	149.3	NS	NS	0.42	12.4	TSM	***
<u>M. semimembranosus</u> (g)	367.0	363.2	NS	NS	0.58	20.5	TSM	***
<u>M. adductor</u> (g)	157.5	156.6	NS	NS	0.35	19.8	TSM	**
<u>M. gluteus medius</u> (g)	334.7	328.3	NS	NS	0.55	20.1	TSM	***
Sublumbar muscles (g)	259.2	254.4	NS	NS	0.62	14.3	TSM	***
<u>M. quadriceps femoris</u> (g)	486.0	473.4	*	S	0.48	20.7	TSM	***
Deep hip muscles (g)	93.2	104.3	NS	NS	0.30	14.4	TSM	NS
Crural muscles (g)	362.8	365.3	NS	NS	0.41	20.3	TSM	**
Rack Cut:								
Total muscle weight (kg)	0.67	0.66	NS	NS	0.51	0.05	TSM	***

For definitions of abbreviations see Table 4-1.

Table 4-27. Least squares means for the muscle distribution within total side muscle (TSM) of Southdown rams of Experiment 5 from two selection lines (fat and meaty).

Cut	Muscle	Selection line (L)		Significance		r ²	RSD	Covariate	
		Fat (F)	Meaty (M)	F vs M	L X covariate			Variable	Significance
Shoulder	Total muscle weight (kg)	3.34	3.46	**	NS	0.90	0.10	TSM	***
	<u>M. infraspinatus</u> weight (g)	169.3	179.4	NS	NS	0.26	21	TSM	*
	<u>M. supraspinatus</u> weight (g)	153.1	157.0	NS	NS	0.77	10	TSM	**
	<u>M. triceps</u> weight (g)	254.6	256.3	NS	NS	0.69	13	TSM	***
Rack	Total muscle weight (kg)	0.645	0.623	NS	NS	0.72	0.045	TSM	***
	<u>M. longissimus</u> weight (g)	204.7	190.2	S	NS	0.47	17	TSM	**
Loin	Total muscle weight (kg)	1.33	1.27	*	NS	0.85	0.06	TSM	***
Leg	Total muscle weight (kg)	2.89	2.83	NS	NS	0.88	0.10	TSM	***
	<u>M. semitendinosus</u> weight (g)	154.3	159.1	NS	NS	0.42	16	TSM	**
	<u>M. semimembranosus</u> weight (g)	392.5	364.0	**	NS	0.68	23	TSM	***
	<u>M. biceps femoris</u> weight (g)	402.0	372.3	**	NS	0.80	20	TSM	***

For definitions of abbreviations see Table 4-1.

Table 4-28. Least squares means for muscle distribution within total side muscle (TSM) of Southdown rams of Experiment 6 for two selection lines (fat and meaty) and within two pasture treatments (White clover and Lotus).

Cut	Muscle	Selection line		Significance	Pasture		Significance	r ²	RSD	Covariate		
		Fat (F)	Meaty (M)	F vs M	Clover (CL)	Lotus (LO)	CL vs LO			Variable	Significance	
Shoulder												
	Total muscle weight (kg)	3.36	3.33	NS	3.35	3.34	NS	0.91	0.085	TSM	***	
	<u>M. infraspinatus</u> (g)	174.0	167.1	S	171.9	159.2	NS	0.71	9.8	TSM	***	
	<u>M. supraspinatus</u> (g)	152.8	148.2	NS	147.3	153.7	NS	0.61	10.6	TSM	***	
	<u>M. triceps</u> (g)	224.1	232.6	NS	231.8	224.8	NS	0.69	15.4	TSM	***	
Rack												
	Total muscle weight (kg)	0.638	0.640	NS	0.634	0.645	NS	0.77	0.029	TSM	***	
	<u>M. longissimus</u> (g)	212.1	210.7	NS	213.2	209.6	NS	0.54	21.1	TSM	***	
Loin												
	Total muscle weight (kg)	1.27	1.33	*	1.31	1.29	NS	0.77	0.073	TSM	***	
	<u>M. longissimus</u> (g)	440.3	465.6	NS	460.8	445.1	NS	0.65	39.0	TSM	***	
Leg												
	Total muscle weight (kg)	2.87	2.84	NS	2.85	2.86	NS	0.89	0.116	TSM	***	
	<u>M. semitendinosus</u> (g)	168.4	158.8	S	167.3	159.8	NS	0.61	11.9	TSM	***	
	<u>M. semimembranosus</u> (g)	398.0	389.8	NS	386.3	401.5	NS	0.58	27.0	TSM	***	
	<u>M. biceps femoris</u> (g)	406.5	379.1	**	393.4	382.3	NS	0.71	19.4	TSM	***	

For definitions of abbreviations see Table 4-1.

significantly heavier M. semimembranosus by 28 g at the same total side muscle weight.

4-1-8 DISTRIBUTION OF BONE

The weight of total bone and individual bones of each cut for Experiments 3, 5 and 6 are presented in Tables 4-29, 4-30 and 4-31 respectively. The weights of bone in four anatomical cuts expressed as a percent of total side bone for Experiments 5 and 6 are shown in Figures 4-5 and 4-6.

At the mean weight of total side bone there were no significant differences between the two selection lines in either weight of bone in each cut or the weight of each recorded bone except those as follows. At the same total side bone weight the meaty line rams had significantly heavier bone weight by 0.03 kg for the hindquarter and by 4.8 g for humerus bone in Experiment 3. For Experiment 6 the loin from the meaty line had significantly (0.013 kg) more bone than that from the fat line at the same total side bone weight. Also the percent of bone in the rack cut was significantly greater in the fat line than in the meaty line in Experiment 6 (Figure 4-6).

The allometric growth coefficients for total cut bone and individual bones relative to total side bone weight in Experiments 3, 5 and 6 are given in Appendix 5. Values of b significantly less than 1.0 were observed for humerus, radius and ulna, and metacarpal bones in Experiments 3 and 6. In addition, the b values for femur, tibia and fibula in Experiment 3 were significantly lower than 1.0.

4-1-9 MUSCULARITY

Least squares means for the ratios of certain individual muscle weights, leg muscle weight, and side muscle weight relative to certain lengths for Experiments 3, 5, and 6 are given in Figure 4-7. When comparisons between lines were made at the same side muscle plus bone weights, the fat line had significantly higher Mm. semitendinosus, semimembranosus, and biceps femoris weights relative to femur length. Although the side muscle weight to body length ratio was significantly higher in the fat line across three experiments, no significant

Table 4-29. Least squares means for bone distribution within total side bone (TSB) of Southdown rams of Experiment 3 from two selection lines (fat and meaty).

Cut	Bone	Selection line (L)		Significance		r ²	RSD	Covariate	
		Fat (F)	Meaty (M)	F vs M	L X covariate			Variable	Significance
Forequarter									
	Total bone weight (kg)	1.19	1.16	NS	NS	0.71	0.06	TSB	***
	Humerus weight (g)	116.0	120.8	*	NS	0.84	4.7	TSB	***
	Radius and ulna weight (g)	93.7	98.3	NS	NS	0.49	8.9	TSB	***
	Metacarpal bone weight (g)	43.3	44.0	NS	NS	0.45	2.9	TSB	**
Hindquarter									
	Total bone weight (kg)	0.638	0.671	*	NS	0.68	0.036	TSB	***
	Femur weight (g)	145.5	149.1	NS	S	0.81	6.1	TSB	***
	Tibia and fibula weight (g)	115.9	116.4	NS	NS	0.75	5.1	TSB	***
Rack									
	Total bone weight (kg)	0.226	0.220	NS	S	0.38	0.017	TSB	**

For definitions of abbreviations see Table 4-1.

Table 4-30. Least squares means for bone weight distribution within total side bone weight (TSB) of Southdown rams of Experiment 5 from two selection lines (fat and meaty).

Cut	Bone	Selection line (L)		Significance		r ²	RSD	Covariate	
		Fat (F)	Meaty (M)	F vs M	L X covariate			Variable	Significance
Shoulder									
	Total bone weight (kg)	0.918	0.952	NS	NS	0.78	0.040	TSB	***
	Humerus bone (g)	115	117	NS	NS	0.88	5	TSB	***
	Radius and ulna (g)	93	93	NS	NS	0.81	4	TSB	***
	Metacarpal bone (g)	40.6	41.6	NS	NS	0.21	4.0	TSB	*
Rack									
	Total bone weight (kg)	0.209	0.190	NS	S	0.67	0.019	TSB	***
Loin									
	Total bone weight (kg)	0.182	0.170	S	NS	0.68	0.011	TSB	***
Leg									
	Total bone weight (kg)	0.793	0.782	NS	NS	0.78	0.043	TSB	***
	Femur (g)	146	154	S	NS	0.89	6	TSB	***
	Tibia and fibula (g)	176	176	NS	NS	0.42	5	TSB	***

For definitions of abbreviations see Table 4-1.

Table 4-31 Least squares means for bone distribution within total side bone (TSB) of Southdown rams of Experiment 6 for two selection lines (fat and meaty) and within two pasture treatments (White clover and Lotus).

Cut	Bone	Selection line		Significance	Pasture		Significance	r ²	RSD	Covariate	
		Fat (F)	Meaty (M)	F vs M	Clover (CL)	Lotus (LO)	CL vs LO			Variable	Significance
Shoulder											
	Total bone weight (kg)	0.921	0.927	NS	0.921	0.933	NS	0.89	0.031	TSB	***
	Humerus (g)	111.5	116.2	S	113.9	113.9	NS	0.78	4.92	TSB	***
	Radius and ulna (g)	93.7	95.3	NS	94.3	94.7	NS	0.69	4.91	TSB	***
	Metacarpus (g)	38.9	40.8	S	39.5	40.2	NS	0.60	1.98	TSB	***
Rack											
	Total bone weight (kg)	0.209	0.205	NS	0.206	0.209	NS	0.72	0.008	TSB	***
Loin											
	Total bone weight (kg)	0.168	0.181	*	0.173	0.176	NS	0.67	0.012	TSB	***
Leg											
	Total bone weight (kg)	0.561	0.541	NS	0.561	0.542	NS	0.73	0.039	TSB	***
	Femur (g)	140.8	143.1	NS	140.6	143.4	NS	0.78	6.57	TSB	***
	Tibia and fibula (g)	114.9	111.6	NS	113.8	112.7	NS	0.68	5.51	TSB	***

For definitions of abbreviations see Table 4-1.

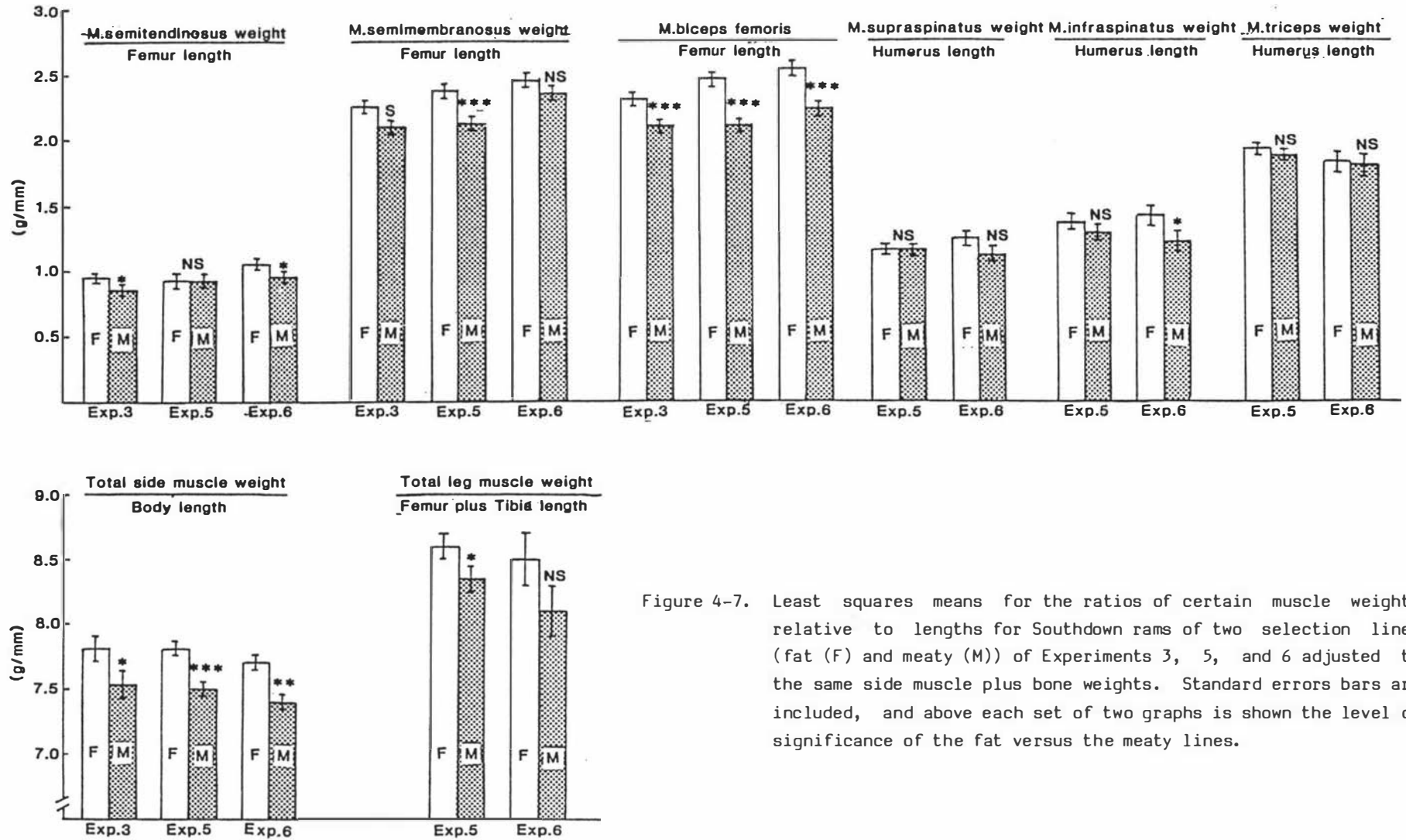


Figure 4-7. Least squares means for the ratios of certain muscle weights relative to lengths for Southdown rams of two selection lines (fat (F) and meaty (M)) of Experiments 3, 5, and 6 adjusted to the same side muscle plus bone weights. Standard errors bars are included, and above each set of two graphs is shown the level of significance of the fat versus the meaty lines.

differences between the two selected lines existed for the ratios of Mm. supraspinatus, infraspinatus, and triceps weights to humerus length, but these ratios were in favour of the fat line. The ratio of leg muscle weight to femur plus tibia length was also higher in the fat line with significant differences in Experiment 5 only.

4-1-10 ADIPOSE TISSUE CELLULARITY

4-1-10-1 Adipose Cell Diameter and Volume

Adipose cell diameters and volumes within the two selection lines for various fat depots of animals in Experiments 4, 5 and 6 are given in Figures 4-8, 4-9 and 4-10, respectively. Rams from the fat line had significantly larger fat cells than the meaty line for all the depots except the omental depot in Experiment 6. Consistent differences in adipose cell size between depots were shown in each selection line with the omental depot having the largest average cell size and the intermuscular depot having the smallest cell size (Figures 4-8 to 4-10).

4-1-10-2 Adipose Cell Number

Figures 4-8, 4-9 and 4-10 show the adipose tissue cell number in each depot studied in Experiments 4, 5 and 6 respectively. The absence of small cells in both lines suggested that hyperplasia was not taking place and that the various adipose tissues from the two lines of sheep were growing in mass solely by adipose cell hypertrophy. However, the only significant difference between the two lines in cell number was found in Experiment 5, where the fat rams had a significantly larger number of subcutaneous fat cells in the subcutaneous fat of the rack cut than the meaty line.

4-1-10-3 Diameter Distribution of Adipocytes

The results for Experiment 6, depicted in Figure 4-11 for five fat depots, show that the diameter values for adipocytes from the meaty and fat lines were normally distributed. Regardless of the anatomical site, the maximum diameter of adipocytes from the fat line was approximately 24 μm greater than for the meaty line (176 vs 152 μm).

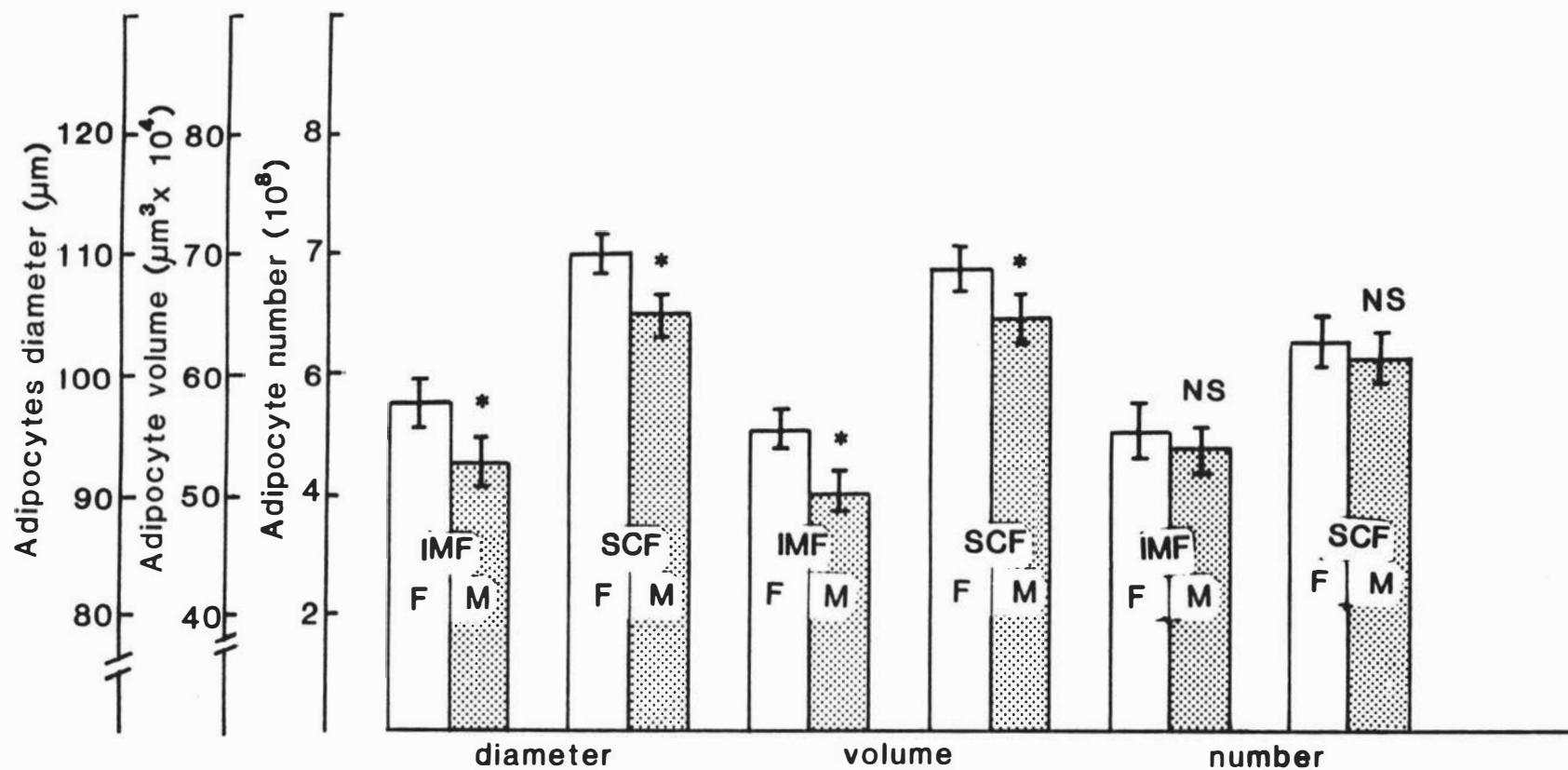


Figure 4.8. Least squares means for adipocyte diameter, volume, and number of two adipose tissue depots (intermuscular [IMF] and subcutaneous [SCF]) for Southdown rams of two selection lines (fat [F] and meaty [M]) of Experiment 4. Standard error bars are included, and above each set of two histograms is shown the level of significance of the fat versus the meaty lines.

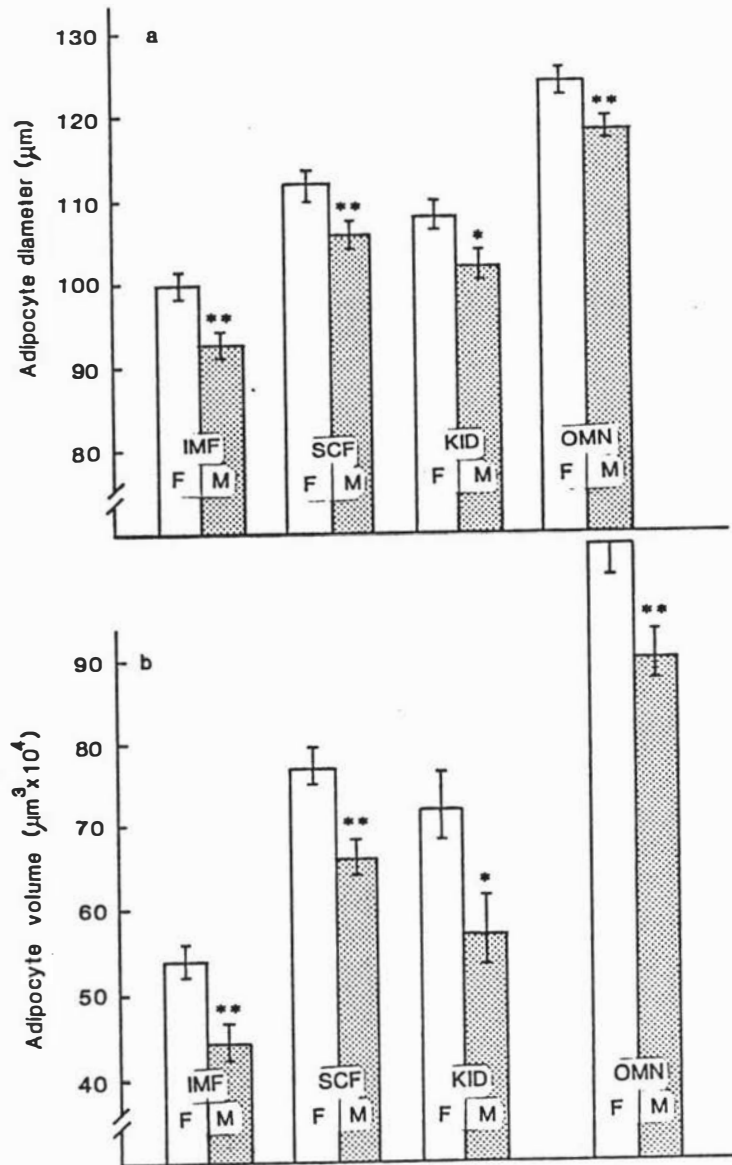


Figure 4-9. Least squares means for adipocyte diameter (a), volume (b) and number (c) for four adipose tissue depots (intermuscular [IMF], subcutaneous [SCF], kidney [KID], and omental [OMN]) for Southdown rams of two selection lines (fat [F] and meaty [M]) of Experiment 5. Standard error bars are included, and above each set of two histograms is shown the significance of the fat and the meaty lines.

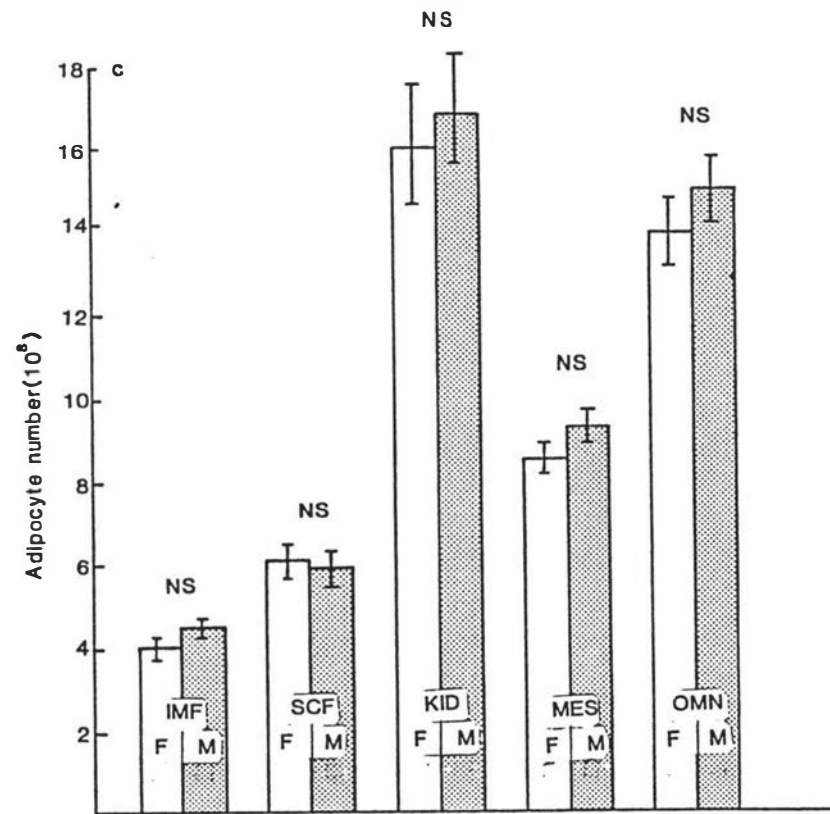
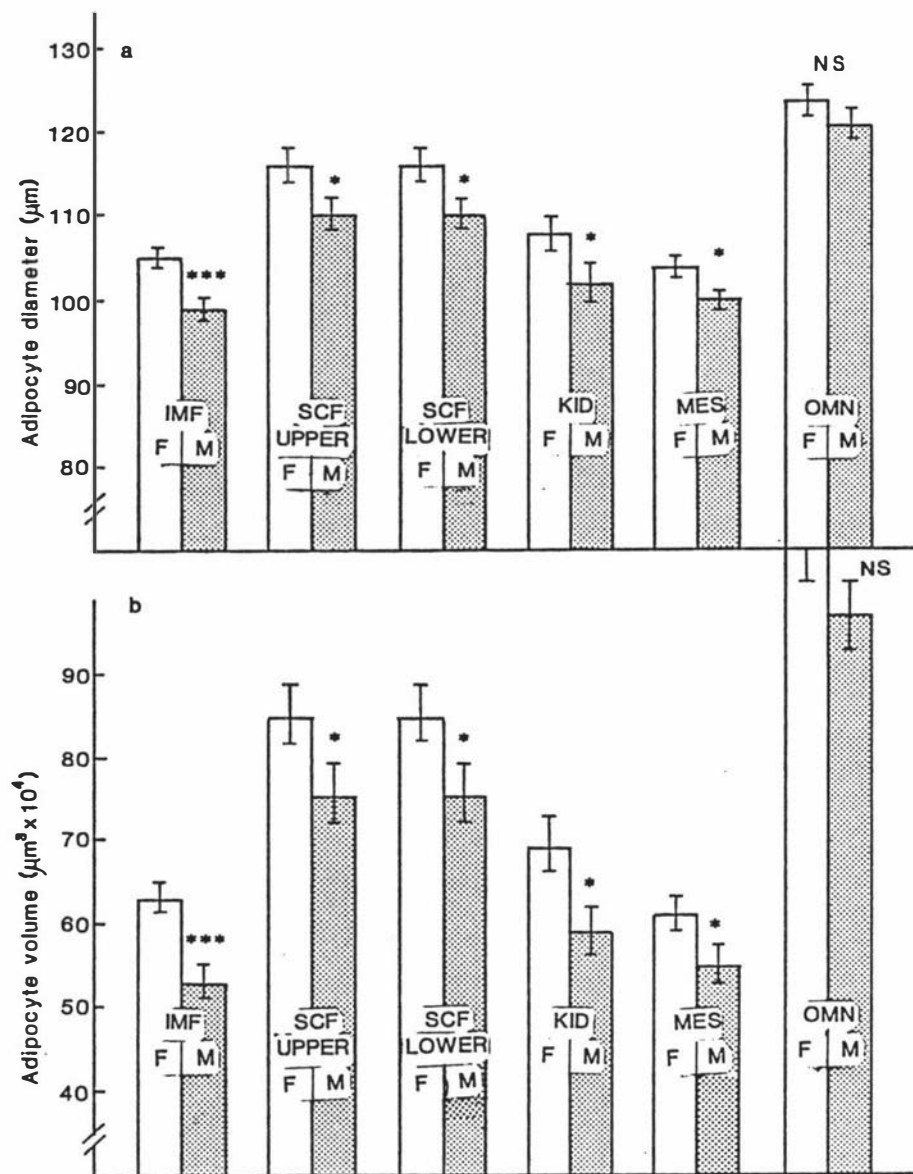


Figure 4-10. Least squares means for adipocyte diameter (a), volume (b) and number (c) of various adipose tissue depots (intermuscular [IMF], subcutaneous [SCF], kidney [KID], mesenteric [MES], and omental [OMN]) for Southdown rams of two selection lines (fat [F] and meaty [M]) of Experiment 6. Standard error bars are included, and above each pair of histograms is shown the significance of the fat and the meaty lines.

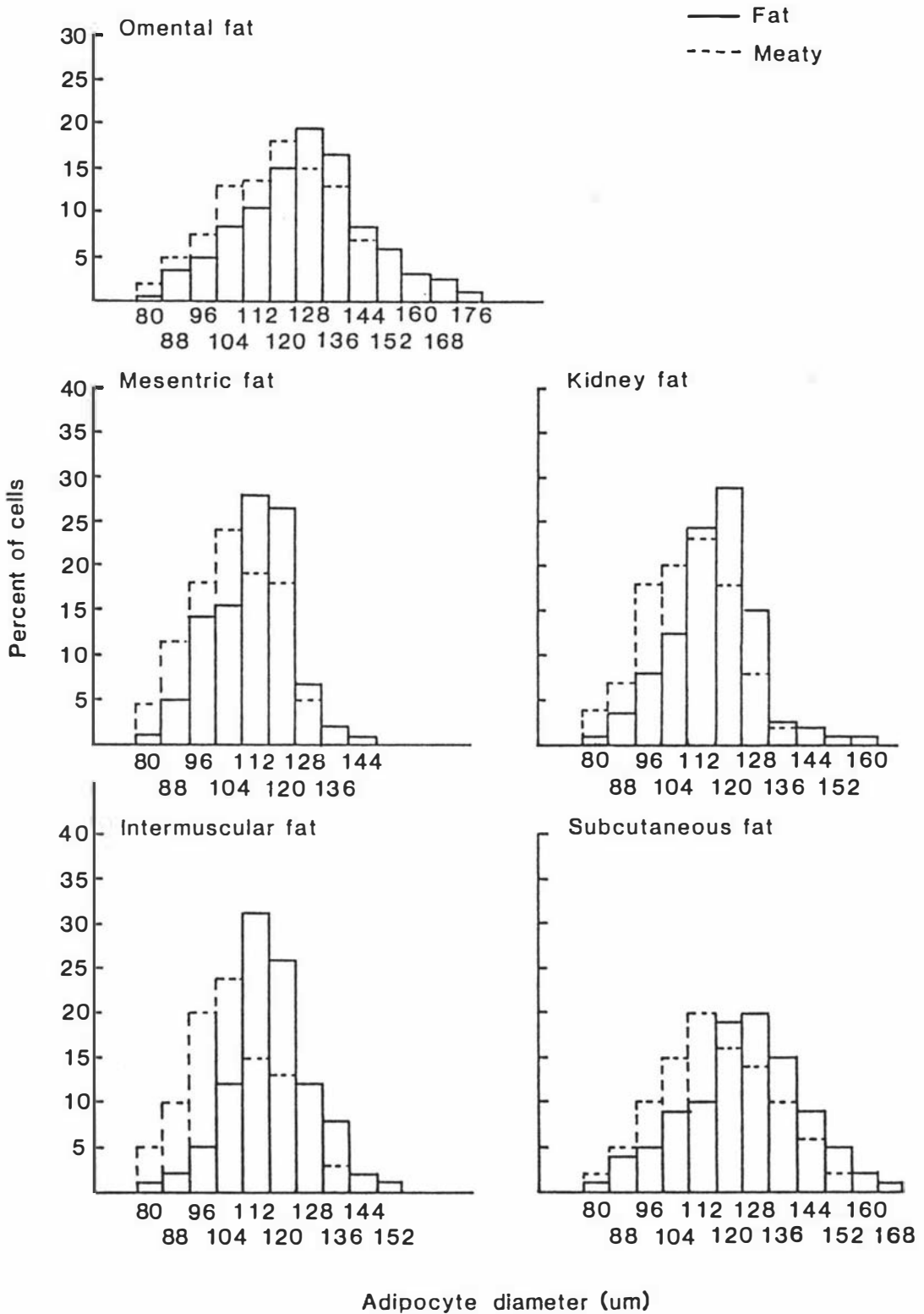


Figure 4-11. Adipocyte diameter distributions from fat and meaty Southdown rams in five fat depots. Each graph depicts the average number included in a range of $\pm 4 \mu\text{m}$ (e.g. 80 ± 4 in the first bar).

Table 4-32. Means and standard errors of correlation coefficients showing the closeness of the adipocyte diameter distribution to a normal distribution. Correlations were calculated for each animal with high values being consistent with normality.

Item	<u>Experiment 4</u>		<u>Experiment 5</u>		<u>Experiment 6</u>	
	<u>Selection line</u>		<u>Selection line</u>		<u>Selection line</u>	
	Fat	Meaty	Fat	Meaty	Fat	Meaty
No. of animals	10	8	12	12	12	12
SCF upper	0.98 \pm 0.01	0.99 \pm 0.01	0.99 \pm 0.02	0.99 \pm 0.02	0.99 \pm 0.01	0.99 \pm 0.01
SCF lower	-	-	-	-	0.99 \pm 0.01	0.99 \pm 0.01
IMF	0.99 \pm 0.01	0.99 \pm 0.01	0.99 \pm 0.01	0.99 \pm 0.01	0.99 \pm 0.01	0.99 \pm 0.01
Omental fat	-	-	0.99 \pm 0.02	0.99 \pm 0.02	0.99 \pm 0.01	0.99 \pm 0.01
Kidney fat	-	-	0.99 \pm 0.01	0.99 \pm 0.01	0.99 \pm 0.01	0.99 \pm 0.01
Mesenteric fat	-	-	-	-	0.99 \pm 0.02	0.99 \pm 0.01

For definitions of abbreviations see Table 4-1.

However, the normal diameter distributions were distinctly different between the fat and meaty rams for a given site and were offset to the right side for the fat rams. The probability plot correlation coefficient test for normality (Filliben, 1975) was used to confirm the above results. Table 4-32 shows the average probability plot correlation coefficients of adipocyte diameter for various fat depots of Experiments 4, 5 and 6. A very highly significant correlation for the meaty and fat lines is consistent with normality (Minitab, 1982).

4-2 REGRESSION EQUATIONS FOR PREDICTING CARCASS COMPOSITION FROM THE COMPOSITION OF THE RACK CUT

One of the objectives of this study was to evaluate the usefulness of sample cuts for the prediction of physical components of the side. A comparison of the four sample cuts (shoulder, rack, loin, and leg) as predictors for the side composition indicated that no cut afforded clear advantages in terms of correlation coefficients and residual standard deviations over the others. Therefore, the prediction equations for the rack cut (ribs 8 to 12) only have been presented in this study because it can be removed from the carcass with greater precision than most others (both sides dissected to eliminate splitting errors) and it is relatively easy to dissect. Three types of prediction equation with coefficients of determination and residual standard deviations are presented for each side component in Tables 4-33, 4-34 and 4-35 for Experiments 3, 5 and 6, respectively.

The percent composition of the side was considered as the dependent variable across three equations, while the independent variables were side weight and weights of rack components in the first equation and the second equation included the percents of rack components besides the side weight and only the percents of rack components in the third one. The first equation in each set generally showed more variation between the two selection lines for each of the components, and the coefficients of determination were lower than for the other two equations.

Comparisons between the second and the third equations showed that the improvement from including side weight did not increase the

Table 4-33. Regression equations relating rack cut composition to side composition for fat and meaty Southdown rams of Experiment 3.

Relationship studied			Regression equation	Significance Fat vs meaty	r ²	RSD
Y%	X ₁	X ₂				
Side muscle	Side wt.	Rack muscle wt.	$69.07 - 1.60X_1 + 17.99X_2$	***	0.60	1.58
	Side wt.	Rack muscle %	$51.11 - 0.64X_1 + 0.35X_2$	S	0.68	1.41
		Rack muscle %	$40.56 + 0.38X_1$	NS	0.64	1.48
Side fat	Side wt.	Rack fat wt.	$20.13 - 0.47X_1 + 25.86X_2$	*	0.83	1.42
	Side wt.	Rack fat %	$7.06 + 0.22X_1 + 0.45X_2$	**	0.90	1.12
		Rack fat %	$9.76 + 0.47X_1$	*	0.89	1.11
Side SCF	Side wt.	Rack SCF wt.	$6.93 + 0.04X_1 + 23.44X_2$	**	0.86	0.98
	Side wt.	Rack SCF %	$-0.68 + 0.50X_1 + 0.39X_2$	***	0.88	0.90
		Rack SCF %	$5.78 + 0.40X_1$	**	0.86	0.97
Side IMF	Side wt.	Rack IMF wt.	$12.78 - 0.42X_1 + 25.22X_2$	NS	0.54	0.83
	Side wt.	Rack IMF %	$8.60 - 0.18X_1 + 0.41X_2$	NS	0.61	0.76
		Rack IMF %	$6.47 + 0.38X_1$	NS	0.60	0.76
Side bone	Side wt.	Rack bone wt.	$12.39 - 0.27X_1 + 19.65X_2$	**	0.38	1.17
	Side wt.	Rack bone %	$4.81 + 0.11X_1 + 0.42X_2$	S	0.50	1.06
		Rack bone %	$6.56 + 0.40X_1$	S	0.49	1.05

For definitions of abbreviations see Table 4-1.

Table 4-34. Regression equations relating rack cut composition to side composition for fat and meaty Southdown rams of Experiment 5.

Relationship studied	Relationship studied		Regression equation	Significance Fat vs meaty	r ²	RSD
	Y%	X ₁				
Side muscle	Side wt.	Rack muscle wt.	$61.86 - 0.88X_1 + 9.81X_2$	***	0.78	1.65
	Side wt.	Rack muscle %	$38.24 - 0.06X_1 + 0.39X_2$	**	0.89	1.18
		Rack muscle %	$36.96 + 0.40X_1$	**	0.89	1.15
Side fat	Side wt.	Rack fat wt.	$26.10 - 0.63X_1 + 21.77X_2$	**	0.94	1.25
	Side wt.	Rack fat %	$5.44 + 0.248X_1 + 0.51X_2$	*	0.96	0.98
		Rack fat %	$7.44 + 0.55X_1$	*	0.96	1.00
Side SCF	Side wt.	Rack SCF wt.	$13.85 - 0.33X_1 + 21.04X_2$	***	0.95	0.85
	Side wt.	Rack SCF %	$3.06 + 0.26X_1 + 0.38X_2$	***	0.95	0.81
		Rack SCF %	$5.93 + 0.42X_1$	***	0.95	0.86
Side IMF	Side wt.	Rack IMF wt.	$12.17 - 0.28X_1 + 22.51X_2$	NS	0.68	0.89
	Side wt.	Rack IMF %	$4.48 + 0.11X_1 + 0.45X_2$	NS	0.68	0.88
		Rack IMF %	$5.62 + 0.48$	NS	0.68	0.87
Side bone	Side wt.	Rack bone wt.	$19.47 - 0.52X_1 + 11.47X_2$	***	0.80	0.66
	Side wt.	Rack bone %	$11.19 - 0.21X_1 + 0.42X_2$	NS	0.89	0.49
		Rack bone %	$6.77 + 0.50X_1$	NS	0.85	0.55

For definitions of abbreviations see Table 4-1.

Table 4-35. Regression equations relating rack cut composition to side composition for fat and meaty Southdown rams of Experiment 6.

Y%	Relationship studied		Regression equation	Significance Fat vs meaty	r ²	RSD
	X ₁	X ₂				
Side muscle	Side wt.	Rack muscle wt.	$61.13 - 1.22X_1 + 16.45X_2$	*	0.48	1.60
	Side wt.	Rack muscle %	$28.72 + 0.04X_1 + 56.11X_2$	NS	0.75	1.10
		Rack muscle %	$29.77 + 0.55X_1$	NS	0.75	1.08
Side fat	Side wt.	Rack fat wt.	$29.98 - 0.94X_1 + 26.19X_2$	NS	0.84	1.25
	Side wt.	Rack fat %	$8.81 - 0.08X_1 + 59.04X_2$	NS	0.88	1.08
		Rack fat %	$8.34 + 0.57X_1$	NS	0.88	1.06
Side SCF	Side wt.	Rack SCF wt.	$15.11 - 0.46X_1 + 25.36X_2$	S	0.88	0.82
	Side wt.	Rack SCF %	$2.16 + 0.26X_1 + 45.97X_2$	S	0.85	0.93
		Rack SCF %	$4.16 + 0.53X_1$	NS	0.83	0.95
Side IMF	Side wt.	Rack IMF wt.	$13.85 - 0.35X_1 + 22.99X_2$	NS	0.40	0.99
	Side wt.	Rack IMF %	$7.87 - 0.07X_1 + 47.46X_2$	NS	0.46	0.95
		Rack IMF %	$7.27 + 0.44X_1$	NS	0.45	0.93
Side bone	Side wt.	Rack bone wt.	$11.80 - 0.66X_1 + 50.93X_2$	**	0.78	0.54
	Side wt.	Rack bone %	$5.25 - 0.04X_1 + 55.04X_2$	S	0.83	0.48
		Rack bone %	$4.38 + 0.57X_1$	S	0.83	0.47

For definitions of abbreviations see Table 4-1.

coefficients of determination across all experiments and all components by more than 0.04 as a maximum. Therefore, the third equation in each set was used as a prediction equation because it offered ease and simplicity in collection and calculation of the data. When calculating the equations given in Table 4-33, data for the two selection lines were pooled because no significant differences in slope were found between the two selection lines. However, there were significant line effects on the intercepts in some cases and for these separate lines are given in Figures 4-12, 4-13 and 4-14 for percent of muscle, fat, subcutaneous fat, intermuscular fat, and bone in Experiments 3, 5 and 6, respectively. The data from Experiment 3 revealed that at the same fat percent in the rack the meaty line side had significantly lower actual side fat percent than did the fat line, so in this case, the use of the common line to predict the percent of fat of the two selection lines would have caused an over-estimate for the meaty line and an under-estimate for the fat line. However, this situation (over- and under-estimates) will be reduced by using the total regression line. Similar trends occurred in the case of subcutaneous and intermuscular fat depots (Figure 4-12).

Figure 4-13 also provides an illustration of extreme prediction bias in Experiment 5. If the common regression lines were used to estimate the average muscle, fat, subcutaneous fat, and intermuscular fat percents of the two selection lines, they would result in an over-estimate for muscle and under-estimate for fat in the fat line and the opposite in the case of the meaty line. In the case of Experiment 5, there may be an advantage by using the total regression equations computed from all the data in order to decrease the bias arising from the common regression. For Experiment 6, there were no selection line differences for any predicted percent components. The inclusion of a quadratic component in the prediction equations did not decrease the significance of the line effects, and, in all cases, the line effect on slope was not significant. These results indicated that, because the carcasses differed significantly in their components between the two selections lines, particularly in fat percent, use of a common regression equation was not always an accurate method for predicting the side composition of the two selection lines.

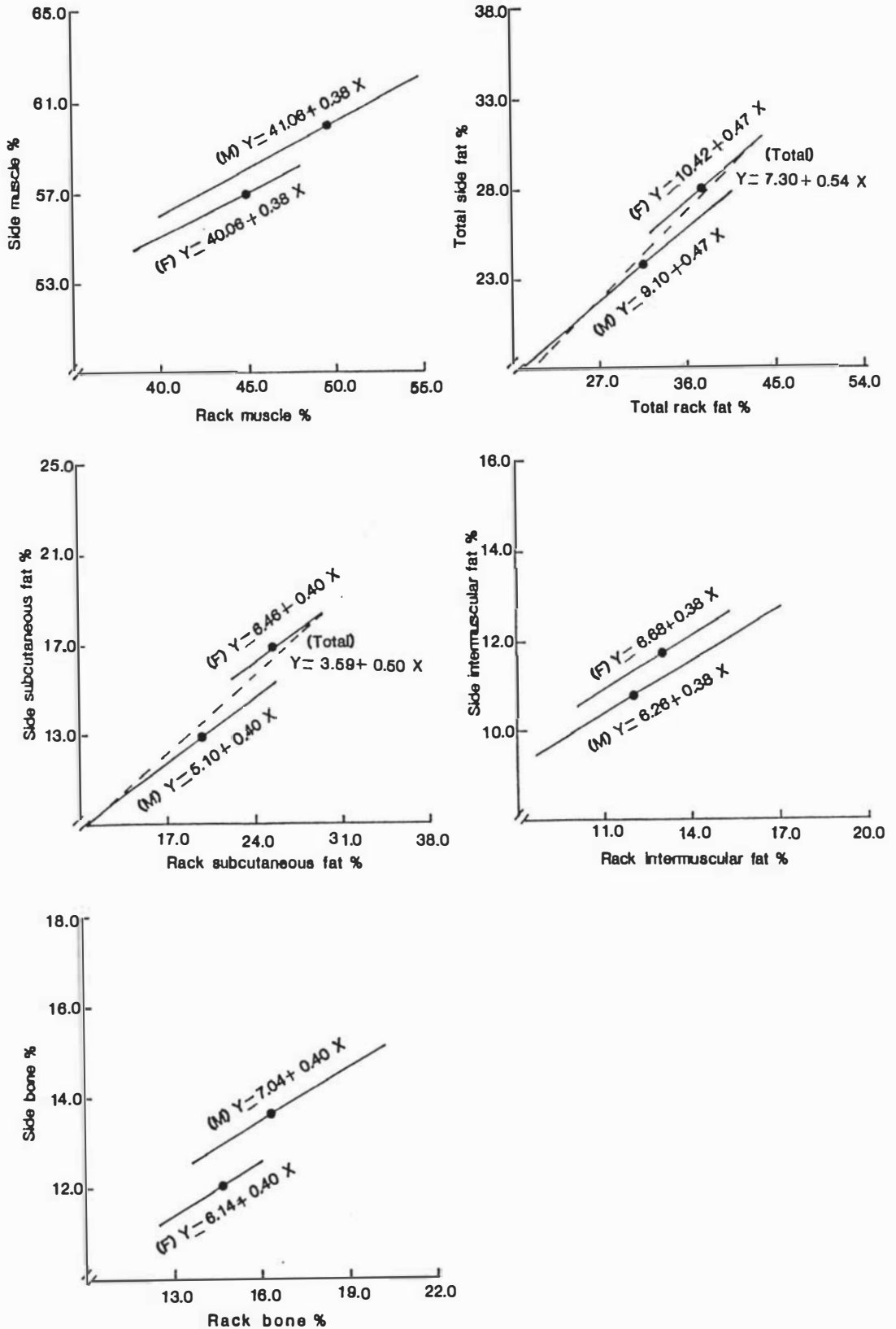


Figure 4-12. Regression lines relating percent of rack cut composition to side composition for fat (F) and meaty (M) Southdown rams of Experiment 3. Regression lines are shown over the appropriate range for the fat and meaty lines with the line means shown as dots. When there was a significant line effect on the relationship, the total regression equation is also shown as a dashed line.

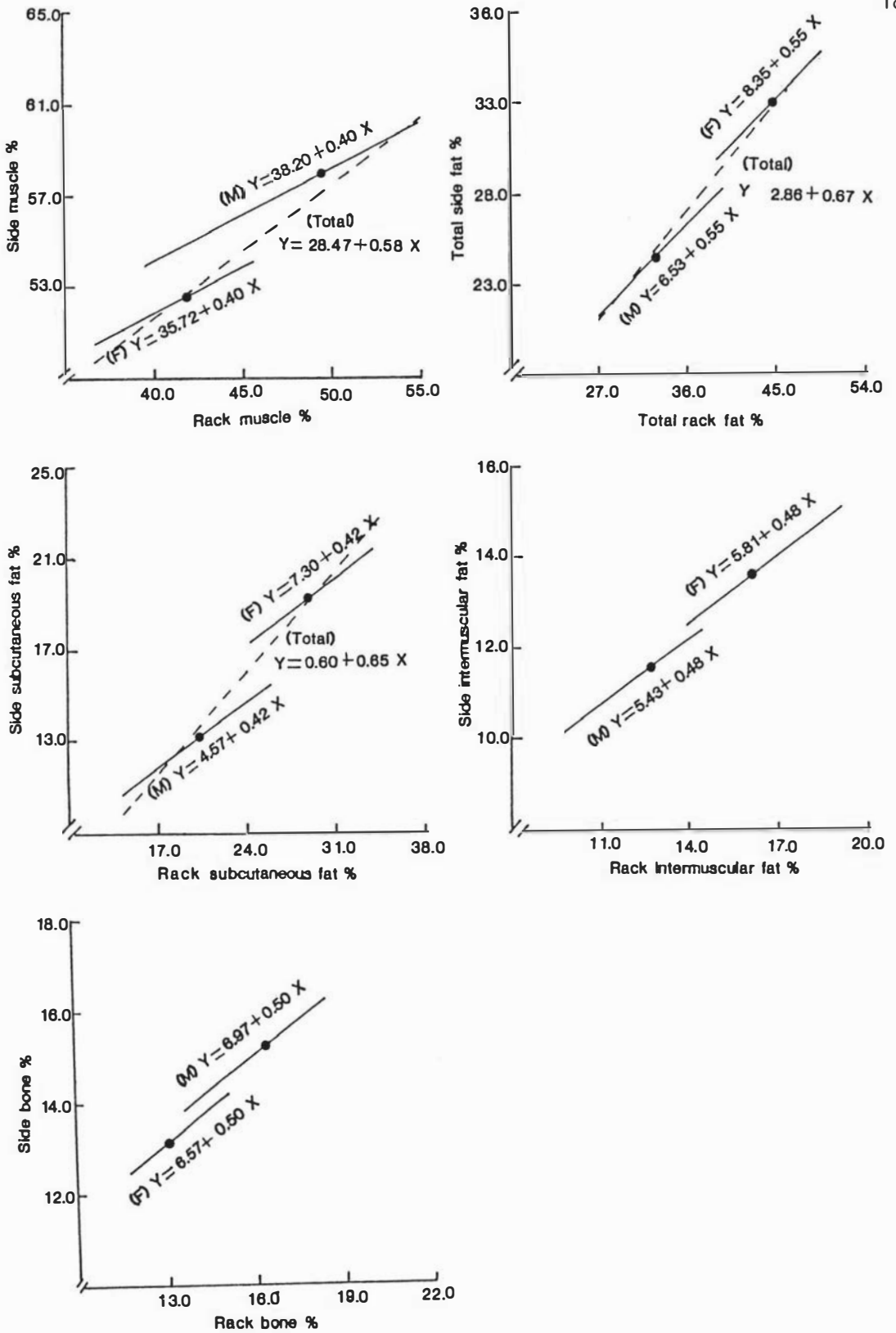


Figure 4-13. Regression lines relating percent of rack cut composition to side composition for fat (F) and meaty (M) Southdown rams of Experiment 5. Regression lines are shown over the appropriate range for the fat and meaty lines with the line means shown as dots. When there was a significant line effect on the relationship, the total regression equation is also shown as a dashed line.

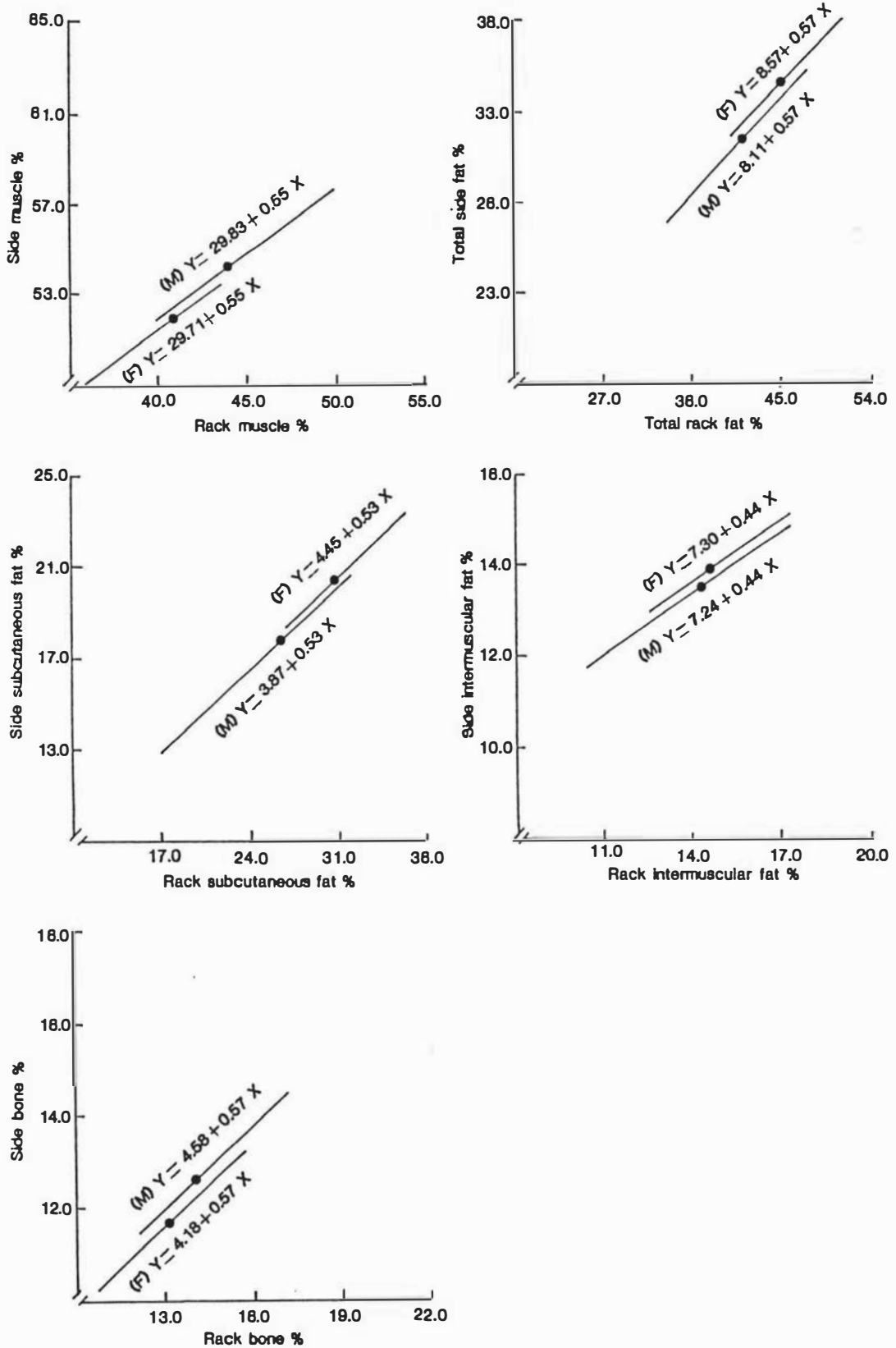


Figure 4-14. Regression lines relating percent of rack cut composition to side composition for fat (F) and meaty (M) Southdown rams of Experiment 6. Regression lines are shown over the appropriate range for the fat and meaty lines with the line means shown as dots.

4-3 EFFECTS OF SELECTION LINE AND POSTMORTEM TREATMENTS ON MUSCLE CHARACTERISTICS

4-3-1 PHYSICAL RESPONSE TO ELECTRICAL STIMULATION

As soon as the current was applied the carcasses contracted tetanically with flexion of the fore limbs, contraction of the rib cage, contraction of the thigh muscle mass and arching of the back which raised the neck region about 15 cm from its resting position (Figure 3-1). Within 30 sec fatigue was evidenced by slow sagging of the fore limbs, but at the end of 90 sec stimulation, the muscles were still partly contracted and when the current was turned off, the carcasses relaxed further to assume their original posture. The carcasses from the meaty line appeared to respond to electrical stimulation more than those from the fat line. This difference may have been because the carcasses from the meaty line were lighter in weight and had proportionately more muscle than the fat line.

4-3-2 MUSCLE TEMPERATURE

Because the measurement of the internal temperatures of M. longissimus was not always at the same time postmortem, quadratic regression equations (Snedecor and Cochran, 1980) were derived for the temperature/time relationship for each muscle, so that predicted temperatures at 2 h intervals could be calculated. These are shown in Figures 4-15 and 4-16 for Experiments 5 and 6, respectively. For the quadratic regression equations the range of coefficients of determination was from 0.98 to 1.00 with an average of 0.99 and for residual standard deviation the range was from 0.25 to 2.41 with an average of 1.31 (Experiment 5). In Experiment 6, the range was from 0.97 to 1.00 with an average of 0.99 for the coefficient of determination and from 0.15 to 2.39 with an average of 1.29 for the residual standard deviation. Muscles in the untrimmed treatment group had higher mean internal temperatures in the M. longissimus than did the trimmed group after 2, 4, 6, 8 and 10 h of chilling postmortem, but the differences were significant ($P < 0.05$) only for 4, 6 and 8 h postmortem. This indicated that untrimmed sides showed a slower decline of temperature for the first 8 h postmortem, resulting in a maximum temperature difference of 2°C between trimmed and untrimmed sides for both experi-

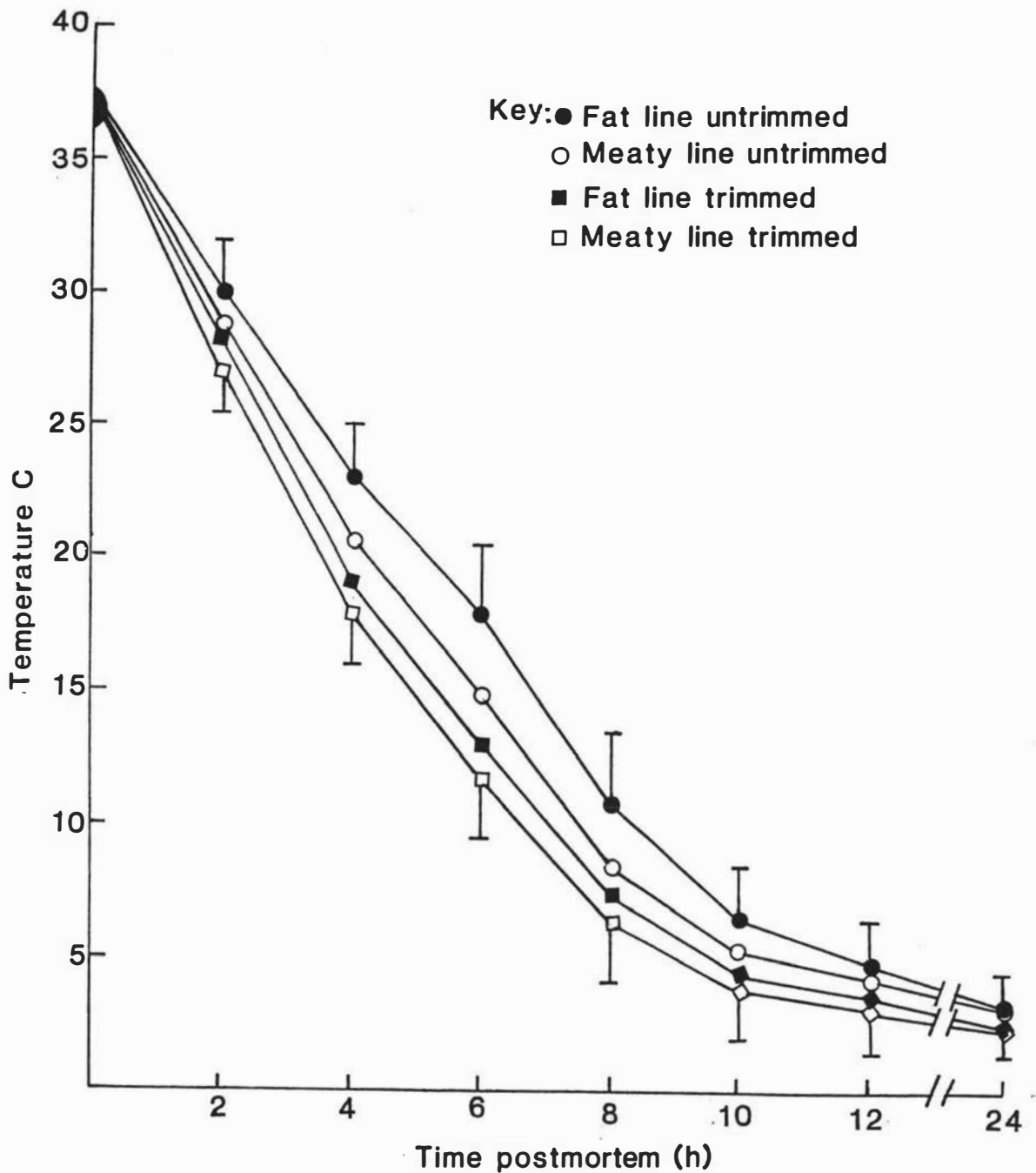


Figure 4-15. Postmortem temperature declines within *M. longissimus* for the side with subcutaneous fat removed (trimmed) and for the side with subcutaneous fat left on (untrimmed). Results are shown for Southdown rams from the fat and the meaty lines of Experiment 5.

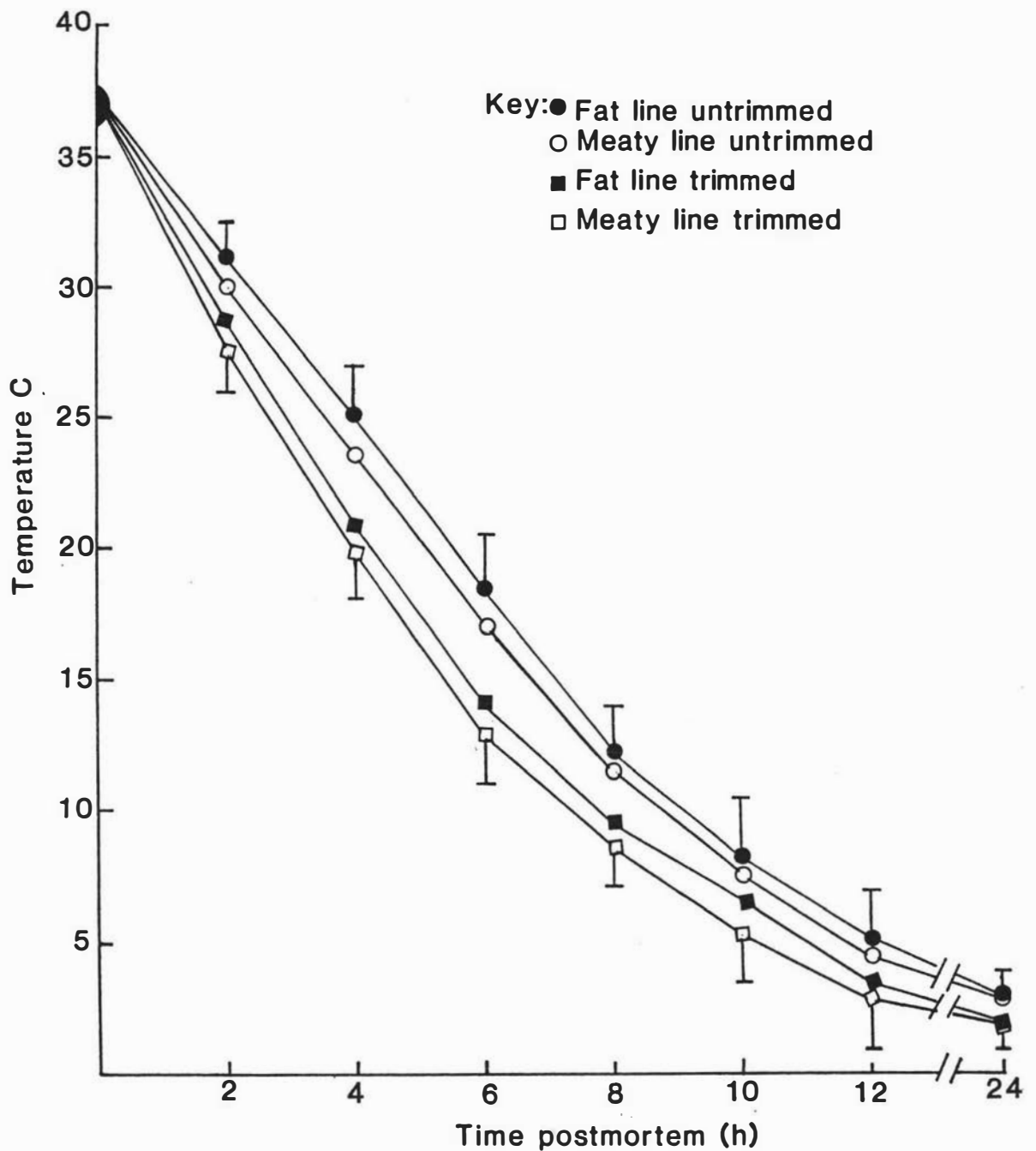


Figure 4-16. Postmortem temperature declines within *M. longissimus* for the side with subcutaneous fat removed (trimmed) and for the side with subcutaneous fat left on (untrimmed). Results are shown for Southdown rams from the fat and the meaty lines of Experiment 6.

ments. The temperature difference, although its magnitude was decreasing, was maintained up to 24 h postmortem. Temperatures varied to some extent within the groups between fat and meaty lines, particularly at 4 and 8 h postmortem. However, the differences were not statistically significant. Electrical stimulation had no significant effects on muscle temperature.

4-3-3 ULTIMATE pH VALUES

4-3-3-1 Southdown X Romney Lambs (Experiments 1 and 2)

Tables 4-36 and 4-37 present data on ultimate pH of different muscles from four sires (two sires within fat and meaty lines), four pastures, and two sexes. Although the ultimate pH values for the four muscles varied to some extent between the two sire groups within each line, the differences were not significant. In spite of this variability within line, there were no significant differences in the ultimate pH between the two lines, but the meaty line had slightly higher pH values than the fat line for each muscle. The interactions between the main factors were omitted from the Tables because none was significant. Paired t-tests were used to assess the differences between muscles within each experiment. In both experiments, the M. biceps femoris had significantly ($P < 0.05$) higher pH values than M. semimembranosus (Table 4-36; Experiment 1 and Table 4-37; Experiment 2).

4-3-3-2 Southdown Rams (Experiments 4, 5 and 6)

Ultimate pH measurements were made on unstimulated muscles from the two lines in Experiment 4 (Table 4-38) and on stimulated and unstimulated muscles from the two lines in Experiments 5 (Table 4-39) and 6 (Table 4-40) at 24 h postmortem. Again the ultimate pH values varied to some extent between the two lines and between electrically stimulated and unstimulated carcasses, but these differences were not significant.

The data for ultimate pH values of the different muscles and different postmortem treatments in Experiments 4, 5 and 6 are given in Tables 4-38, 4-39 and 4-40, respectively. These tables indicate that

Table 4-36. Least squares means of shear force values, percent cooking losses, and pH values for four muscles from two selection lines (fat and meaty) within four pastures and two sexes of Southdown X Romney cross lambs in Experiment 1.

Item	Overall mean	Selection line				Significance	Pasture				Significance	Sex		Significance	r ²	RSD	
		Fat	Fat	Meaty	Meaty		White clover	Lucerne	Lotus	Perennial rye grass		Methers	Ewe				
		Sire 1	Sire 2	Sire 3	Sire 4												
No. of animals	64	18	14	16	16		16	16	16	16		31	33				
Shear force value:																	
<u>M. biceps femoris</u>	3.15 ^a	3.10	3.05	3.13	3.30	S	3.28	3.00	3.00	3.37	NS	3.10	3.19	NS	0.42	0.53	
<u>M. semimembranosus</u>	4.80 ^b	4.85	4.44	4.70	5.20	S	4.94	4.83	4.84	4.59	S	4.44	5.15	NS	0.48	0.97	
<u>M. semitendinosus</u>	3.14 ^a	3.12	2.88	3.26	3.29	NS	3.02	3.25	3.24	3.06	S	3.10	3.17	NS	0.51	0.39	
<u>M. lonoissimus</u>	2.63 ^c	2.58	2.52	2.66	2.74	S	2.68	3.00	2.39	2.47	S	2.52	2.72	NS	0.54	0.52	
Percent cooking loss:																	
<u>M. biceps femoris</u>	30.6 ^a	31.0	30.9	30.3	30.3	NS	28.7	28.5	29.6	29.8	NS	29.1	29.2	NS	0.53	1.94	
<u>M. semimembranosus</u>	31.2 ^b	31.8	30.9	30.5	31.5	NS	29.6	29.7	29.5	31.3	NS	29.8	30.3	NS	0.56	1.98	
<u>M. semitendinosus</u>	31.6 ^b	31.8	31.9	31.0	31.6	NS	30.3	31.0	31.2	30.8	NS	30.9	30.7	S	0.53	1.40	
<u>M. lonoissimus</u>	25.0 ^c	24.0	23.8	25.7	26.6	NS	26.6	23.8	25.1	25.6	NS	25.2	24.8	**	0.50	2.39	
pH value:																	
<u>M. biceps femoris</u>	5.68 ^a	5.68	5.65	5.67	5.70	NS	5.67	5.63	5.68	5.60	S	5.67	5.68	NS	0.57	0.08	
<u>M. semimembranosus</u>	5.64 ^b	5.64	5.62	5.64	5.66	NS	5.64	5.58	5.64	5.65	NS	5.63	5.65	NS	0.53	0.09	
<u>M. semitendinosus</u>	5.67 ^a	5.68	5.62	5.67	5.69	NS	5.70	5.65	5.68	5.68	NS	5.82	5.83	NS	0.61	0.11	
<u>M. lonoissimus</u>	5.68 ^a	5.65	5.66	5.69	5.71	NS	5.66	5.66	5.66	5.70	NS	5.67	5.69	NS	0.33	0.09	

For definitions of abbreviations see Table 4-1.

a, b, c Overall means for a particular characteristic which do not have a common superscript differ significantly (P<0.05).

Table 4-37. Least squares means of shear force values, percent cooking losses and pH values for two muscles from two selection lines (fat and meaty) within four pastures and two sexes of Southdown X Romney cross lambs in Experiment 2.

Item	Overall mean	Selection line				Significance	Pasture				Significance	Sex		Significance	r ²	RSD
		Fat		Meaty			White clover	Lucerne	Lotus	Perennial rye grass		Wether	Ewe			
		Sire 1	Sire 2	Sire 3	Sire 4											
No. of animals	64	16	16	16	16		16	16	16	16		31	33			
<u>Shear force value:</u>																
<u>M. biceps femoris</u>	4.23 ^a	4.13	4.20	4.18	4.42	NS	4.22	4.13	4.34	3.72	NS	4.08	3.99	NS	0.41	0.83
<u>M. semimembranosus</u>	6.38 ^b	5.86	6.56	6.71	6.40	NS	6.90	6.94	5.83	6.16	NS	6.38	6.49	NS	0.53	1.27
<u>Percent cooking loss:</u>																
<u>M. biceps femoris</u>	30.27 ^a	29.27	30.78	30.37	30.66	NS	29.96	29.88	29.71	31.53	NS	30.05	30.49	NS	0.43	2.04
<u>M. semimembranosus</u>	31.90 ^b	31.35	32.18	32.14	31.92	NS	31.13	31.73	32.11	32.61	NS	31.94	31.76	NS	0.30	1.75
<u>pH value:</u>																
<u>M. biceps femoris</u>	5.66 ^a	5.64	5.68	5.67	5.65	NS	5.65	5.66	5.62	5.68	NS	5.66	5.65	NS	0.57	0.07
<u>M. semimembranosus</u>	5.62 ^b	5.60	5.62	5.61	5.63	NS	5.60	5.63	5.57	5.61	NS	5.62	5.59	NS	0.51	0.07

For definitions of abbreviations see Table 4-1.

a, b Overall means for a particular characteristic which do not have a common superscript differ significantly (P<0.05).

Table 4-38. Least squares means of shear-force values, expressed juice *, percent cooking losses, and pH values for four muscles from the two selection lines (fat and meaty) of Southdown rams of Experiment 4.

Item	Overall mean	Selection line (L)		Significance	
		Fat (F)	Meaty (M)	F vs M	RSD
No. of animals	18	10	8		
<u>Shear force value (kg):</u>					
<u>M. semitendinosus</u>	3.79 ^a	3.74	3.83	NS	0.56
<u>M. biceps femoris</u>	3.89 ^a	3.80	3.98	NS	0.62
<u>M. semimembranosus</u>	5.10 ^b	5.03	5.15	NS	0.70
<u>M. longissimus</u>	3.39 ^c	3.26	3.52	NS	0.51
<u>Expressed juice:</u>					
<u>M. biceps femoris</u>	31.65 ^a	31.76	31.53	NS	1.32
<u>M. semimembranosus</u>	31.18 ^b	31.36	31.00	NS	1.28
<u>M. longissimus</u>	31.25 ^b	31.45	31.05	NS	2.81
<u>Percent cooking loss:</u>					
<u>M. semitendinosus</u>	30.51 ^a	30.68	30.34	NS	1.82
<u>M. biceps femoris</u>	30.25 ^{ab}	30.26	30.24	NS	1.75
<u>M. semimembranosus</u>	30.70 ^{ac}	30.84	30.55	NS	1.82
<u>M. longissimus</u>	26.29 ^e	26.60	25.97	NS	2.62
<u>pH values:</u>					
<u>M. semitendinosus</u>	5.69 ^a	5.68	5.70	NS	0.06
<u>M. biceps femoris</u>	5.68 ^a	5.67	5.68	NS	0.07
<u>M. semimembranosus</u>	5.65 ^a	5.64	5.66	NS	0.06
<u>M. longissimus</u>	5.60 ^b	5.59	5.60	NS	0.04

* Expressed juice = water area (cm²)/sample weight (g).

For definitions of abbreviations see Table 4-1.

a, b, c Overall means for a particular characteristic which do not have a common superscript differ significantly (P<0.05)

Table 4-39. The effect of post-mortem treatment on pH values for four muscles from two selection lines (fat and meaty) of Southdown rams of Experiment 5. Half of the carcasses were electrically stimulated (least squares means).

Item	Overall mean	Selection Line (L)				Significance			
		Fat (F)		Meaty (M)		F vs M	C vs ES	L vs	
		Unstimulated (C)	Electrically stimulated (ES)	Unstimulated (C)	Electrically stimulated (ES)			Treatment	RSD
No. of animals	24	6	6	6	6				
M. biceps femoris:									
24 h on ice	5.72 ^a	5.69	5.71	5.72	5.74	NS	NS	NS	0.05
24 h ambient temperature	5.63 ^b	5.61	5.63	5.63	5.64	NS	NS	NS	0.05
Difference (ice-ambient)		0.08	0.08	0.09	0.10	NS	NS	NS	0.05
M. semimembranosus:									
1 d ageing	5.63 ^b	5.61	5.63	5.62	5.64	NS	NS	NS	0.06
15 d ageing	5.61 ^b	5.60	5.62	5.60	5.62	NS	NS	NS	0.05
Difference (1 d - 15 d)		0.01	0.01	0.02	0.02	NS	NS	NS	0.01
M. longissimus (from loin cut):									
Trimmed fat	5.65 ^b	5.59	5.66	5.66	5.69	NS	NS	NS	0.09
Untrimmed fat	5.63 ^b	5.57	5.64	5.65	5.66	NS	NS	NS	0.10
Difference (trimmed-untrimmed)		0.03	0.02	0.01	0.03	NS	NS	NS	0.04
M. longissimus (from rack cut):									
Untrimmed fat	5.58 ^c	5.55	5.59	5.56	5.60	NS	NS	NS	0.07
Difference (loin-rack)		0.02	0.05	0.09	0.06	NS	NS	NS	0.11
M. semitendinosus:									
	5.64 ^b	5.60	5.68	5.63	5.65	NS	NS	NS	0.08

For definitions of abbreviations see Table 4-1.

a, b, c Overall means in the same column with no common superscripts differ (P<0.05).

Table 4-40. The effect of post-mortem treatment on pH values for four muscles from two selection lines (fat and meaty) of Southdown rams of Experiment 6. Half of the carcasses were electrically stimulated (least square means).

Item	Overall mean	Selection Line (L)				Significance			
		Fat (F)		Meaty (M)		F vs M	C vs ES	L vs Treatment	RSD
		Unstimulated (C)	Electrically stimulated (ES)	Unstimulated (C)	Electrically stimulated (ES)				
No. of animals	12	6	6	6	6				
<u>M. biceps femoris:</u>									
24 h on ice	5.69 ^a	5.72	5.67	5.65	5.72	NS	NS	NS	0.10
24 h ambient temperature	5.53 ^b	5.52	5.53	5.51	5.55	NS	NS	NS	0.06
Difference (ice-ambient)		0.19	0.14	0.14	0.17	NS	NS	NS	0.11
<u>M. semimembranosus:</u>									
1 d ageing	5.57 ^b	5.51	5.54	5.61	5.65	NS	NS	NS	0.63
<u>M. longissimus:</u>									
Trimmed fat (loin)	5.57 ^b	5.54	5.58	5.60	5.61	NS	NS	NS	0.07
Untrimmed fat (loin)	5.57 ^b	5.51	5.55	5.58	5.58	NS	NS	NS	0.07
Difference (trimmed-untrimmed)		0.03	0.03	0.02	0.03	NS	NS	NS	0.02
<u>M. semitendinosus:</u>									
	5.60 ^b	5.60	5.55	5.61	5.58	NS	NS	NS	0.09

For definitions of abbreviations see Table 4-1.

a, b Overall means in the same column with common superscripts differ ($P < 0.05$)

the ultimate pH was not affected by ageing or by the trimming of the subcutaneous fat from the loin region, but was affected by cold shortening.

It appears from the present studies that the thickness of the fat or electrical stimulation were not important factors determining the ultimate pH values.

4-3-4 RATE OF POST-MORTEM GLYCOLYSIS

Initial pH measurements were made on M. semitendinosus from the two selection lines commencing between 60 and 70 min post-mortem in Experiments 5 and 6. The initial pH values varied slightly within lines, but were not significantly different. These variations possibly reflect the degree of struggling at the time of death.

The pH values at specific times postmortem were predicted by using quadratic regression equations (Snedecor and Cochran, 1980) relating pH to time for each muscle. The range of coefficients of determination and residual standard deviation for these relationships were from 0.93 to 1.00 with an average of 0.97 for the former and from 0.01 to 0.11 with an average of 0.04 for the latter in Experiment 5. In the same sequence for Experiment 6 they were from 0.96 to 1.00 with an average of 0.96 and from 0.02 to 0.17 with an average of 0.07. In both experiments the pH fell at almost a constant rate for 4 h or more. The rate of fall of pH at early stages in the stimulated muscles was significantly greater than in the unstimulated muscles in both experiments, but there were no significant differences between the two lines.

Figures 4-17 and 4-18 show pH values at various times postmortem for the fat and meaty lines and for electrically stimulated and unstimulated carcasses with 12 ram carcasses in each group. The pH values (from 1 h through 24 h postmortem) were consistently higher for the meaty line group than for the fat line, but the differences were not significant.

When comparing the pH decline between electrically stimulated and unstimulated muscles within each line, it is evident that the pH

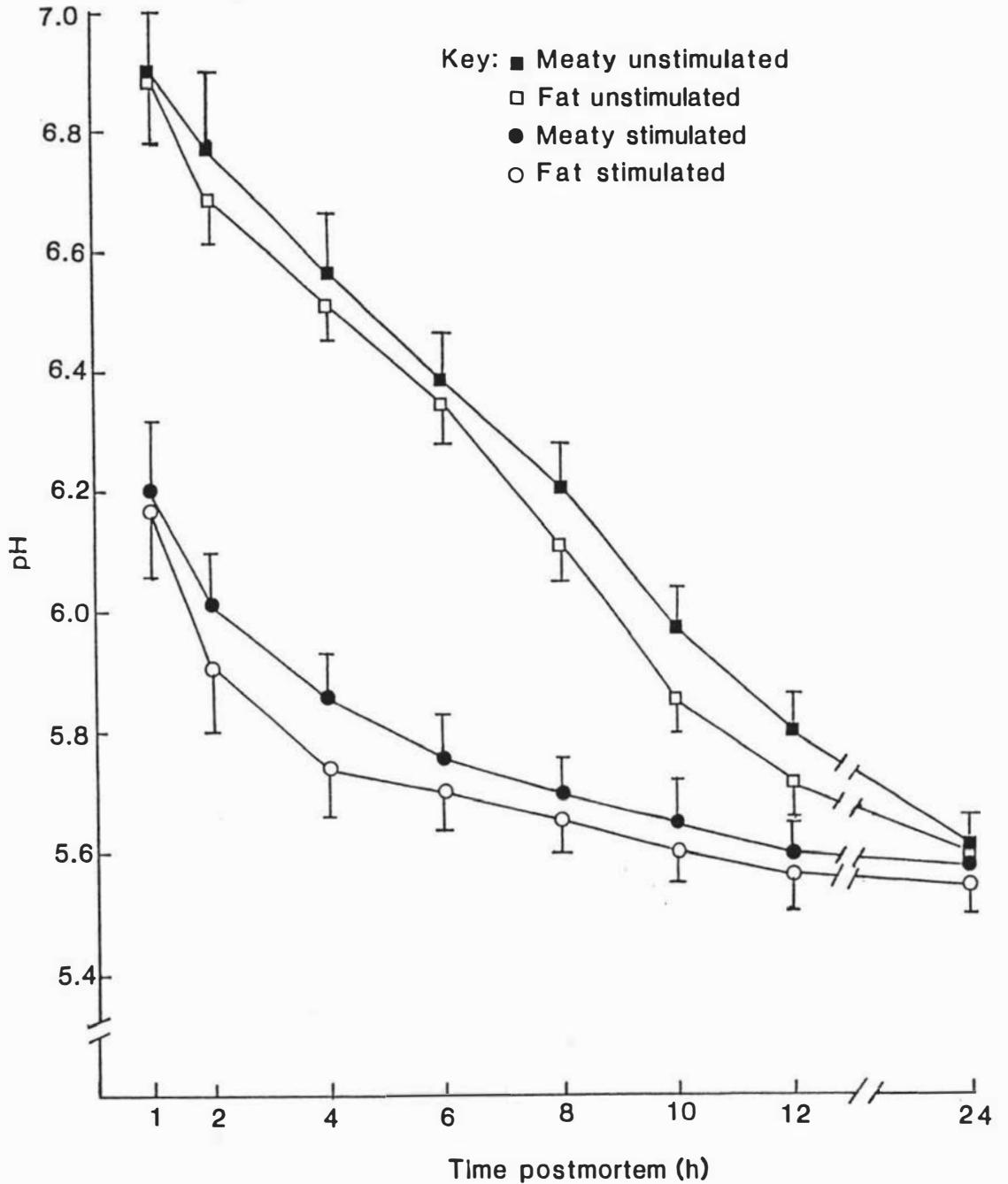


Figure 4-17. Least squares means and standard errors for pH of M. semitendinosus of Southdown rams for electrically stimulated and unstimulated groups and two selection lines (fat and meaty; Experiment 5).

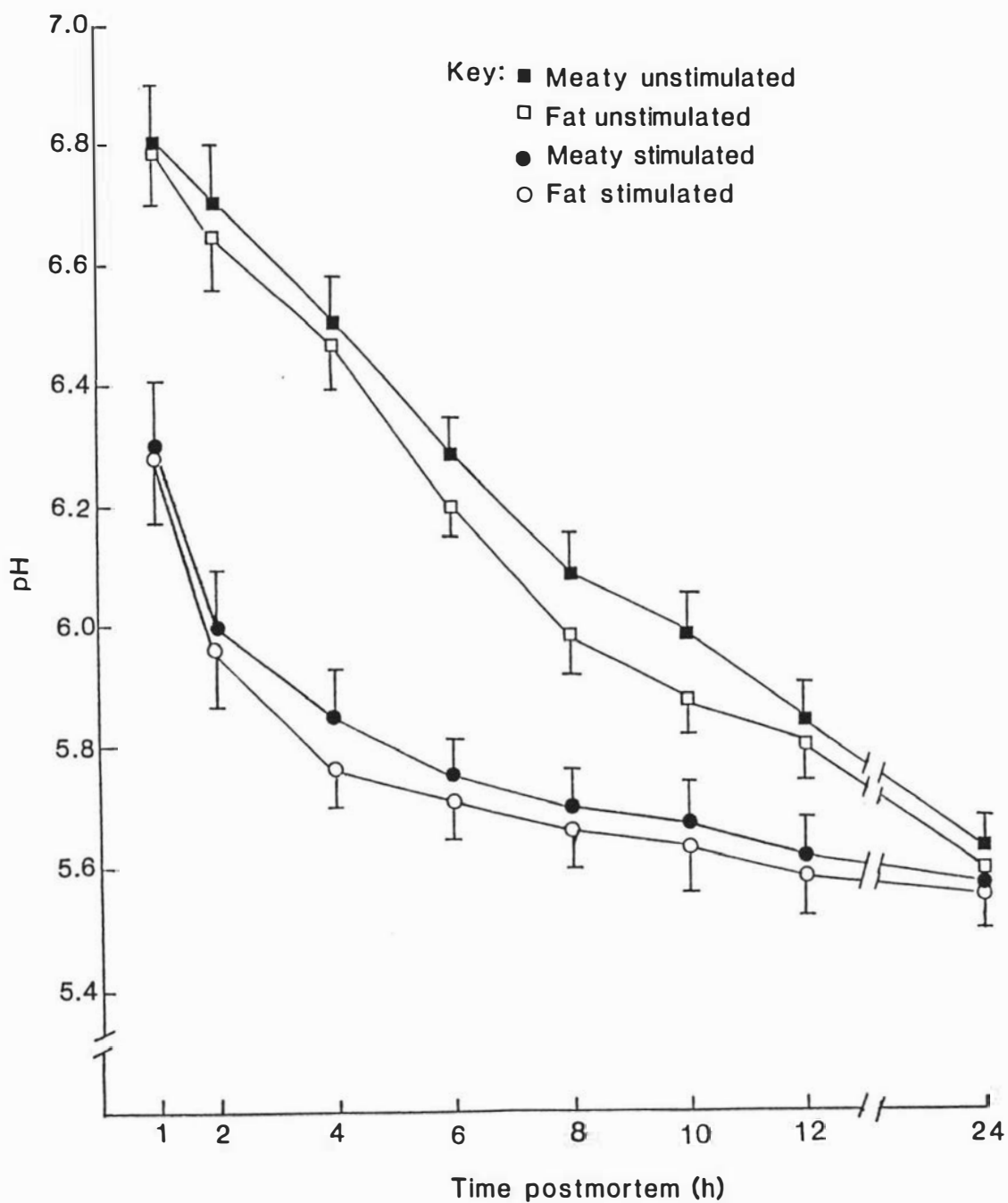


Figure 4-18. Least squares means and standard errors for pH of M. semitendinosus of Southdown rams for electrically stimulated and unstimulated groups and two selection lines (fat and meaty; Experiment 6).

declined significantly ($P < 0.01$) faster for the electrically stimulated carcasses particularly during the first 4 h postmortem. The differences between the pH of electrically stimulated and unstimulated carcasses from 4 to 12 h postmortem were also significant ($P < 0.05$).

4-3-5 MUSCLE FIBRE TYPE AND NUMBER

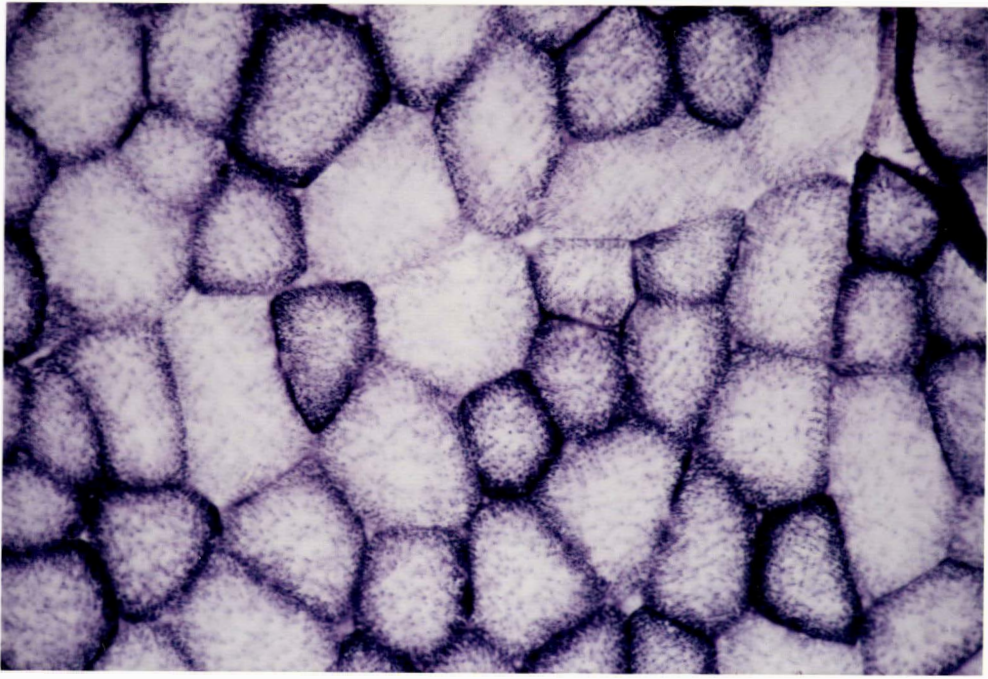
4-3-5-1 Histological Evaluation

Muscle fibres in sections prepared to measure succinic dehydrogenase (SDH) activity were classified as (β R) red fibres, (α R) intermediate fibres and (α W) white fibres (Ashmore et al., 1972) as shown in Figure 4-19. The red fibres were all intensely stained and located mostly in clusters within a muscle fascicle. They showed heavy diffuse deposition of diformazan granula. The intermediate stained fibres (α R) were mostly located around the (β R) red cluster, and exhibited a dense subsarcolemmal accumulation of diformazan granula. The remaining weakly stained fibres were referred to as (α W) white fibres.

Muscle fibres stained for ATPase activity were classified into two types (Figure 4-20), namely dark fibres which were all negatively stained, while the light fibres were all positively stained.

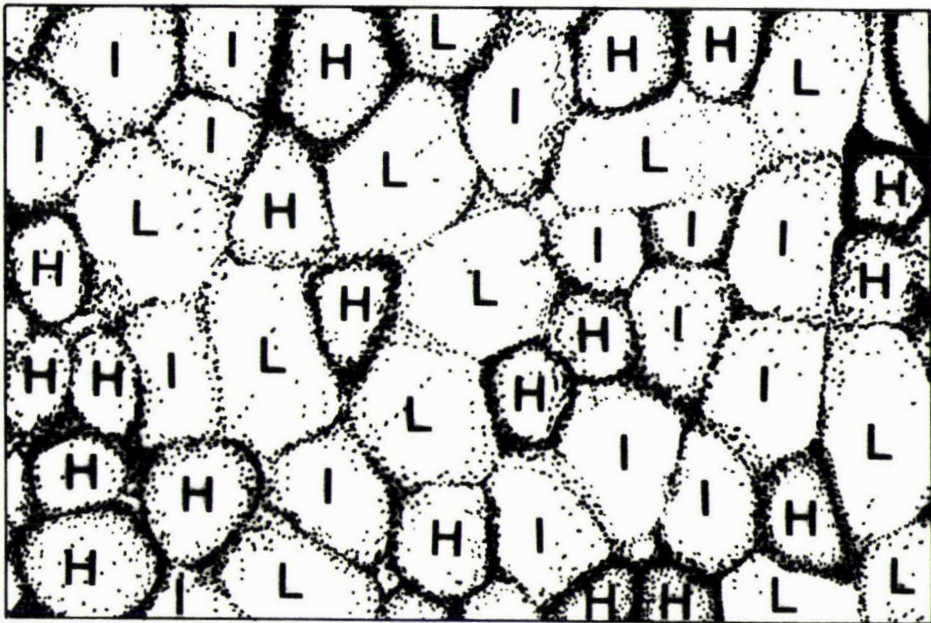
4-3-5-2 Fibre Type Proportions

Figures 4-21 and 4-22 show a comparison of the three muscle fibre type proportions based on staining with SDH for the two selection lines in Experiments 5 and 6, respectively. One of the main points to note is that muscles from the fat line sheep possessed significantly higher proportions of red fibre type (high intensity) compared with muscle from sheep in the meaty line for Experiments 5 and 6. Although the differences were not significant, there were corresponding decreases in the proportions of intermediate and white muscle fibres in the fat line as compared with the meaty line. In Figure 4-23 the proportions of the two fibre types classified according to ATPase activity for the two selection lines in Experiment 6 are presented. The average values of light and dark fibres did not differ significantly between the lines.



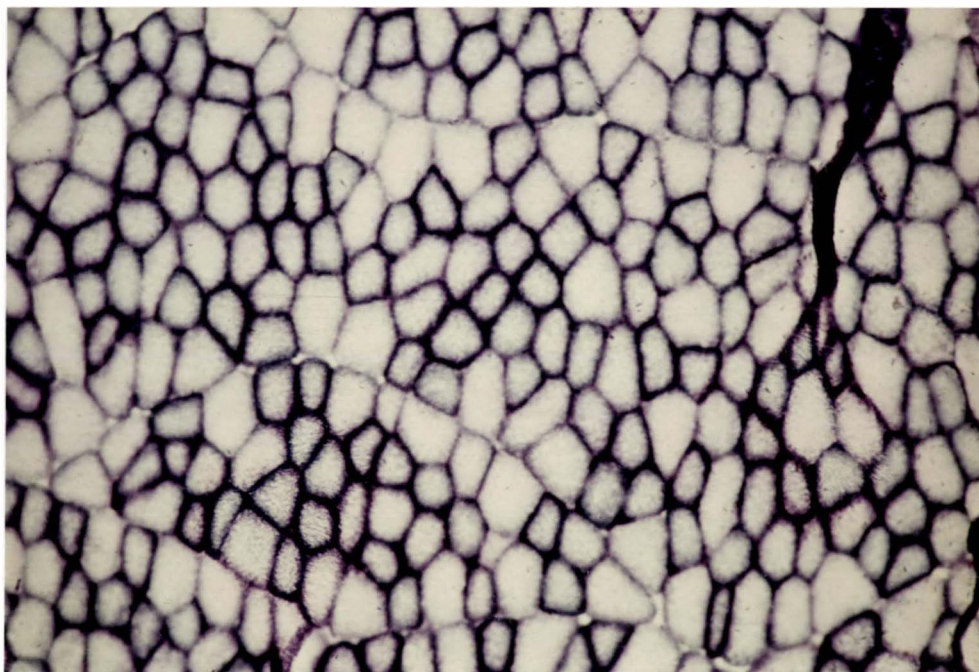
(a)

| 100 μm |

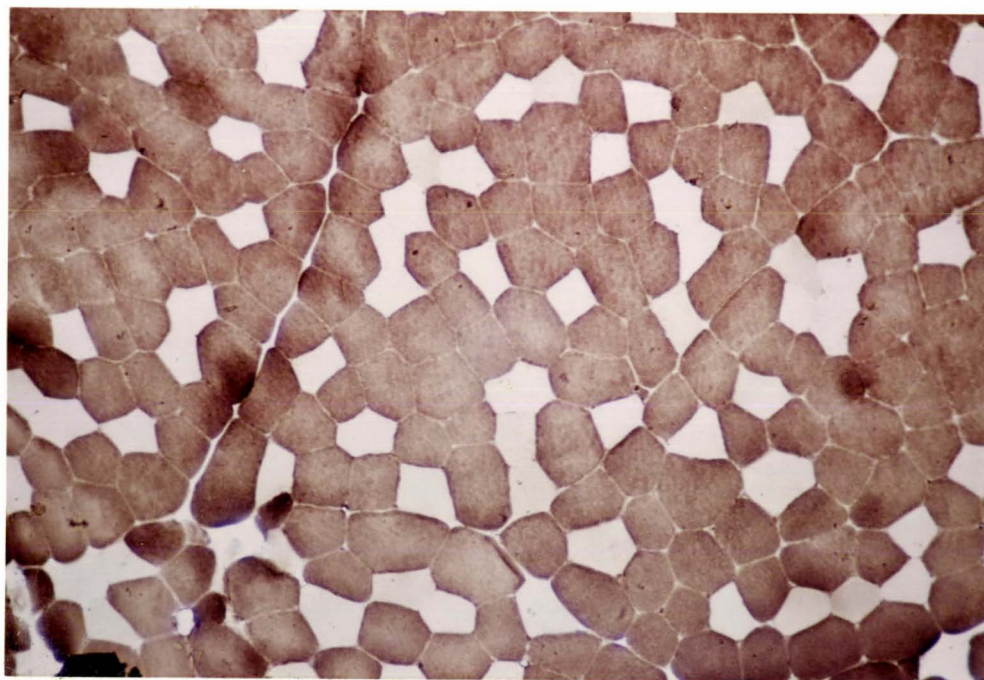


(b)

Figure 4-19. (a) Photomicrograph of transverse section of M. semitendinosus, stained for succinic dehydrogenase (magnification X 250). (b) A drawing of (a) with H, L and I indicating the high staining activity (red fibre), low staining activity (white fibre) and intermediate staining activity (intermediate fibre), respectively.



(a)

 $\overline{200 \mu\text{m}}$ 

(b)

Figure 4-20. Photomicrographs of transverse sections of M. semitendinosus, stained for succinic dehydrogenase (a) and for myosin ATPase (b) (magnification X 100).

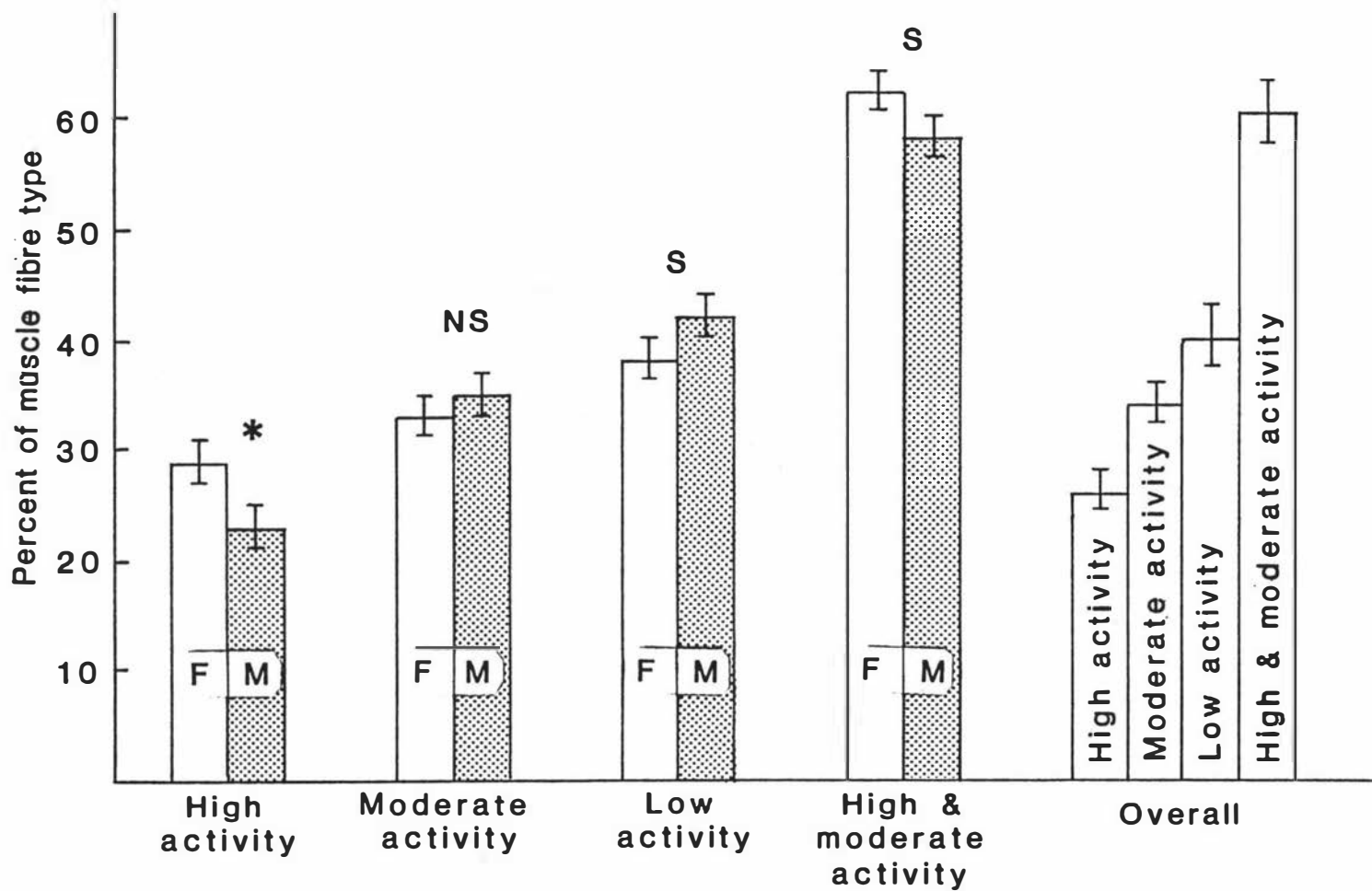


Figure 4-21. Percents of the three muscle fibre types (high (red), moderate (intermediate), and low (white) intensity of staining reactions for succinic dehydrogenase) of *M. semitendinosus* for Southdown rams within two selection lines (fat and meaty) of Experiment 5. Standard error bars are included, and above each set of two histograms is shown the level of significance of the fat (F) versus the meaty (M) lines.

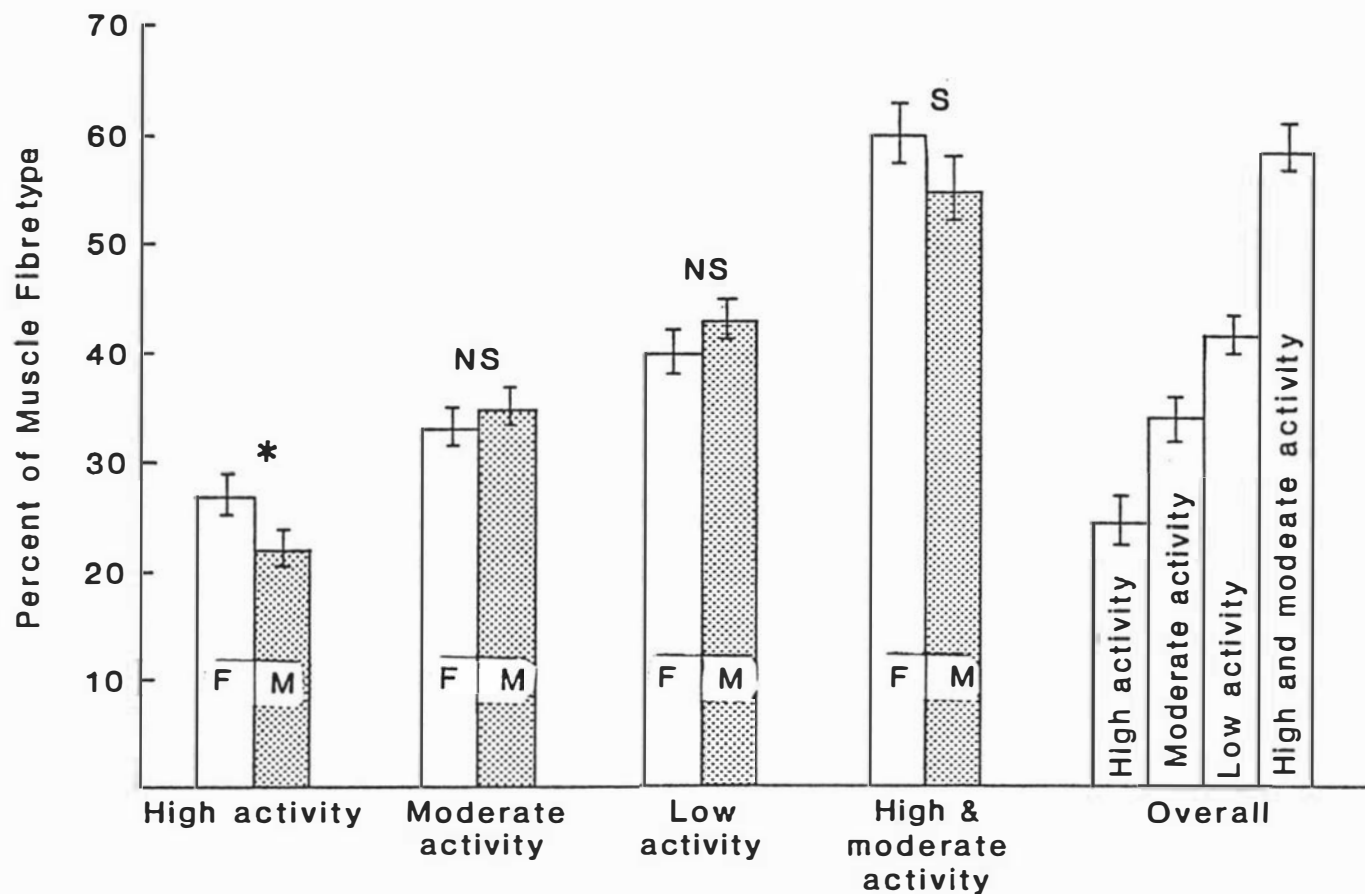


Figure 4-22. Percents of three muscle fibre types (high (red), moderate (intermediate), and low (white) intensity of staining reactions for succinic dehydrogenase) of *M. semitendinosus* for Southdown rams within two selection lines (fat and meaty) of Experiment 6. Standard error bars are included, and above each set of two histograms is shown the level of significance of the fat (F) versus the meaty (M) lines.

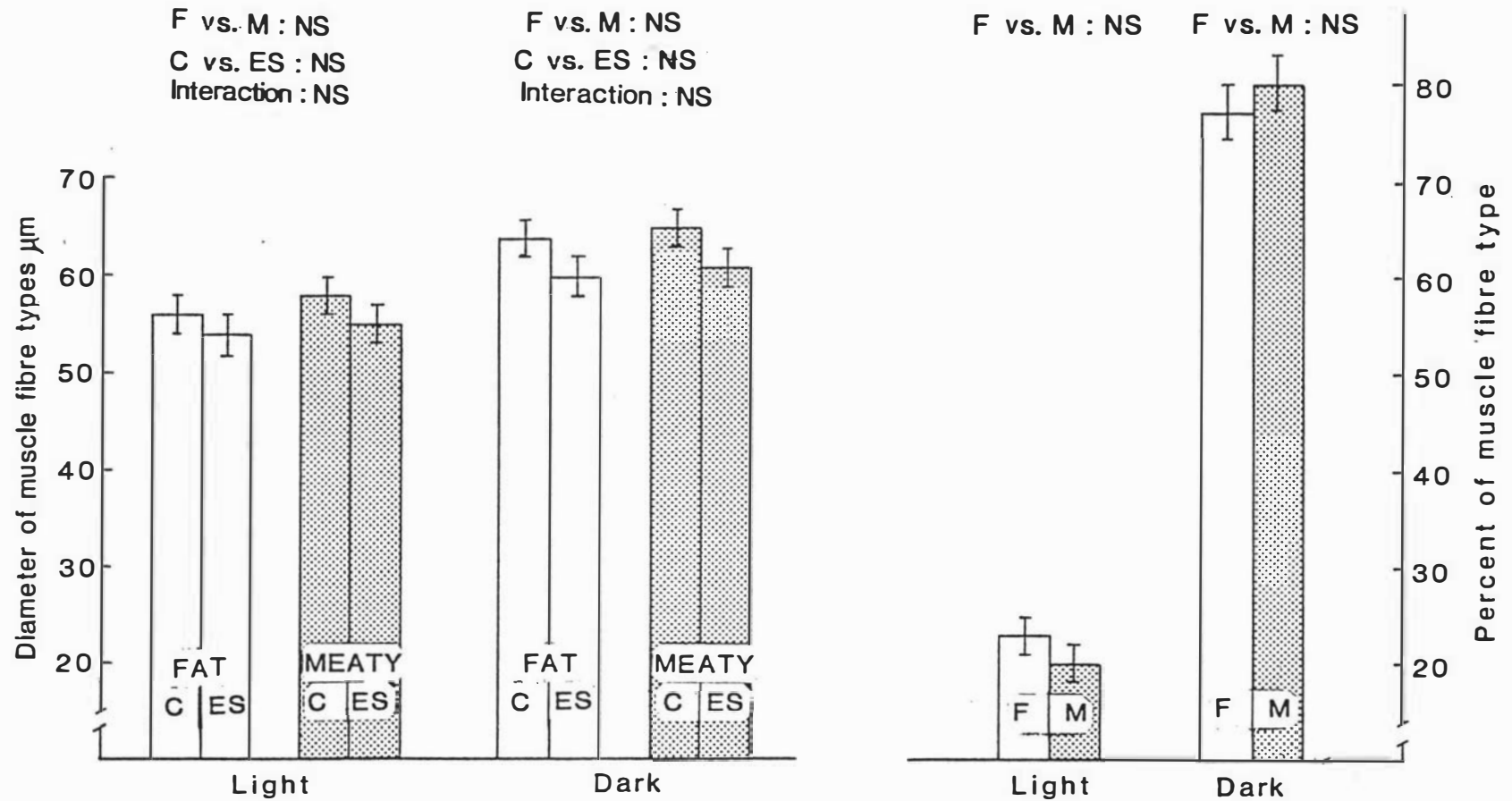


Figure 4-23. Muscle fibre diameter and percent of two muscle fibre types (low [light] and high [dark] intensity of staining reactions for ATPase) of *M. semitendinosus* for Southdown rams from two selection lines (fat and meaty) of Experiment 6. Standard error bars are included, and above each set of histograms is shown the level of significance of the fat (F) versus the meaty (M) lines, of the unstimulated (C) versus the electrically stimulated (ES) treatments and of the interaction.

4-3-5-3 Fibre Diameter

Least squares means and standard errors for the diameters of the different fibre types based on SDH staining for the two selection lines (fat and meaty) and two treatments (electrical stimulation vs control) in Experiments 5 and 6 are given in Figures 4-24 and 4-25, respectively. In both lines, the red fibres had the smallest diameters and the white fibres the largest, while the intermediate fibres were intermediate in size. The meaty line possessed non-significantly larger fibre diameters regardless of histochemical type. The electrically stimulated carcasses had slightly smaller mean fibre diameters than the control carcasses for all muscle fibre types but the differences were not significant. Similar results were obtained for the diameter of muscle fibre types based on ATPase staining (Figure 4-23). The interactions between treatments and lines were not statistically significant for any of the muscle fibre parameters.

4-3-5-4 Fibre Diameter Distribution

Diameter distribution curves for the three muscle fibre types based on succinic dehydrogenase staining in Experiments 5 and 6 are shown in Figures 4-26 and 4-27, respectively. These curves were constructed by summing the individual percent values of the 12 fat and 12 meaty rams. The individual histograms were based on measurements of at least 50 red fibres, 150 intermediate fibres, and 180 white fibres per animal. The three Figures reveal pairs of similar-shaped curves, with the meaty line curves extended to the right of the corresponding fat line curves in the ascending parts of the diagrams.

4-3-6 REFLECTANCE SPECTROPHOTOMETRY FOR ASSAY OF MUSCLE COLOUR

Tables 4-41, 4-42 and 4-43 present the mean percent reflectance values for the two lines and for different treatments for all muscles considered in Experiments 4, 5 and 6, respectively.

The fat line muscle samples had a higher reflectance at all four wavelengths across experiments, but the differences were not statistically significant. Measurements to estimate reduced myoglobin (R474 nm/R525 nm) and metmyoglobin (R572 nm/R525 nm or R630 nm/R525 nm)

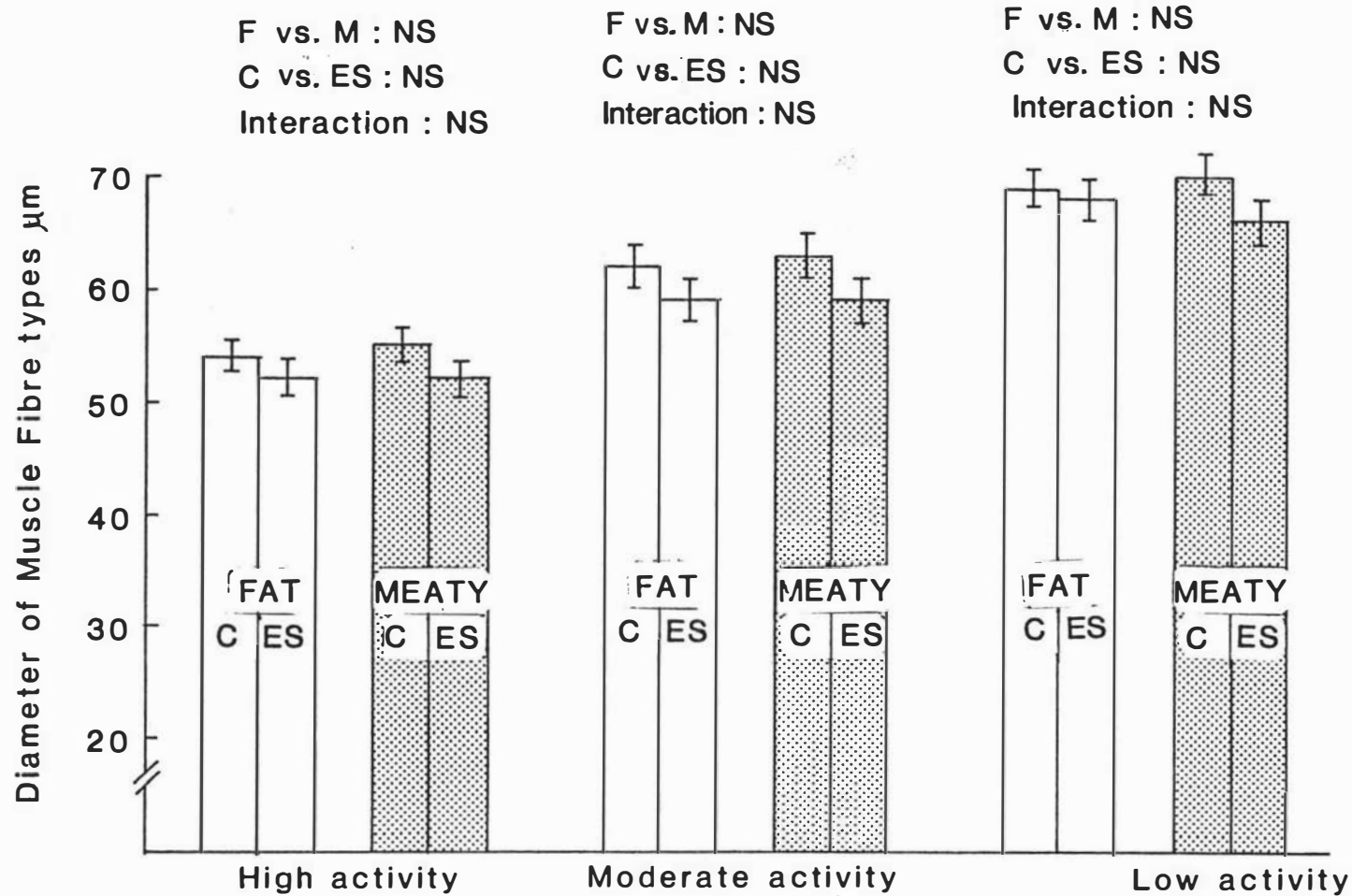


Figure 4-24. Muscle fibre diameter for three fibre types (high [red], moderate [intermediate], and low [white] intensity of staining reactions for succinic dehydrogenase) within *M. semitendinosus* for Southdown rams within two selection lines (fat and meaty) of Experiment 5, half of which had been electrically stimulated (least squares means). Standard error bars are included, and above each set of four histograms are shown the levels of significance of the fat (F) versus the meaty (M) lines, of the unstimulated (C) versus the electrically stimulated (ES) treatments and of the interaction.

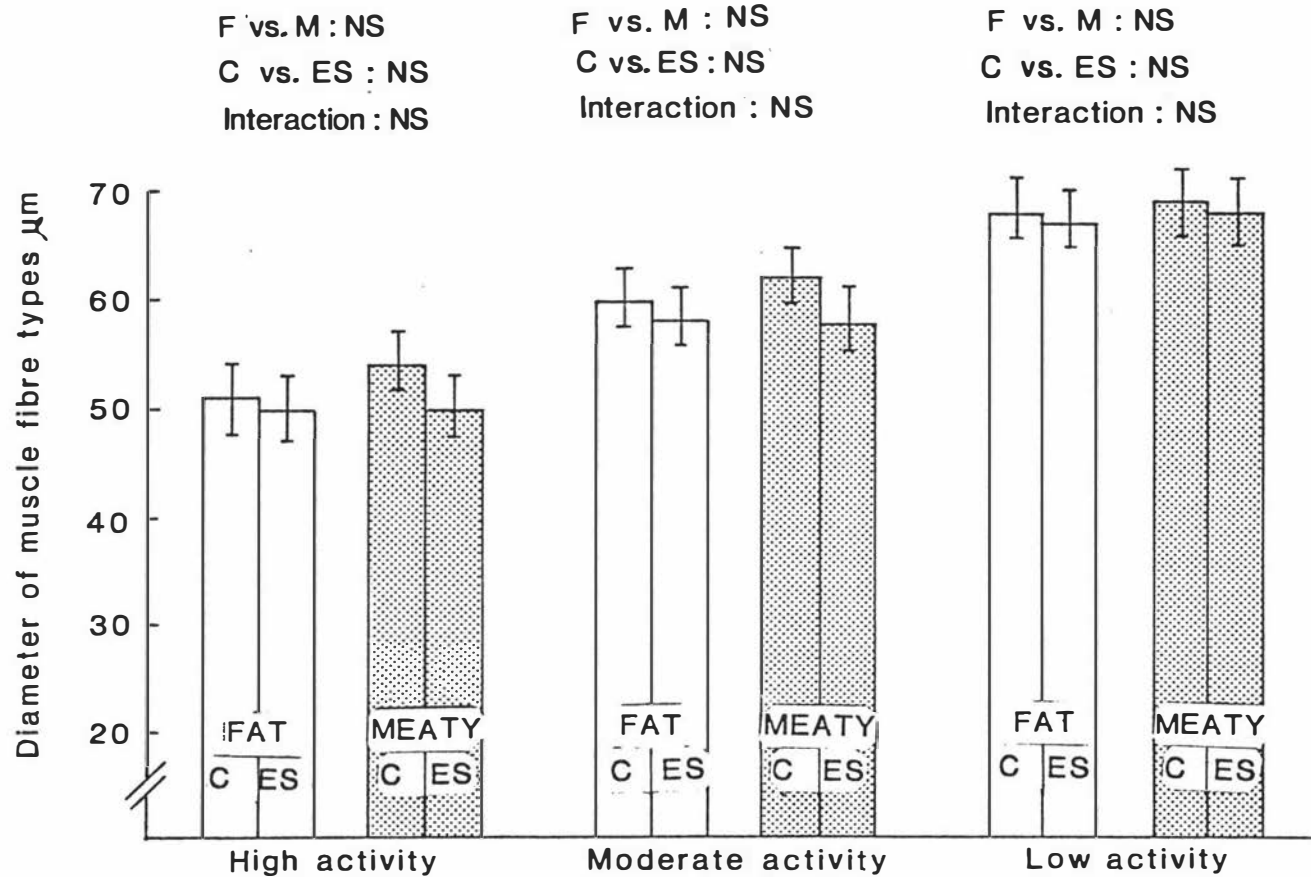


Figure 4-25. Muscle fibre diameter for three fibre types (high (red), moderate (intermediate), and low (white) intensity of staining reactions for succinic dehydrogenase) within *M. semitendinosus* for Southdown rams within two selection lines (fat and meaty) of Experiment 6, half of which had been electrically stimulated (least squares means). Standard error bars are included, and above each set of four histograms are shown the levels of significance of the fat (F) versus the meaty (M) lines, of the unstimulated (C) versus the electrically stimulated (ES) treatments and of the interaction.

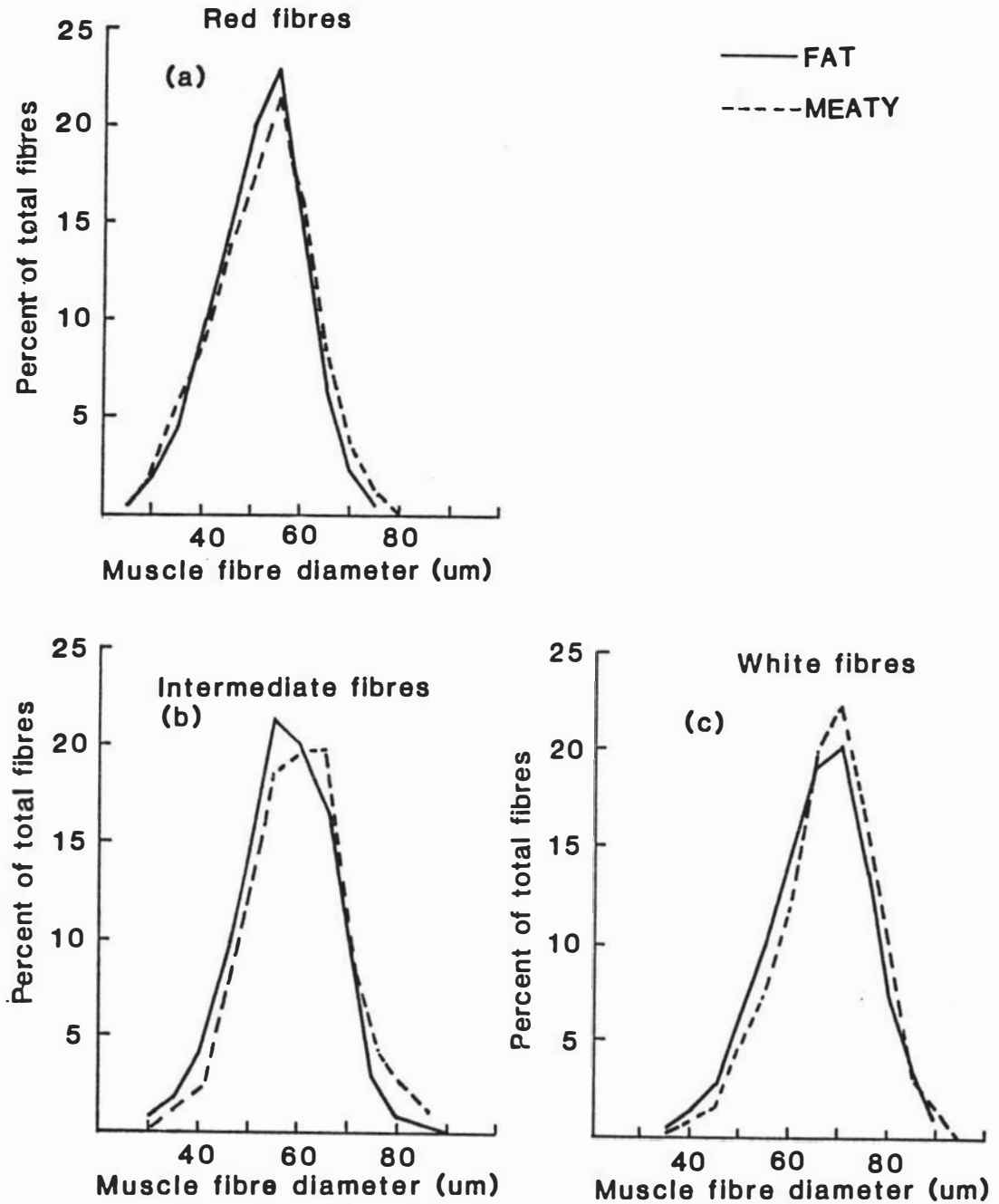


Figure 4-26. Diameter distributions curves for *M. semitendinosus* red fibres (a), intermediate fibres (b), and white fibres (c) for two selection lines of Southdown rams in Experiment 5. Each point includes the average number ± 2 (e.g. 25 ± 2 for the first point of the red muscle fibres curve (a)).

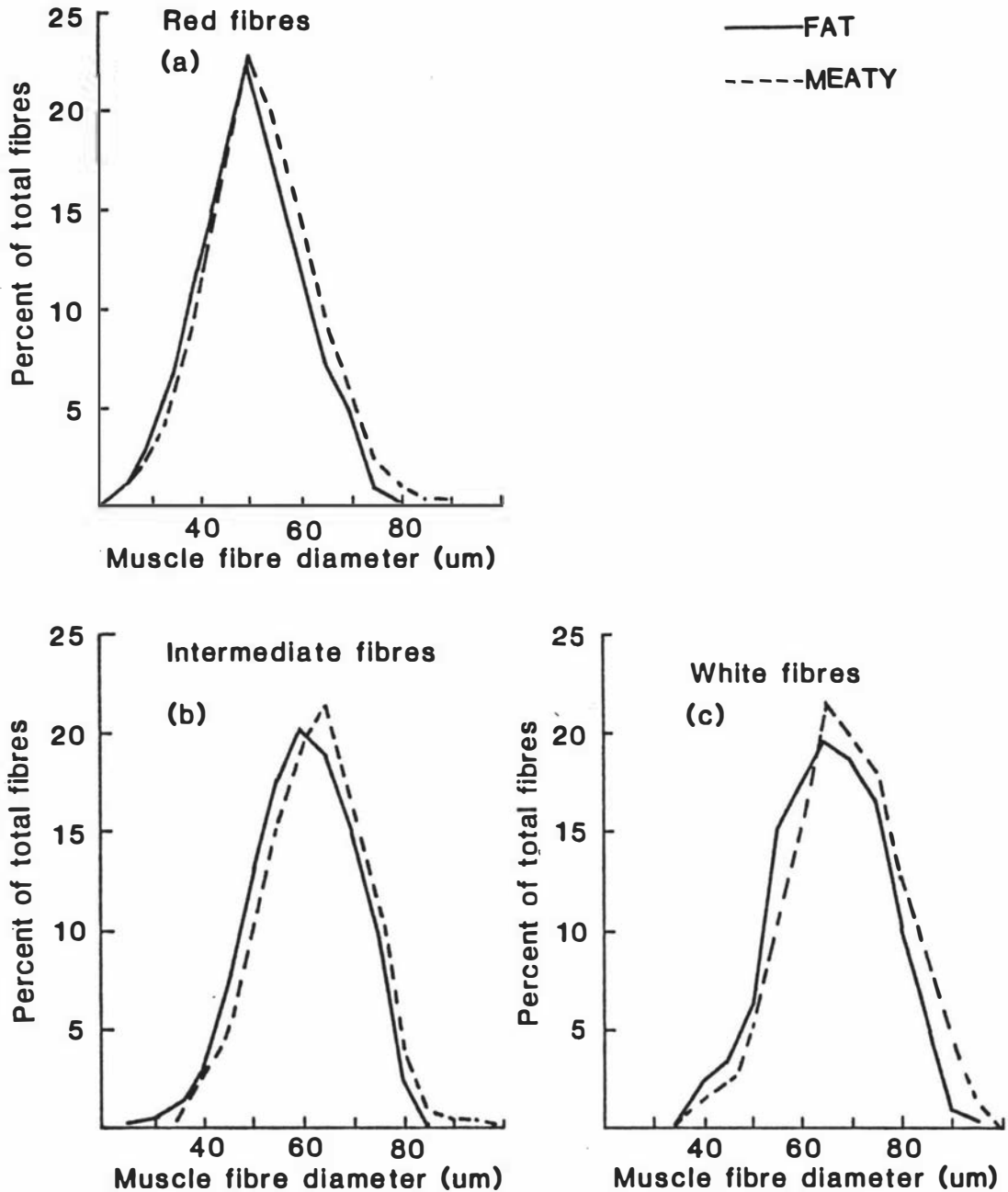


Figure 4-27. Diameter distributions curves for *M. semitendinosus* red fibres (a), intermediate fibres (b), and white fibres (c) for two selection lines of Southdown rams in Experiment 6. Each point includes the average number ± 2 (e.g. 20 ± 2 for the first point of the red muscle fibres curve (a)).

indicated that these chemical states were uniform between the two lines across all muscles considered.

Electrically stimulated muscles appeared more faded and lighter coloured than unstimulated muscles for all experiments, but the differences were small and non-significant.

The most interesting features in the reflectance results were the differences between postmortem treatments and between different muscles at any particular wavelength (Figures 4-28, 4-29 and 4-30). Generally, differences between muscles within each experiment are clear from the Figures and levels of significance are shown in Tables 4-41, 4-42 and 4-43, with the M. semitendinosus having the highest reflectance values at all four wavelengths in Experiment 6 (Figure 4-30). After M. semitendinosus, M. longissimus had the highest reflectance values at most wavelengths and M. semimembranosus had the lowest for all wavelengths. Similar results were found in Experiments 4 (Figure 4-28) and 5 (Figure 4-29). In general, for the ratios R474 nm/R525 nm, R572 nm/R525 nm and R630 nm/R525 nm the differences between muscles were slight and non-significant. In Experiment 6, no significant differences were found at 474 nm or 525 nm or 572 nm between M. biceps femoris at ambient temperature and those on ice. However, at 630 nm the samples at ambient temperature had significantly higher ($P < 0.01$) reflectance values than those on ice.

4-3-7 EXPRESSED JUICE

The data in Tables 4-38, 4-44 and 4-45 show the expressible juice as a measure of water-holding capacity of different muscles from the fat and meaty lines for Experiments 4, 5 and 6, respectively.

Electrical stimulation did not significantly affect the amount of expressible juice for Experiments 5 and 6 (Tables 4-44 and 4-45, respectively), but the stimulated muscles had slightly higher expressible juice value than the unstimulated muscles. The same Tables show the differences between different muscles and between different treatments. In Experiments 5 and 6 the expressible juice content was significantly lower for M. biceps femoris on ice than that at ambient temperature.

Table 4-41. Least squares means for percent reflectance of fresh cut muscle at various wavelengths (nm) for three muscles from two selection lines (fat and meaty) of Southdown rams of Experiment 4.

Item	Overall mean	Selection line		Significance	
		Fat (F)	Meaty (M)	F vs M	RSD
No. of animals	18	10	8		
<u>M. biceps femoris:</u>					
Wavelength (nm):					
474	5.98 ^a	6.06	5.90	NS	1.06
525	5.25 ^a	5.28	5.21	NS	0.91
572	4.53 ^a	4.67	4.38	NS	0.96
630	15.95 ^a	15.96	15.94	NS	1.39
474/525	1.14 ^a	1.15	1.13	NS	0.09
572/525	0.86 ^a	0.88	0.84	NS	0.10
630/525	3.05 ^a	3.03	3.06	NS	0.44
<u>M. semimembranosus:</u>					
Wavelength (nm):					
474	5.23 ^b	5.28	5.18	NS	0.57
525	4.74 ^b	4.81	4.66	NS	0.45
572	3.65 ^b	3.72	3.58	NS	0.40
630	16.43 ^a	16.48	16.38	NS	1.49
474/525	1.11 ^a	1.10	1.11	NS	0.07
572/525	0.78 ^b	0.77	0.78	NS	0.08
630/525	3.48 ^b	3.44	3.51	NS	0.37
<u>M. longissimus:</u>					
Wavelength (nm)					
474	6.92 ^c	6.96	6.88	NS	0.70
525	6.13 ^c	6.11	6.14	NS	0.80
572	5.19 ^c	5.28	5.09	NS	0.85
630	17.77 ^b	18.14	17.39	NS	2.28
474/525	1.14 ^a	1.15	1.12	NS	0.07
572/525	0.85 ^a	0.87	0.83	NS	0.09
630/525	2.91 ^c	2.98	2.84	NS	0.51

For definitions of abbreviations see Table 4-1.

a, b, c, Overall means for a particular wavelength or ratio of wavelengths which do not have common superscripts differ significantly ($P < 0.05$).

Table 4-42. Percent reflectance of fresh cut muscle at various wavelengths (nm) for three muscles from two selection lines (fat and meaty) of Southdown rams of Experiment 5. Half of the carcasses were electrically stimulated (least squares means).

Item	Selection Line					Significance			RSD
	Overall means	Fat (F)		Meaty (M)		F vs M	C vs ES	Inter-action	
		Unstimulated (C)	Electrically stimulated (ES)	Unstimulated (C)	Electrically stimulated (ES)				
No. of animals	24	6	6	6	6				
<i>M. biceps femoris:</i> (24 h ambient temperature)									
Wavelength (nm):									
474	6.14 ^a	6.22	6.23	5.97	6.15	NS	NS	NS	0.86
525	4.86 ^a	4.88	4.95	4.78	4.82	NS	NS	NS	0.58
572	4.06 ^{ab}	4.02	4.20	3.90	4.10	NS	NS	NS	0.48
630	16.75 ^a	16.77	17.35	16.15	16.73	NS	NS	NS	1.64
474/525	1.27 ^a	1.28	1.22	1.28	1.28	NS	NS	NS	0.22
572/525	0.84 ^a	0.83	0.85	0.82	0.85	NS	NS	NS	0.07
630/525	3.46 ^a	3.49	3.40	3.45	3.48	NS	NS	NS	0.47
<i>M. semimembranosus:</i> (1 d ageing)									
Wavelength (nm):									
474	4.97 ^b	5.00	5.07	4.85	4.97	NS	NS	NS	0.48
525	4.55 ^a	4.50	4.68	4.42	4.60	NS	NS	NS	0.61
572	3.74 ^a	3.75	3.84	3.60	3.75	NS	NS	NS	0.48
630	15.41 ^b	15.29	15.63	15.20	15.51	NS	NS	NS	1.05
474/525	1.10 ^b	1.12	1.09	1.10	1.09	NS	NS	NS	0.10
572/525	0.82 ^a	0.83	0.83	0.81	0.82	NS	NS	NS	0.10
630/525	3.79 ^a	3.87	3.53	3.87	3.32	NS	NS	NS	0.49
<i>M. longissimus:</i> (untrimmed subcutaneous fat side)									
Wavelength (nm):									
474	6.30 ^a	6.35	6.42	6.19	6.25	NS	NS	NS	0.83
525	5.23 ^b	5.29	5.36	5.11	5.17	NS	NS	NS	0.69
572	4.30 ^b	4.45	4.52	4.09	4.13	NS	NS	NS	0.72
630	17.05 ^a	17.09	17.23	16.92	16.95	NS	NS	NS	2.10
474/525	1.21 ^a	1.20	1.20	1.21	1.21	NS	NS	NS	0.09
572/525	0.82 ^a	0.84	0.84	0.80	0.80	NS	NS	NS	0.10
630/525	3.26 ^a	3.23	3.21	3.31	3.28	NS	NS	NS	0.49

For definitions of abbreviations see Table 4-1.

a, b, c Overall means for a particular wavelength or ratio of wavelengths which do not have common superscripts differ significantly ($P < 0.05$).

Table 4-43. Percent reflectance of fresh cut muscle at various wavelengths for four muscles from two selection lines (fat and meaty) of Southdown rams of Experiment 6. Half of the carcasses were electrically stimulated (least squares means).

Item	Selection Line					Significance			
	Overall mean	Fat (F)		Meaty (M)		F vs M	C vs ES	Inter-action	RSD
		Unstimulated (C)	Electrically stimulated (ES)	Unstimulated (C)	Electrically stimulated (ES)				
No. of animals	24	6	6	6	6				
M. biceps femoris: (24 h on ice)									
Wavelength (nm):									
474	5.90 ^a	6.03	5.75	6.02	5.81	NS	NS	NS	0.70
525	5.16 ^a	5.33	5.33	5.15	4.83	NS	NS	NS	0.84
572	4.05 ^a	4.18	4.60	3.85	3.55	S	NS	NS	0.61
630	13.44 ^a	13.10	14.23	13.88	12.55	NS	NS	S	1.53
474/525	1.14 ^{ab}	1.13	1.08	1.17	1.20	NS	NS	NS	0.12
572/525	0.79 ^a	0.78	0.89	0.76	0.73	S	NS	NS	0.18
630/525	2.61 ^{ab}	2.54	2.73	2.75	2.63	NS	NS	NS	0.52
M. biceps femoris: (24 h ambient temperature)									
Wavelength (nm):									
474	6.23 ^a	6.45	6.77	5.55	6.15	S	NS	NS	0.76
525	5.60 ^{ab}	5.55	6.23	5.30	5.33	S	NS	NS	0.76
572	4.58 ^b	4.08	5.37	4.38	4.47	NS	S	S	0.84
630	15.95 ^a	15.65	16.25	15.50	16.40	NS	NS	NS	1.71
474/525	1.11 ^a	1.17	1.08	1.18	1.06	NS	S	NS	0.13
572/525	0.82 ^a	0.73	0.87	0.82	0.83	NS	S	NS	0.09
630/525	2.85 ^a	2.85	2.63	3.23	3.00	S	NS	NS	0.50
M. semimembranosus: (1 d ageing)									
Wavelength (nm):									
474	6.18 ^a	6.50	6.60	5.75	5.88	S	NS	NS	0.92
525	5.30 ^{ab}	5.20	5.63	5.13	5.23	NS	NS	NS	0.60
572	4.40 ^{ab}	4.40	4.50	4.27	4.43	NS	NS	NS	0.83
630	14.97 ^{ab}	14.43	15.50	14.36	15.57	NS	NS	NS	2.01
474/525	1.17 ^{ab}	1.25	1.17	1.12	1.12	NS	NS	NS	0.17
572/525	0.83 ^a	0.85	0.80	0.83	0.85	NS	NS	NS	0.15
630/525	2.83 ^a	2.79	2.75	2.80	2.98	NS	NS	NS	0.38
M. longissimus: (untrimmed subcutaneous fat side)									
Wavelength (nm):									
474	7.13 ^b	6.80	7.72	6.75	7.23	NS	NS	NS	1.38
525	5.89 ^b	5.63	6.67	5.41	5.85	NS	NS	NS	0.97
572	4.79 ^b	4.88	5.08	4.41	4.80	NS	NS	NS	0.75
630	16.84 ^b	17.17	17.50	15.75	16.92	NS	NS	NS	4.12
474/525	1.21 ^b	1.21	1.16	1.25	1.24	NS	NS	NS	0.14
572/525	0.81 ^a	0.87	0.76	0.82	0.82	NS	NS	NS	0.15
630/525	2.86 ^a	3.05	2.62	2.91	2.89	NS	NS	NS	0.78
M. semitendinosus:									
Wavelength (nm):									
474	8.55 ^c	8.40	8.72	8.50	8.53	NS	NS	NS	0.97
525	7.61 ^c	7.47	8.05	7.33	7.58	NS	NS	NS	1.01
572	6.61 ^c	6.83	7.07	6.20	6.33	S	NS	NS	0.85
630	18.87 ^c	19.08	19.50	18.33	18.58	S	NS	NS	1.12
474/525	1.13 ^a	1.13	1.08	1.18	1.13	NS	NS	NS	0.08
572/525	0.87 ^b	0.92	0.88	0.85	0.84	NS	NS	NS	0.10
630/525	2.48 ^b	2.64	2.39	2.57	2.45	NS	NS	NS	0.31

For definitions of abbreviations see Table 4-1.

a, b, c, Overall means for a particular wavelength or ratio of wavelengths which do not have common superscripts differ significantly ($P < 0.05$).

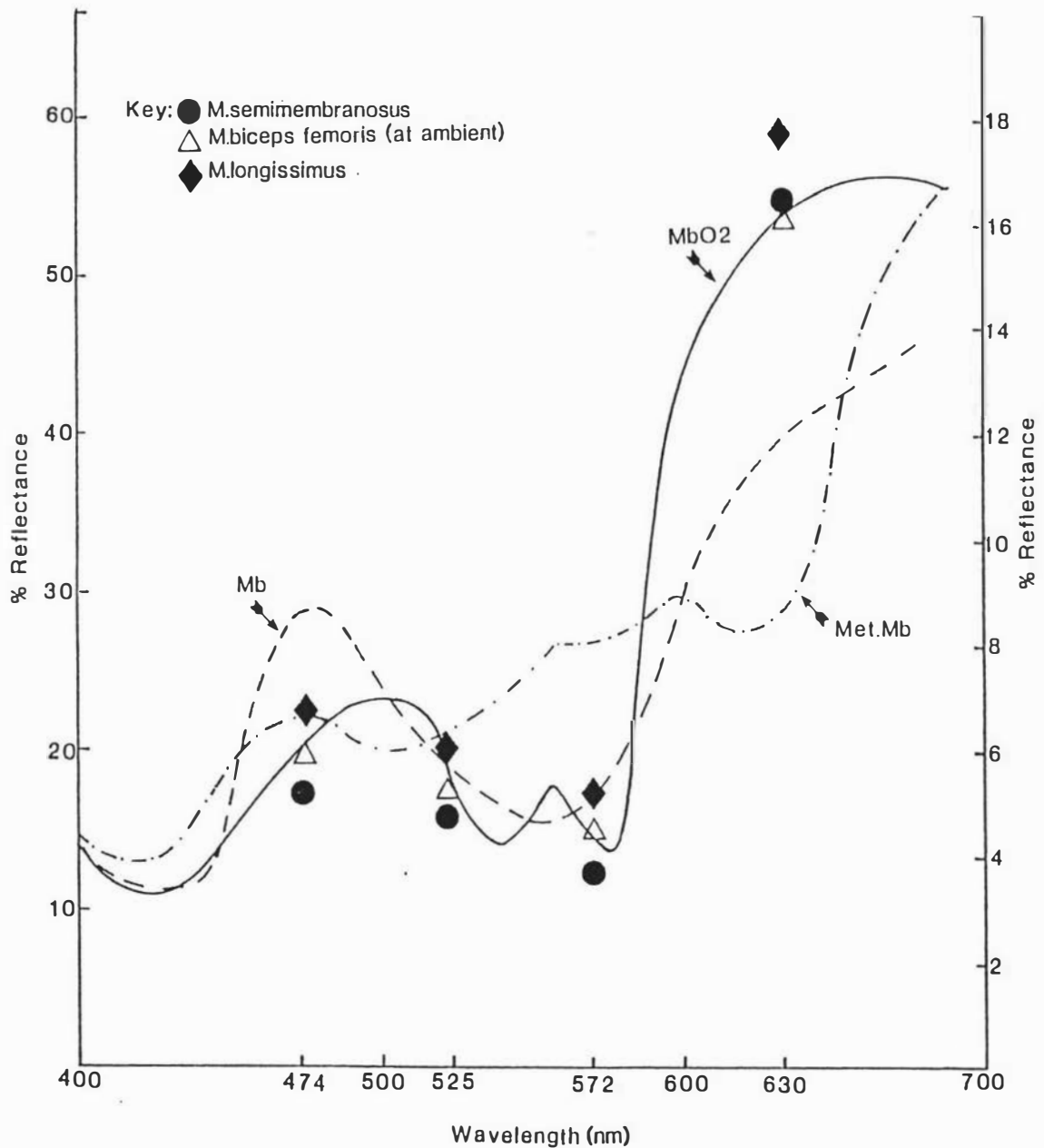


Figure 4-28. The reflectance spectra of different muscles for South-down rams of Experiment 4 (right-hand scale), superimposed on curves representing the reflectance spectra of myoglobin (Mb), oxymyoglobin (MbO_2), and metmyoglobin (Met.Mb) (left-hand scale). (Source of diagram, Strange et al., 1974.)

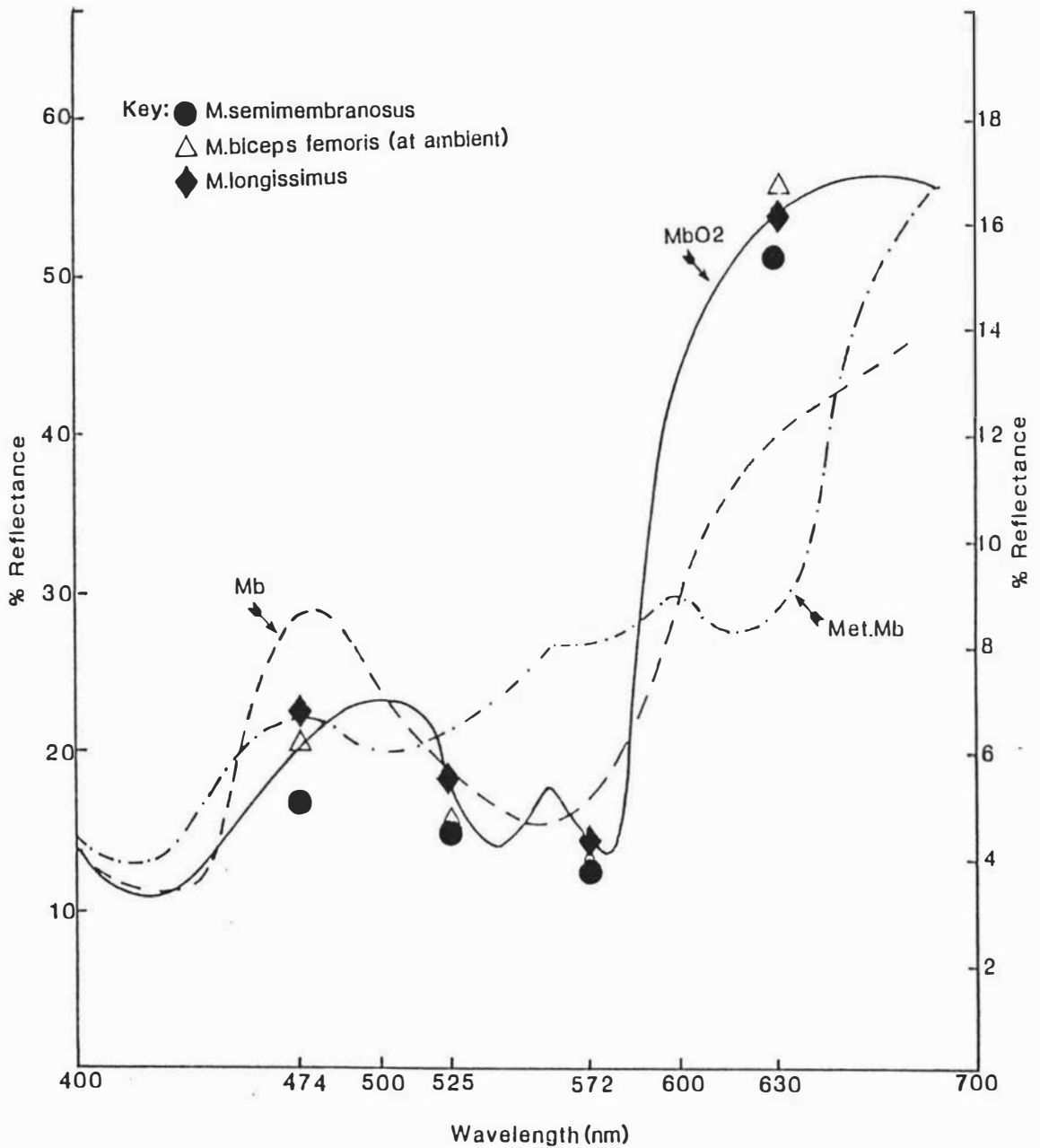


Figure 4-29. The reflectance spectra of different muscles for South-down rams of Experiment 5 (right-hand scale), superimposed on curves representing the reflectance spectra of myoglobin (Mb), oxymyoglobin (MbO₂), and metmyoglobin (Met.Mb) (left-hand scale). (Source of diagram, Strange et al., 1974.)

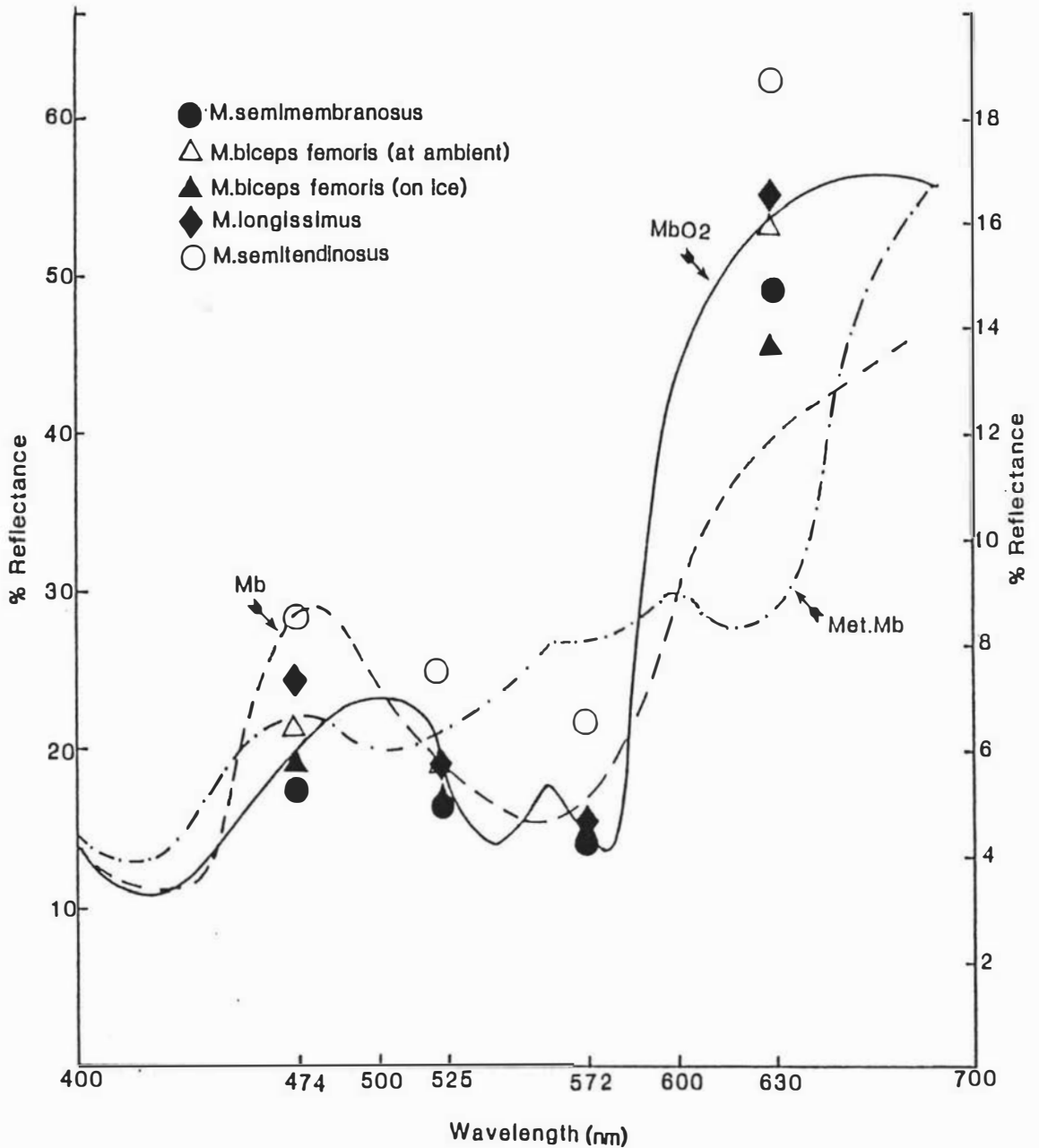


Figure 4-30. The reflectance spectra of different muscles for South-down rams of Experiment 6 (right-hand scale), superimposed on curves representing the reflectance spectra of myoglobin (Mb), oxymyoglobin (MbO₂), and metmyoglobin (Met.Mb) (left-hand scale). (Source of diagram, Strange *et al.*, 1974.)

Table 4-44. The effect of post-mortem treatment on expressed juice* for three muscles from two selection lines (fat and meaty) of Southdown rams of Experiment 5. Half of the carcasses were electrically stimulated (least squares means).

Item	Overall mean	Selection Line				Significance			RSD
		Fat (F)		Meaty (M)		F vs M	C vs ES	Inter-action	
		Unstimulated (C)	Electrically stimulated (ES)	Unstimulated (C)	Electrically stimulated (ES)				
No. of animals	24	6	6	6	6				
<u>M. biceps femoris:</u>									
24 h on ice	31.33 ^a	31.25	31.82	30.90	31.34	NS	NS	NS	1.73
24 h ambient temperature	32.35 ^b	32.03	33.02	31.84	32.50	NS	NS	NS	1.45
Difference (ice-ambient)		-0.78	-1.20	-0.94	-1.16	NS	NS	NS	1.63
<u>M. semimembranosus:</u>									
1 d ageing	29.18 ^c	29.21	29.73	28.91	29.49	NS	NS	NS	1.78
<u>M. longissimus:</u>									
Untrimmed fat (rack)	30.42 ^d	30.77	30.72	29.93	30.68	NS	NS	NS	2.37

* Expressed juice = water area (cm²)/sample weight (g).

For definitions of abbreviations see Table 4-1.

a, b, c Overall means in the same column with no common superscripts differ (P<0.05).

Table 4-45. The effect of post-mortem treatment on expressed juice* for three muscles from two selection lines (fat and meaty) of Southdown rams of Experiment 6. Half of the carcasses were electrically stimulated (least squares means).

Item	Overall mean	Selection line				Significance			RSD
		Fat (F)		Meaty (M)		F vs M	C vs ES	Inter-action	
		Unstimulated (C)	Electrically stimulated (ES)	Unstimulated (C)	Electrically stimulated (ES)				
No. of animals	24	6	6	6	6				
M. biceps femoris:									
24 h on ice	32.39 ^a	31.18	33.85	31.96	32.57	NS	NS	NS	2.23
24 h ambient temperature	34.79 ^b	33.94	36.24	34.31	34.67	NS	S	NS	1.84
Difference (ice-ambient)		-2.76	-2.39	-2.35	-2.10	NS	NS	NS	2.51
M. semimembranosus:									
1 d ageing	29.74 ^c	29.86	29.95	29.50	29.64	NS	NS	NS	2.10
M. longissimus:									
Trimmed fat (loin)	30.43 ^c	30.41	30.46	30.21	30.62	NS	NS	NS	2.46
Untrimmed fat (loin)	30.35 ^c	30.37	30.40	30.13	30.48	NS	NS	NS	2.99
Difference (trimmed-untrimmed)		0.04	0.06	0.08	0.14	NS	NS	NS	0.34

* Expressed juice = water area (cm²)/sample weight (g).

For definitions of abbreviations see Table 4-1.

a, b, c Overall means in the same column with no common superscripts differ (P<0.05).

The expressible juice content of M. biceps femoris was higher than M. semimembranosus and M. longissimus across all experiments, and it was significant in Experiments 5 and 6. However, the only significant differences between M. longissimus and M. semimembranosus was in Experiment 5.

4-3-8 SARCOMERE LENGTH

Mean sarcomere lengths for different muscles in the two selection lines are presented in Figures 4-31 to 4-35. Muscles from sheep of the fat line had slightly longer sarcomere lengths, but these differences were not significant.

A similar trend occurred in the case of electrically stimulated and unstimulated samples (in the same Figures), with sarcomere length being in some cases significantly shorter for the unstimulated group. The only non-significant difference between the two stimulation treatments in Experiment 5 was for M. longissimus from the untrimmed side, while in Experiment 6 the stimulation effect was not significant in M. longissimus from either side or for M. biceps femoris at ambient temperature. The interaction between stimulation and selection line was not significant.

Figures 4-31 and 4-32 show a large effect of treatment during the first 24 hours (on ice vs ambient) on sarcomere length from M. biceps femoris. The muscles on ice had significantly shorter sarcomeres than those at ambient temperature (Table 4-48). The electrical stimulation treatment significantly increased the sarcomere lengths of M. biceps femoris samples on ice and at ambient temperature for one experiment. Stimulation resulted in a non-significant reduction in the difference between these two treatments. Also a considerable difference between the left and right side M. semitendinosus sarcomere lengths was found in Experiment 6 (Figure 4-35). The right side muscle was kept on ice at 30 min postmortem and in liquid nitrogen at about 70 min post-mortem, while the left side was left with the carcass overnight at 1°C; these differences were very highly significant (Table 4-48).

A similar, but much smaller, trend occurred with respect to the effect of trimming the subcutaneous fat from over the M. longissimus

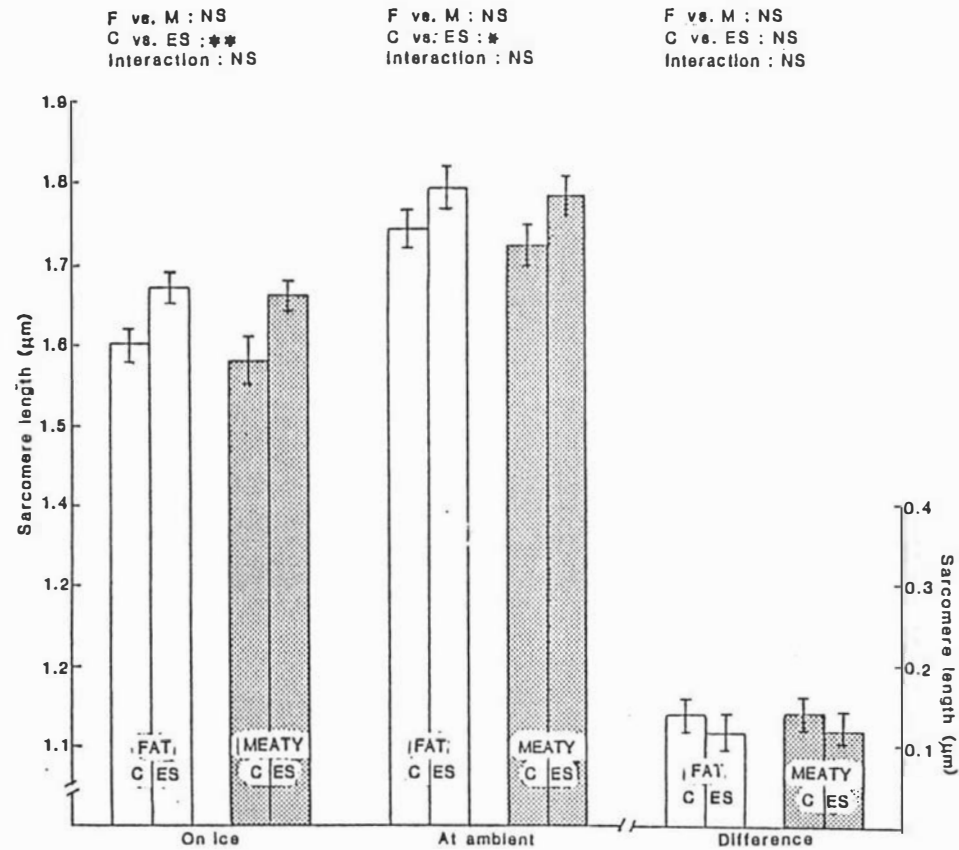


Figure 4-31. The effect of postmortem temperature and of electrical stimulation on sarcomere lengths of M. biceps femoris for Southdown rams from two selection lines (fat and meaty; Experiment 5). Least squares means for the two treatments during the first 24 h and for the difference between the treatments are shown. Standard error bars are included, and above each set of four histograms are shown the levels of significance of the fat versus the meaty lines, of the unstimulated (C) versus the stimulated (ES) treatments and of the interaction.

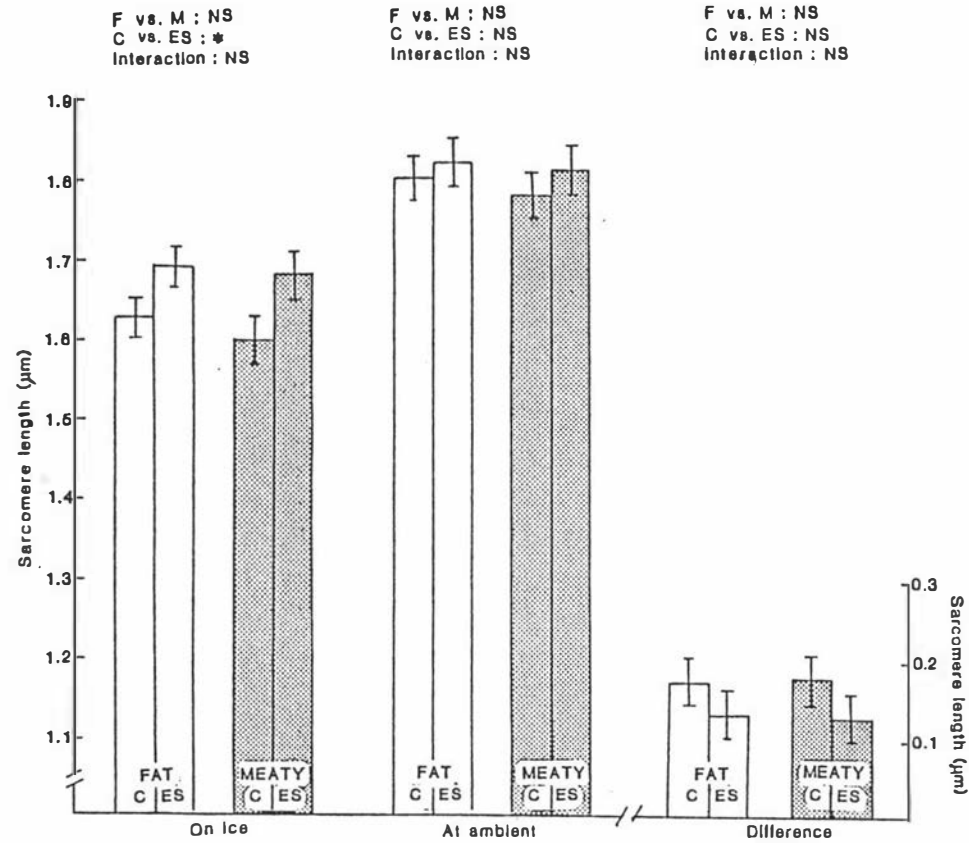


Figure 4-32. The effect of postmortem temperature and of electrical stimulation on sarcomere lengths of *M. biceps femoris* for Southdown rams from two selection lines (fat and meaty; Experiment 6). Least squares means for the two treatments during the first 24 h and for the difference between the treatments are shown. Standard error bars are included, and above each set of four histograms are shown the levels of significance of the fat versus the meaty lines, of the unstimulated (C) versus the stimulated (ES) treatments and of the interaction.

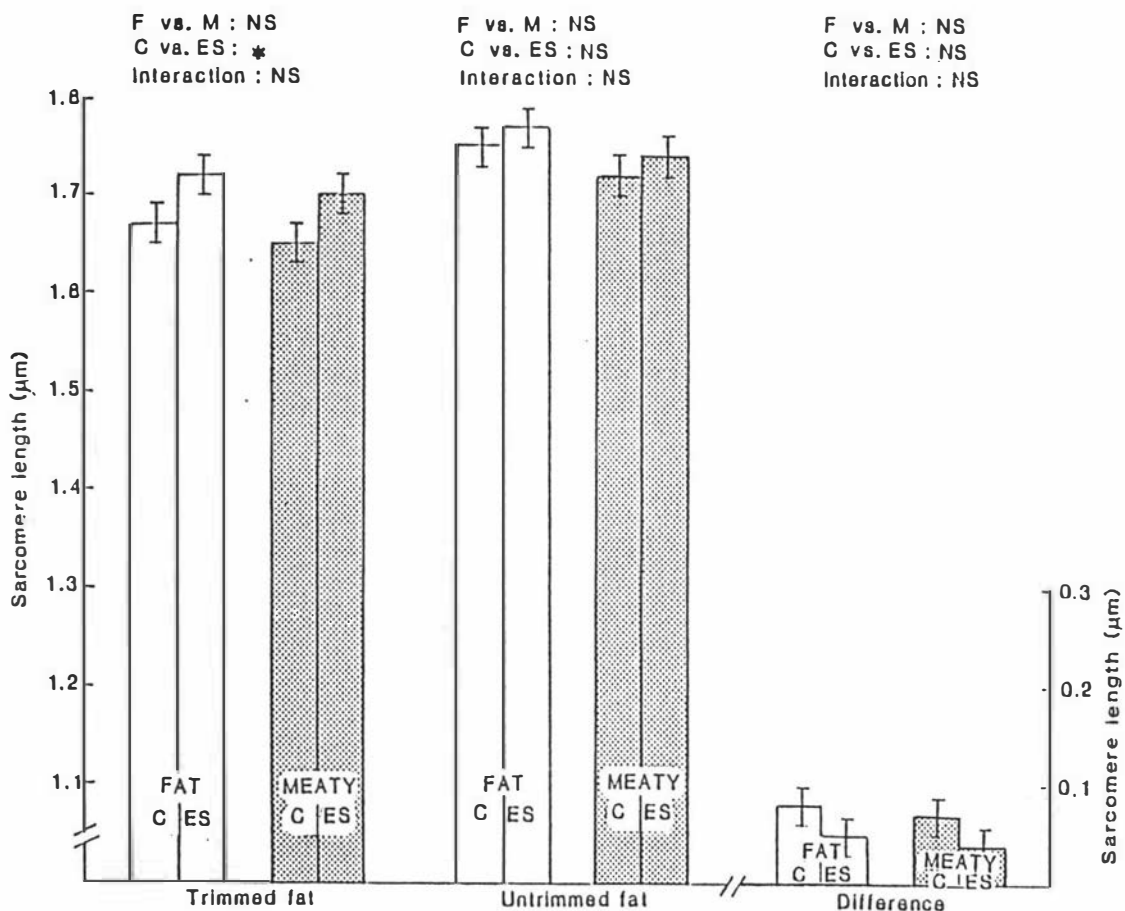


Figure 4-33. The effect of trimming the subcutaneous fat from *M. longissimus* of the right side and of electrical stimulation on sarcomere lengths of that muscle for Southdown rams from two selection lines (fat and meaty; Experiment 5). Least squares means for the two treatments and the difference between the treatments are shown. Standard error bars are included, and above each set of four histograms are shown the levels of significance of the fat versus the meaty lines, of the unstimulated (C) versus the stimulated (ES) treatments and of the interaction.

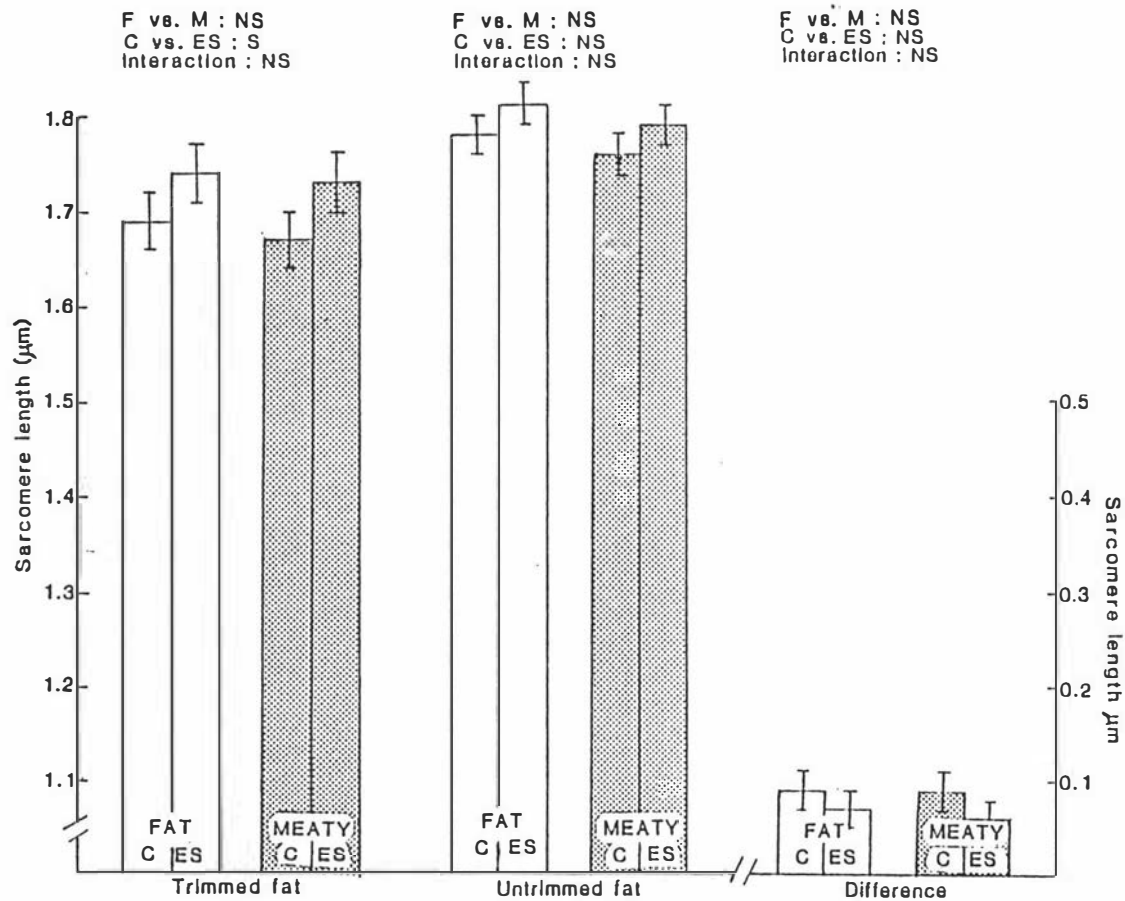


Figure 4-34. The effect of trimming the subcutaneous fat from *M. longissimus* of the right side and of electrical stimulation on sarcomere lengths of that muscle for Southdown rams from two selection lines (fat and meaty; Experiment 6). Least squares means for the two treatments and the difference between the treatments are shown. Standard error bars are included, and above each set of four histograms are shown the levels of significance of the fat versus the meaty lines, of the unstimulated (C) versus the stimulated (ES) treatments and of the interaction.

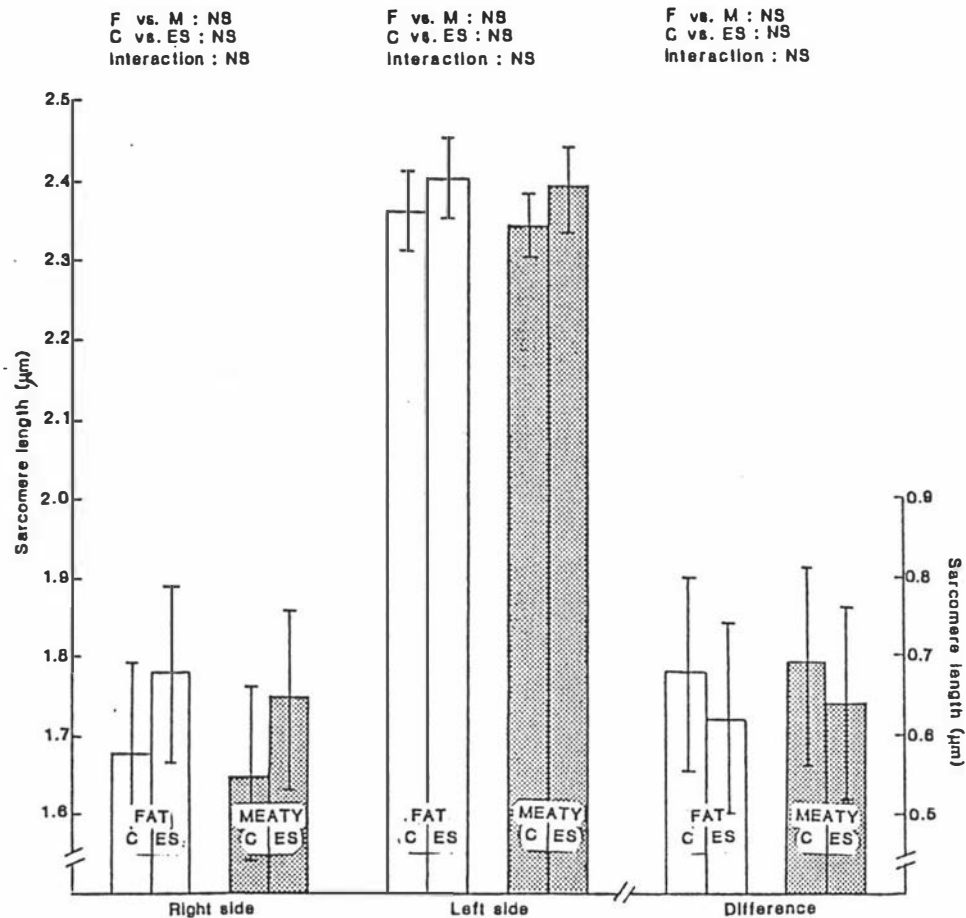


Figure 4-35. The effect of postmortem temperature and of electrical stimulation on sarcomere lengths of M. semitendinosus for Southdown rams from two selection lines (fat and meaty; Experiment 6). Least squares means for the two treatments and the difference between the treatments are shown. Standard error bars are included and above each set of four histograms are shown the levels of significance of the fat versus the meaty lines, of the unstimulated (C) versus the stimulated (ES) and of the interaction.

from one side only in Experiments 5 and 6 (Figures 4-33 and 4-34). Thus, sarcomere lengths were significantly shorter for the muscle from the trimmed side than those from the untrimmed side (Table 4-48). Again the sarcomere length values for M. longissimus from the trimmed and untrimmed sides indicated that the interaction between stimulation and trimming subcutaneous fat for the two selection lines was not significant.

4-3-9 PERCENT COOKING LOSSES

4-3-9-1 Southdown X Romney Cross Lambs (Experiments 1 and 2)

The overall percent cooking losses for different muscles were not greatly affected by sire group, pasture treatment, or sex group in Experiments 1 and 2 (Tables 4-36 and 4-37). However, percent cooking losses were slightly greater for the samples from the fat line. Significant differences were found between muscles, with M. semitendinosus having the highest percent cooking losses and M. longissimus the lowest.

4-3-9-2 Southdown Rams (Experiments 4, 5 and 6)

The data in Tables 4-38, 4-46 and 4-47 show the percent cooking losses for the different muscles from the two lines and postmortem treatments. The four muscles from the fat line had slightly (non-significant) higher percent cooking losses than those from the meaty line. The same Tables show that the differences in percent cooking losses between muscles from electrically stimulated and unstimulated groups were not significant. The differences in percent cooking losses between muscles were significant, with M. semitendinosus having the highest percent cooking losses and M. longissimus having the lowest.

An interesting feature was the significantly higher percent cooking losses from the M. biceps femoris in Experiment 6 that had been on ice relative to the muscle that had been held at ambient temperature for 24 h. In Experiment 5, however, no significant differences between the same two treatments were found.

Table 4-46. The effect of post-mortem treatment on percent cooking losses for four muscles from two selection lines (fat and meaty) of Southdown rams of Experiment 5. Half of the carcasses were electrically stimulated (least squares means).

Item	Overall mean	Selection Line				Significance			
		Fat (F)		Meaty (M)		F vs M	C vs ES	Inter-action	RSD
		Unstimulated (C)	Electrically stimulated (ES)	Unstimulated (C)	Electrically stimulated (ES)				
No. of animals	24	6	6	6	6				
<u>M. biceps femoris:</u>									
24 h on ice	31.60 ^{ad}	31.58	31.83	31.27	31.74	NS	NS	NS	1.02
24 h ambient temperature	30.87 ^a	30.77	31.05	30.76	30.91	NS	NS	NS	1.48
Difference (ice-ambient)		0.81	0.78	0.51	0.83	NS	NS	NS	0.99
<u>M. semimembranosus:</u>									
1 d ageing	29.95 ^b	29.75	30.27	29.66	30.19	NS	NS	NS	1.14
15 d ageing	30.08 ^b	29.92	30.35	29.75	30.26	NS	NS	NS	0.80
Difference (1 d - 15 d)		-0.17	-0.08	-0.13	-0.07	NS	NS	NS	0.84
<u>M. longissimus: (from loin cut)</u>									
Trimmed fat	25.61 ^C	25.75	25.98	25.02	25.68	NS	NS	NS	1.79
Untrimmed fat	26.33 ^C	26.40	26.77	25.88	26.27	NS	NS	NS	1.30
Difference (trimmed-untrimmed)		-0.65	-0.79	-0.86	-0.59	NS	NS	NS	1.12
<u>M. longissimus: (from rack cut)</u>									
Untrimmed fat	24.62 ^C	24.33	25.-2	24.40	24.73	NS	NS	NS	1.38
Difference (rack-loin)		-1.55	-1.25	-2.00	-2.04	NS	NS	NS	1.29
<u>M. semitendinosus:</u>									
	31.65 ^d	31.75	32.27	31.13	31.35	NS	NS	NS	1.32

For definitions of abbreviations see Table 4-1.

a, b, c, d, Overall means in the same column with no common superscripts differ ($P < 0.05$).

Table 4-47. The effect of post-mortem treatment on percent cooking losses for four muscles from two selection lines (fat and meaty) of Southdown rams of Experiment 6. Half of the carcasses were electrically stimulated (least squares means).

Item	Selection Line					Significance			
	Overall mean	Fat (F)		Meaty (M)		F vs M	C vs ES	Inter-action	RSD
		Unstimulated (C)	Electrically stimulated (ES)	Unstimulated (C)	Electrically stimulated (ES)				
No. of animals	24	6	6	6	6				
<u>M. biceps femoris:</u>									
24 h on ice	30.91 ^a	31.02	31.14	29.99	31.48	NS	NS	NS	1.34
24 h ambient temperature	29.59 ^b	29.99	2.960	29.51	29.26	NS	NS	NS	1.44
Difference (ice-ambient)		1.03	1.54	0.48	1.22	NS	NS	NS	1.57
<u>M. semimembranosus:</u>									
1 d ageing	29.96 ^{bc}	29.85	30.35	29.78	29.86	NS	NS	NS	1.85
15 d ageing	30.10 ^c	29.91	30.53	29.89	30.06	NS	NS	NS	1.57
Difference (1 d - 15 d)		-0.06	-0.18	-0.11	-0.20	NS	NS	NS	1.02
<u>M. longissimus: (from loin cut)</u>									
Trimmed fat	26.45 ^d	26.44	26.56	26.36	26.43	NS	NS	NS	1.63
Untrimmed fat	26.60 ^d	26.62	26.70	26.47	26.59	NS	NS	NS	1.45
Difference (trimmed-untrimmed)		-0.18	-0.14	-0.11	-0.16	NS	NS	NS	1.89
<u>M. semitendinosus:</u>									
	30.57 ^a	30.55	30.65	30.48	30.61	NS	NS	NS	1.28

For definitions of abbreviations see Table 4-1.

a, b, c, d, Overall means in the same column with no common superscripts differ ($P < 0.05$).

Table 4-48. Overall means for WB shear force values and sarcomere lengths for different muscles and different post-mortem treatments in Experiments 5 and 6.

Item	Experiment 5		Experiment 6	
	Shear force value	Sarcomere length	Shear force value	Sarcomere length
No. of animals	24	24	24	24
<u>M. biceps femoris:</u>				
24 h on ice	7.07 ^a	1.63 ^a	6.33 ^a	1.66 ^a
24 h at ambient temperature	4.64 ^b	1.76 ^b	3.76 ^b	1.82 ^b
<u>M. semimembranosus:</u>				
1 d ageing	6.85 ^a	-	6.15 ^a	-
15 d ageing	4.82 ^b	-	4.12 ^b	-
<u>M. longissimus:</u>				
Trimmed fat	4.50 ^{bc}	1.68 ^a	3.49 ^{bd}	1.70 ^a
Untrimmed fat	3.93 ^d	1.74 ^b	3.21 ^d	1.79 ^b
<u>M. semitendinosus:</u>				
24 h on carcass	4.27 ^{bd}	-	4.12 ^c	2.38 ^c
Cold treatment*	-	-	-	1.71 ^d

a, b, c, d Overall means in the same column with no common superscripts differ ($P < 0.05$).

* The meat samples were placed on ice at 35 ± 2 min postmortem and at about 60-90 min postmortem were transferred to liquid nitrogen for 15 min and finally kept at -30°C for 24 h.

4-3-10 WARNER-BRATZLER SHEAR FORCE VALUES

4-3-10-1 Southdown X Romney Cross Lambs (Experiments 1 and 2)

Warner-Bratzler shear force values represent the kg pressure required to shear through a 13 x 13 mm core of cooked muscle. Comparisons of least squares means for shear force values between the fat and meaty lines from Southdown X Romney lambs are presented in Tables 4-36 and 4-37 for Experiments 1 and 2, respectively. The data revealed that the shear force values were higher from M. biceps femoris, M. semimembranosus, M. semitendinosus and M. longissimus from the meaty line than from the fat line, but the differences were not significant. In the same Tables, it is shown that there were significant differences between different muscles, with M. semimembranosus having the highest shear force values and M. longissimus having the lowest. The same Tables show that there were no effects of the four pastures or the two sexes on shear force values of the muscles studied.

4-3-10-2 Southdown Rams (Experiments 4, 5 and 6)

Differences between the fat and meaty lines for meat tenderness of four muscles, as measured by Warner-Bratzler shear force values are presented in Table 4-38 (Experiment 4) and in Figures 4-36 to 4-42 for Experiments 5 and 6, respectively. Slight differences were observed between the shear force values for the fat and meaty lines in Experiment 4, in which the shear values were lower for samples of M. longissimus, M. semimembranosus, M. biceps femoris and M. semitendinosus from sheep of the fat line, but the differences were not statistically significant. Similar results were observed across Experiments 5 and 6, with the fat line having slightly lower (non-significant) shear force values than the meaty line.

The effects of electrical stimulation on muscle tenderness are presented in Figures 4-36, 4-37, 4-39 and 4-41 (Experiment 5) and Figures 4-36, 4-38, 4-40 and 4-42 (Experiment 6). In Experiment 5, shear force values indicated that M. longissimus, M. semimembranosus, M. biceps femoris and M. semitendinosus from stimulated carcasses were highly significantly more tender than corresponding muscles from the

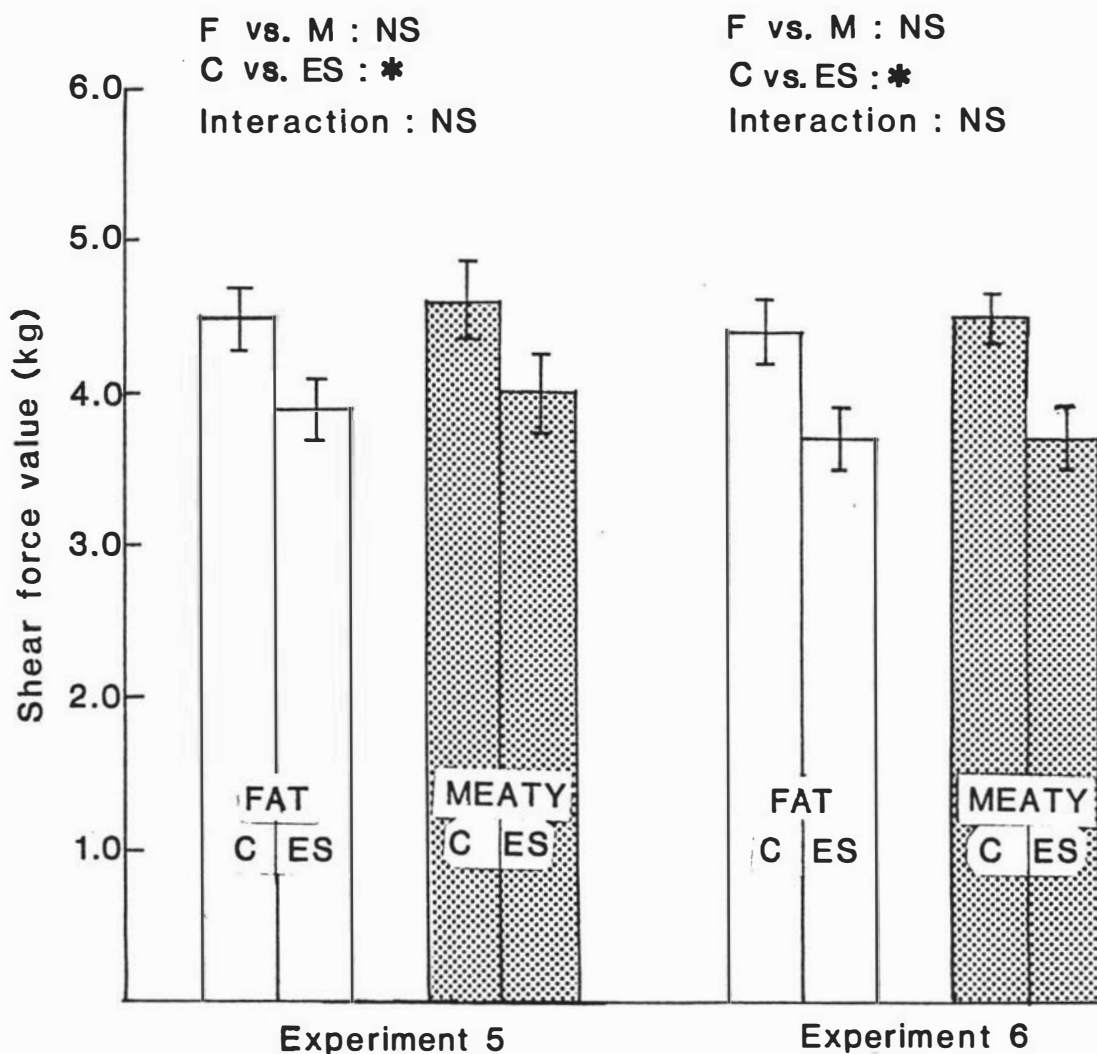


Figure 4-36. The effect of electrical stimulation on shear force values of *M. semitendinosus* for Southdown rams from two selection lines (fat and meaty; Experiments 5 and 6). Half of the carcasses were electrically stimulated (least squares means). Standard error bars are included and above each set of four histograms are shown the levels of significance of the fat versus the meaty lines, of the unstimulated (C) versus the stimulated (ES) treatments and of the interaction.

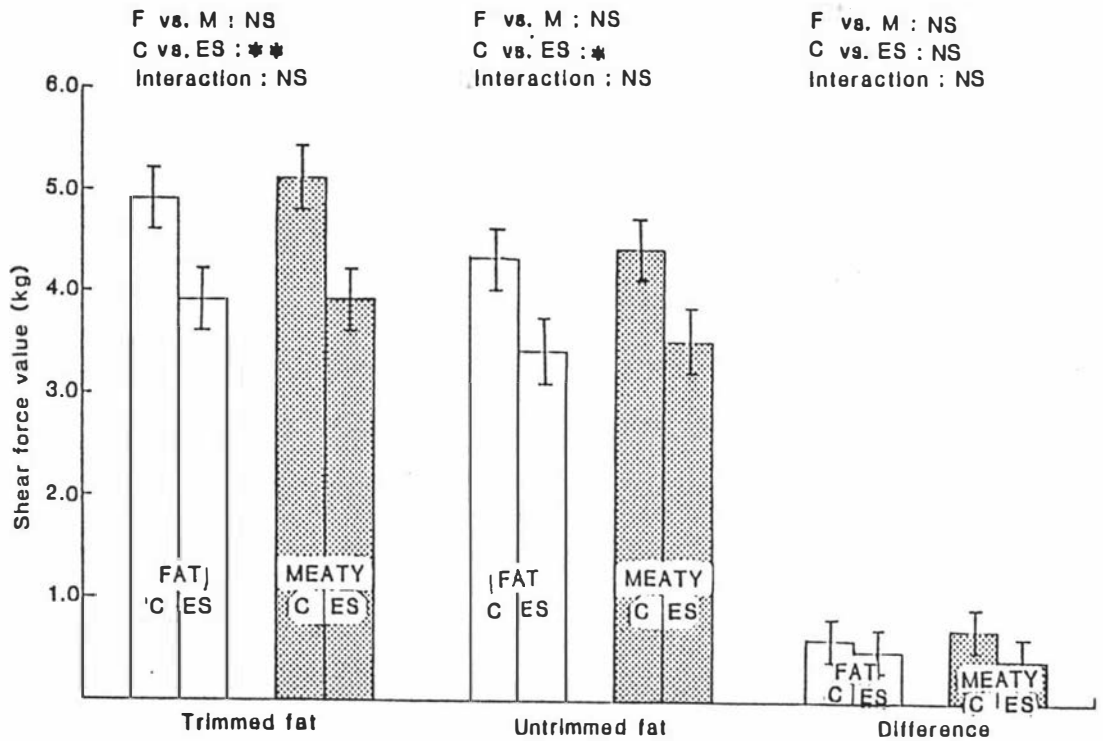


Figure 4-37. Effect of trimming the subcutaneous fat from M. longissimus of the right side and of electrical stimulation on shear force values of that muscle for Southdown rams from two selection lines (fat and meaty; Experiment 5). Least squares means for the two treatments and the difference between the treatments are shown. Standard error bars are included and above each set of four histograms are shown the levels of significance of the fat versus the meaty lines, of the unstimulated (C) versus the stimulated (ES) treatments and of the interaction.

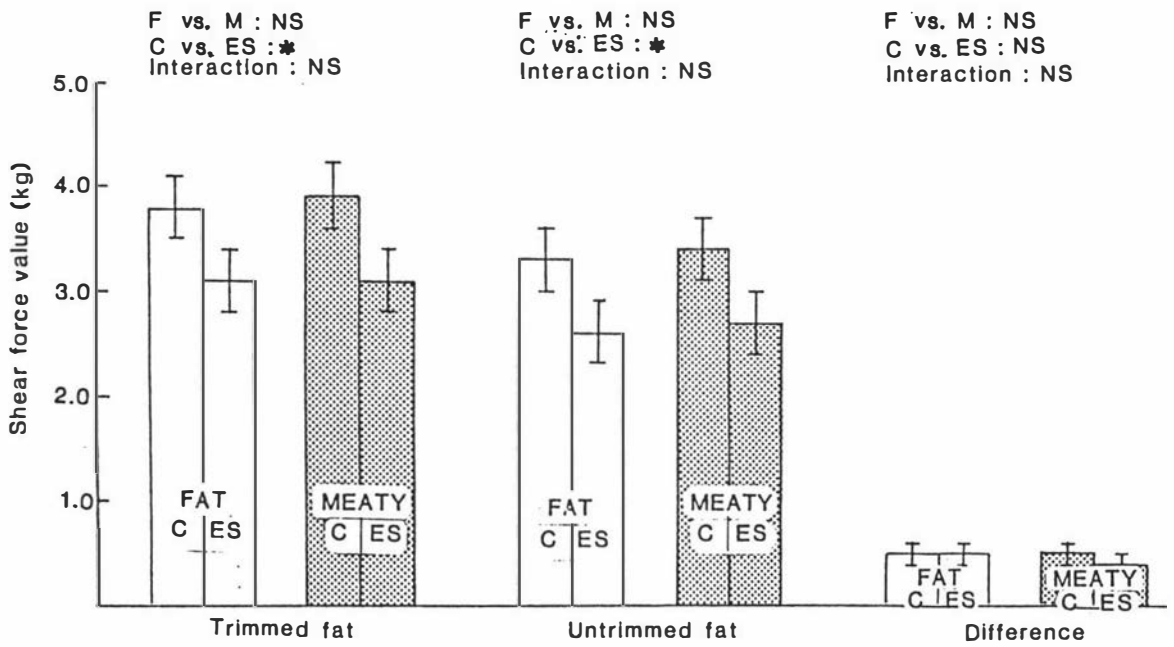


Figure 4-38. Effect of trimming the subcutaneous fat from M. longissimus of the right side and of electrical stimulation on shear force values of that muscle for Southdown rams from two selection lines (fat and meaty; Experiment 6). Least squares means for the two treatments and the difference between the treatments are shown. Standard error bars are included and above each set of four histograms are shown the levels of significance of the fat versus the meaty lines, of the unstimulated (C) versus the stimulated (ES) treatments and of the interaction.

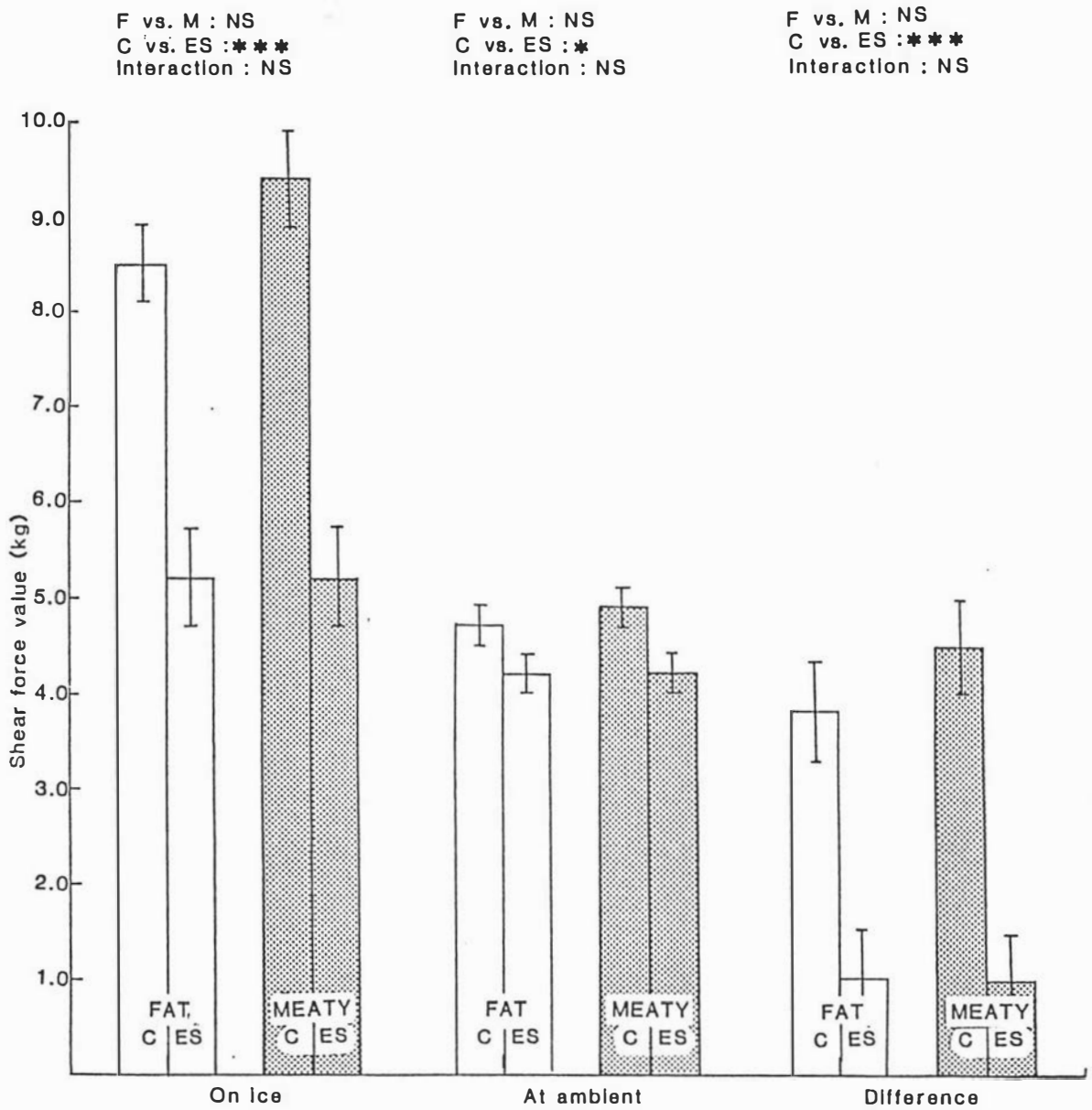


Figure 4-39. The effect of postmortem temperature and electrical stimulation on shear force values of M. biceps femoris for Southdown rams from two selection lines (fat and meaty; Experiment 5). Least squares means for the two treatments and the difference between the treatments are shown. Standard error bars are included and above each set of four histograms are shown the levels of significance of the fat versus the meaty lines, of the unstimulated (C) versus the stimulated (ES) treatments and of the interaction.

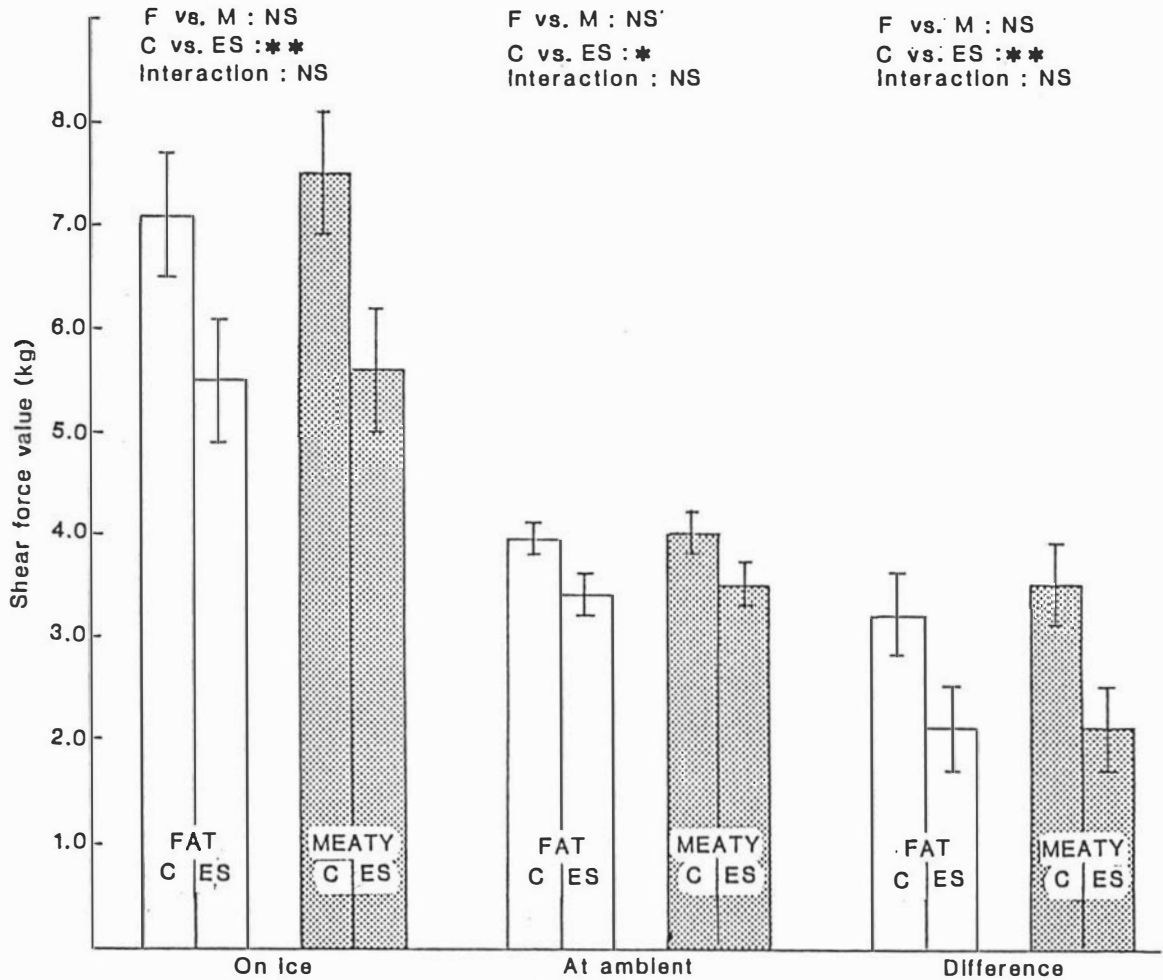


Figure 4-40. The effect of postmortem temperature and electrical stimulation on shear force values of M. biceps femoris for Southdown rams from two selection lines (fat and meaty; Experiment 6). Least squares means for the two treatments and the difference between the treatments are shown. Standard error bars are included and above each set of four histograms are shown the levels of significance of the fat versus the meaty lines, of the unstimulated (C) versus the stimulated (ES) treatments and of the interaction.

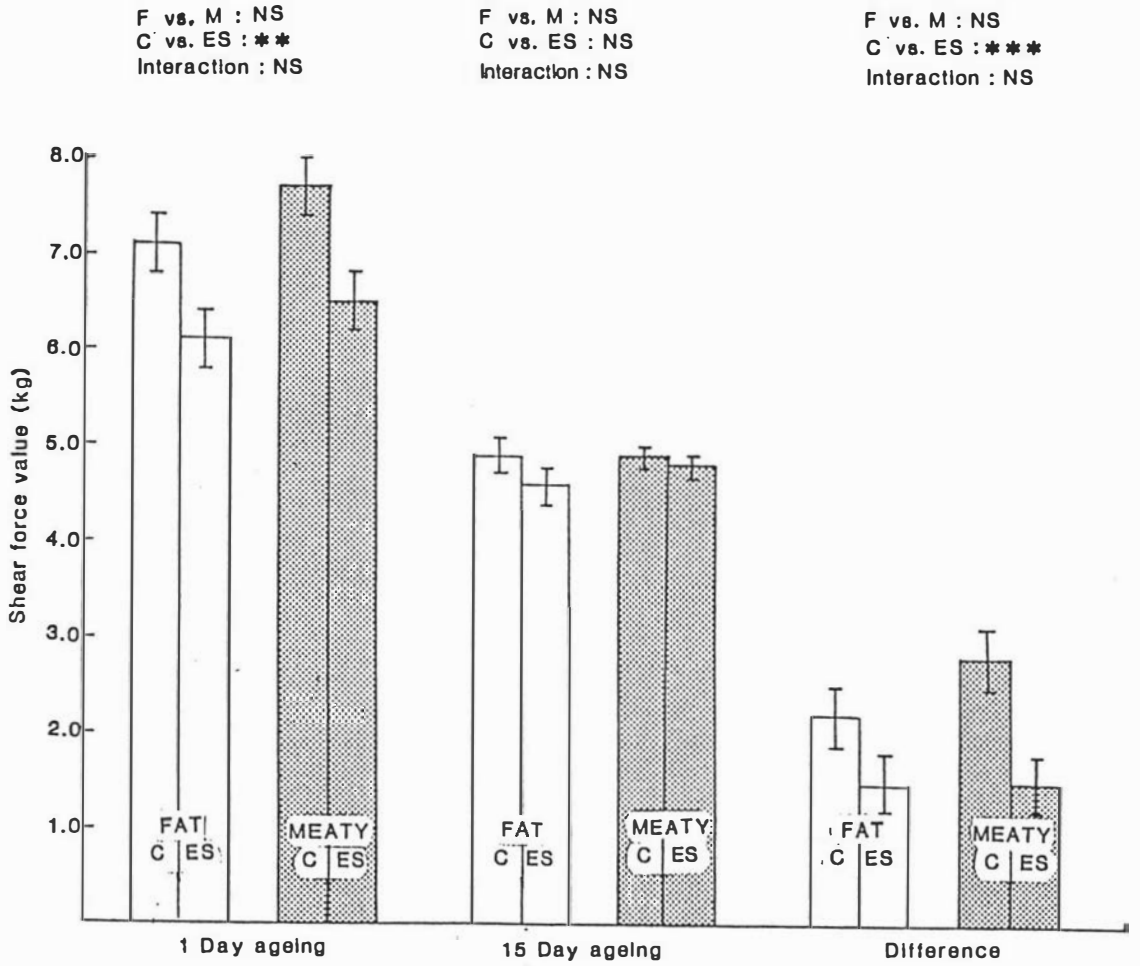


Figure 4-41. The effect of postmortem aging and of electrical stimulation on shear force values of *M. semimembranosus* for Southdown rams from two selection lines (fat and meaty; Experiment 5). Least squares means for the two treatments and the difference between the treatments are shown. Standard error bars are included and above each set of four histograms are shown the levels of significance of the fat versus the meaty lines, of the unstimulated (C) versus the stimulated (ES) treatments and of the interaction.

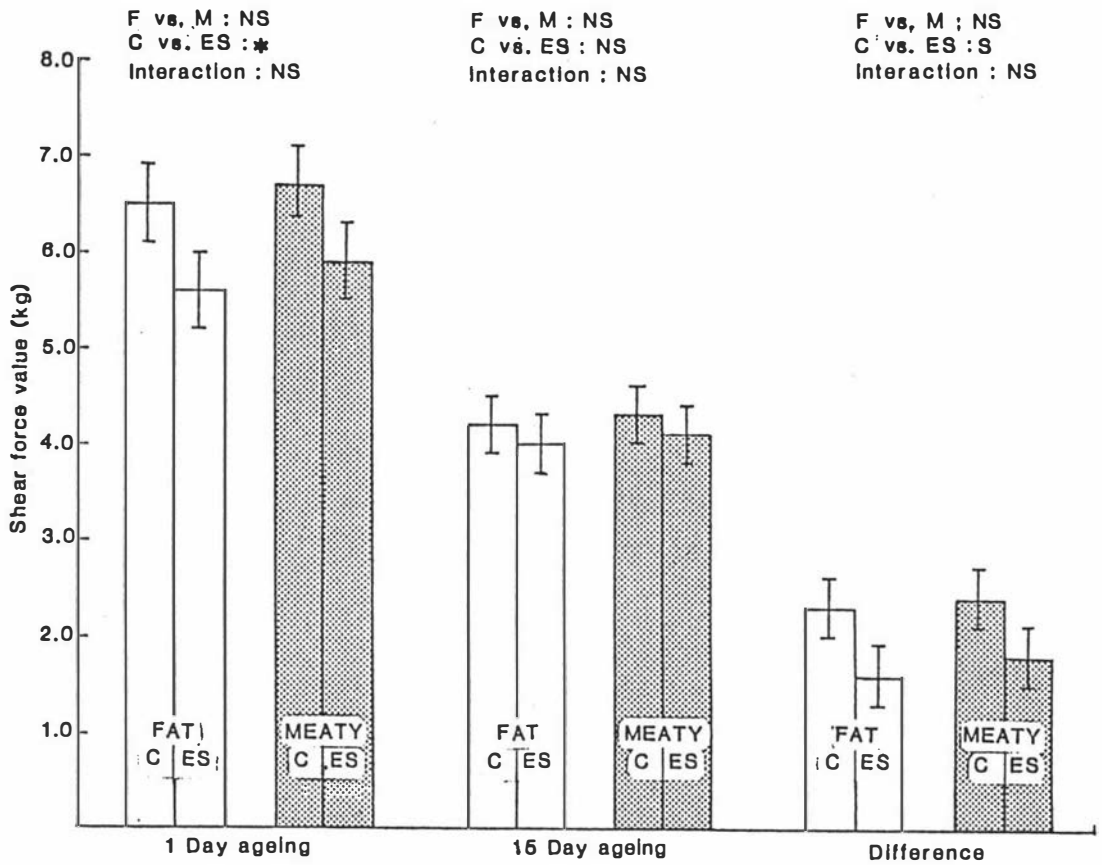


Figure 4-42. The effect of postmortem aging and of electrical stimulation on shear force values of *M. semimembranosus* for Southdown rams from two selection lines (fat and meaty; Experiment 6). Least squares means for the two treatments and the difference between the treatments are shown. Standard error bars are included and above each set of four histograms are shown the levels of significance of the fat versus the meaty lines, of the unstimulated (C) versus the stimulated (ES) treatments and of the interaction.

unstimulated carcasses, regardless of the selection line or the postmortem treatments. In Experiment 6, the shear force values of the same four muscles from the two treatment groups were also significantly different, but the differences between the two groups were less than those in Experiment 5. The smaller stimulation effects on shear values in Experiment 6, as compared with Experiment 5, can probably be explained by the fact that the stimulation was applied 5 min later for Experiment 6. In general, meat from the meaty line showed slightly larger responses to stimulation than that from the fat line, but this response was not reflected in significant interaction effects for either Experiment 5 or 6.

The importance of interactions between the two selection lines and the postmortem treatments other than electrical stimulation, was assessed by analysing for line effects on the differences between the mean shear forces for the various treatments in Experiments 5 and 6. The most salient evidence for the relationship between subcutaneous fat and tenderness is provided in Figures 4-37 and 4-38, which show significant differences ($P < 0.05$) between trimmed and untrimmed sides for tenderness of M. longissimus for Experiments 5 and 6. The interactions between stimulation and trimming treatments were not significant in either experiment. This indicated that the stimulation treatment was not helping to prevent cold shortening when the fat had been trimmed from over M. longissimus. Furthermore, selection line by trimming treatments interaction was also not significant.

Figures 4-39 and 4-40 show results for the M. biceps femoris which had been held either at 0°C or at ambient temperature for 24 h postmortem. These results revealed a highly significant difference between the two temperatures regardless of the two lines and stimulation treatments (Table 4-48). In Experiment 5, the reductions in shear values in response to electrical stimulation were 45% and 39% for the meaty and fat lines, respectively, while the corresponding reductions in Experiment 6 were 25% and 23%. However, interactions between selection line and stimulation were not significant. On the other hand, the toughening effect of holding a muscle on ice for 24 h postmortem was much less ($P < 0.01$) for muscles from carcasses that had been electrically stimulated (Figures 4-39 and 4-40 for Experiments 5 and 6, respectively).

Least squares means for shear force values (kg) for the two selection lines, the two ageing times and for electrical stimulations are given in Figures 4-41 (Experiment 5) and 4-42 (Experiment 6), for M. semimembranosus. The shear force values for muscles from the 1-day ageing treatment were significantly higher than those from the 15-day ageing treatment. Shear force values decreased in response to ageing treatments by 29.6% (6.85 vs 4.82) and 33% (6.15 vs 4.12) over 14-days ageing for Experiments 5 and 6, respectively (Table 4-48). In Experiment 5, the differences between the two ageing times revealed that the shear force values in the fat line dropped significantly by 30% between stimulated and unstimulated treatments, whereas a 42% drop was observed under the same circumstances for the meaty line, but the difference of 12% was not significant. In Experiment 6 also, the difference of 7% between the selection lines was not significant.

The significant improvement in tenderness resulting from ageing, or ageing plus stimulation treatments, compared to the untreated control was evident in Figures 4-41 and 4-42 for Experiments 5 and 6, respectively. The significant difference between stimulation, and stimulation plus ageing treatments, and also between stimulation and ageing treatments, was also shown in the same Figure, but no significant difference between ageing and stimulation plus ageing treatments was found in either experiment.

4-4 CORRELATIONS BETWEEN FATNESS AND OTHER CARCASS AND MUSCLE CHARACTERISTICS

Simple correlation coefficients between carcass fatness, linear measurements, weights of certain non-carcass components, physico-chemical characteristics of muscle, and meat quality parameters are presented in this Section. The homogeneity of the two correlations (within the fat and meaty lines) was tested for each characteristic by first transformation of the two correlations values to Z's and then applying the normal T-test (Steel and Torrie, 1981). This test showed that the two correlations were homogeneous for all the variables considered so that correlations are given without regard for the two selection lines.

4-4-1 CORRELATIONS BETWEEN VARIOUS MEASURES OF FATNESS

Table 4-49 presents simple correlation coefficients between various fatness measurements for each of the 6 experiments. High positive correlations existed between most of the fatness measurements considered in this study. An interesting feature is the consistently high correlation between the ultrasonic fat depth measurement at position C with carcass fat depth C across all experiments. These correlations reflect the precision of the selection. Among the highest and most consistent correlations between various fat depth measurements were those between fat depth J and all other fat depth measurements (Table 4-49). Within these relationships the highest correlations were found between J and GR, while the lowest were between S2 and L2.

The weights of the five fat depots and total side fat were significantly correlated with each other and with all fat depth measurements, with the highest correlations being with tissue depth GR. The correlations in Table 4-49 show that all fatness measurements increased as carcass weight increased. These correlations were consistently higher in Experiments 1 and 2 than in the other four experiments, probably because of the wider range in carcass weight.

4-4-2 CORRELATIONS BETWEEN FATNESS, CARCASS LINEAR MEASUREMENTS AND CERTAIN NON-CARCASS COMPONENTS

Simple correlation coefficients between fatness measurements and carcass linear measurements and the weight of certain non-carcass components are given for the six experiments in Table 4-50. These results suggest that all linear and non-carcass components increased as carcass weight increased. Relationships between carcass length and measures of fatness showed that in about half of the comparisons, the correlation coefficients were significantly negative despite the fact that all were positively related to carcass weight. A similar trend was found for leg length, but the correlations with fatness were non-significant. Table 4-50 also shows many significant correlations between maximum shoulder width, width from scapula to sternum, width behind the shoulder, and gigot and fatness, with the highest correlations being positive ones between fatness and width behind the

Table 4-49. Simple correlation coefficients between various measures of fatness from six experiments. The numbers along the top of the Table correspond to the numbered variables listed on the left-hand side.

Item	Variable No.	Experiment No.	14	13	12	11	10	9	8	7	6	5	4	3	2	
Carcass weight	1	1	-	-	.81	.75	.77	.67	.67	-	-	-	-	-	-	-
		2	-	-	.83	.78	.81	.64	.66	-	-	-	-	-	-	-
		3	-	-	-	-	.36	.38	.33	-	.57	.39	.60	.58	.80	-
		4	-	-	-	-	.36	.33	-	-	.44	.43	-	-	-	-
		5	.43	.50	.74	.63	.58	.48	.45	-	.72	.69	.56	.78	.84	-
		6	.24	.38	.62	.57	.66	.40	.30	.59	.49	.69	.71	.75	.88	-
Total side fat	2	3	-	-	-	.58	.78	.55	-	.70	.80	.68	.80	-	-	
		5	.71	.83	.94	.85	.87	.79	.80	-	.83	.81	.80	.98	-	
		6	.49	.48	.85	.81	.85	.50	.58	.66	.53	.75	.77	.88	-	
Subcutaneous fat (side)	3	3	-	-	-	.64	.72	.65	-	.63	.76	.70	-	-	-	
		5	.70	.83	.92	.83	.91	.86	.86	-	.77	.77	.92	-	-	
		6	.56	.34	.77	.80	.83	.45	.68	.88	.46	.73	.63	-	-	
Intermuscular fat (side)	4	3	-	-	-	.46	.53	.41	-	.75	.65	-	-	-	-	
		5	.64	.71	.86	.76	.69	.57	.57	-	.82	.78	-	-	-	
		6	.52	.33	.69	.49	.62	.37	.30	.52	.90	.92	-	-	-	
Omental fat	5	3	-	-	-	.43	.50	.41	-	.69	-	-	-	-	-	
		4	-	-	-	.41	.46	-	-	.63	-	-	-	-	-	
		5	.69	.67	.77	.63	.67	.62	.62	-	.88	-	-	-	-	
		6	.59	.57	.71	.56	.66	.52	.52	.65	.74	-	-	-	-	
Kidney fat	6	3	-	-	-	.45	.40	.38	-	-	-	-	-	-	-	
		4	-	-	-	.59	.48	-	-	-	-	-	-	-	-	
		5	.60	.66	.75	.59	.67	.60	.59	-	-	-	-	-	-	
		6	.28	.37	.50	.38	.47	.39	.28	.35	-	-	-	-	-	
Mesenteric fat	7	6	.26	.38	.55	.67	.73	.40	.35	-	-	-	-	-	-	
Ultrasonic fat depth C	8	1	-	-	.89	.87	.87	.96	-	-	-	-	-	-	-	
		2	-	-	.86	.85	.83	.93	-	-	-	-	-	-	-	
		3	-	-	-	-	.44	.91	-	-	-	-	-	-	-	
		5	.70	.82	.81	.80	.85	.97	-	-	-	-	-	-	-	
		6	.61	.72	.79	.69	.75	.95	-	-	-	-	-	-	-	
Fat depth C	9	1	-	-	.89	.89	.87	-	-	-	-	-	-	-	-	
		2	-	-	.86	.85	.83	-	-	-	-	-	-	-	-	
		3	-	-	-	-	.84	-	-	-	-	-	-	-	-	
		4	-	-	-	-	.85	-	-	-	-	-	-	-	-	
		5	.65	.77	.81	.79	.83	-	-	-	-	-	-	-	-	
		6	.69	.66	.77	.80	.80	-	-	-	-	-	-	-	-	
Fat depth J	10	1	-	-	.98	.94	-	-	-	-	-	-	-	-	-	
		2	-	-	.98	.92	-	-	-	-	-	-	-	-	-	
		5	.73	.74	.92	.84	-	-	-	-	-	-	-	-	-	
		6	.68	.68	.90	.80	-	-	-	-	-	-	-	-	-	
Fat depth S2	11	1	-	-	.94	-	-	-	-	-	-	-	-	-	-	
		2	-	-	.91	-	-	-	-	-	-	-	-	-	-	
		5	.60	.73	.93	-	-	-	-	-	-	-	-	-	-	
		6	.42	.52	.74	-	-	-	-	-	-	-	-	-	-	
Tissue depth GR	12	5	.73	.77	-	-	-	-	-	-	-	-	-	-	-	
		6	.50	.60	-	-	-	-	-	-	-	-	-	-	-	
Fat depth LG	13	5	.66	-	-	-	-	-	-	-	-	-	-	-	-	
		6	.51	-	-	-	-	-	-	-	-	-	-	-	-	
Fat depth L2	14	5	-	-	-	-	-	-	-	-	-	-	-	-	-	
		6	-	-	-	-	-	-	-	-	-	-	-	-	-	

For N=64: P<0.05 when r>.25 and P<0.01 when r>.33 (Experiments 1 and 2).
 For N=30: P<0.05 when r>.35 and P<0.01 when r>.45 (Experiment 3).
 For N=18: P<0.05 when r>.44 and P<0.01 when r>.56 (Experiment 4).
 For N=24: P<0.05 when r>.39 and P<0.01 when r>.50 (Experiments 5 and 6).
 C, J, S2, GR, LG and L2 are described in Table 3-3 and Figure 3-3.

Table 4-50. Simple correlation coefficients showing relationships between fatness and carcass linear measurements and certain non-carcass components for four experiments.

	Experiment No.	Carcass weight	Carcass							
			TSF	C	J	S2	GR	LG	L2	
Carcass length (LB)	3	.41	-.25	-.59	-.27	-	-	-	-	
	4	.19	-	-.65	-.52	-	-	-	-	
	5	.30	-.19	-.45	-.46	-.39	-.36	-.41	-.51	
	6	.19	-.15	-.33	-.34	-.25	-.33	-.40	-.12	
	Maximum shoulder width (WF)	3	.64	.40	.26	.24	-	-	-	-
		4	.66	-	.22	.14	-	-	-	-
5		.80	.75	.49	.52	.71	.75	.55	.45	
Depth from scapula to sternum (Th)	6	.29	.34	.35	.40	.42	.36	.39	.33	
	5	.64	.50	.23	.35	.40	.43	.33	.06	
	6	.21	.25	.40	.44	.33	.44	.47	.22	
Width behind shoulder (WTH)	3	.24	.53	.53	.36	-	-	-	-	
	4	.36	-	.63	.51	-	-	-	-	
	5	.78	.91	.75	.83	.91	.94	.77	.72	
	6	.31	.28	.42	.46	.37	.45	.47	.17	
	Gigot (G)	3	.55	.42	.28	.23	-	-	-	-
		4	.55	-	.12	.15	-	-	-	-
5		.87	.63	.34	.33	.42	.52	.43	.30	
Leg length (T)	6	.07	.18	.39	.37	.27	.37	.45	.17	
	3	.52	-.10	-.59	-.23	-	-	-	-	
	4	.29	-	-.27	-.28	-	-	-	-	
M. Longissimus depth (B)	5	.32	-.02	-.19	-.24	-.12	-.13	-.28	-.45	
	6	.25	-.14	-.34	-.33	-.24	-.32	-.21	-.13	
	1	.75	-	.51	.68	.64	.71	-	-	
	2	.79	-	.50	.69	.65	.71	-	-	
	3	.24	.28	.33	.21	-	-	-	-	
	4	.68	-	.24	.23	-	-	-	-	
M. Longissimus width (A)	5	.61	.74	.61	.67	.79	.80	.69	.59	
	6	.10	.16	.36	.35	.26	.35	.43	.16	
	1	.54	-	.21	.25	.29	.32	-	-	
	2	.55	-	.17	.21	.26	.26	-	-	
	3	.16	-.19	-.17	-.27	-	-	-	-	
	4	.46	-	-.45	-.43	-	-	-	-	
M. Longissimus area	5	.24	-.10	-.28	-.23	-.01	-.04	-.29	-.31	
	6	.32	.13	-.34	-.32	-.23	-.32	-.21	-.15	
	1	.78	-	.52	.65	.65	.71	-	-	
	2	.80	-	.46	.62	.60	.66	-	-	
	3	.42	.32	.28	.38	-	-	-	-	
	4	.65	-	.06	.08	-	-	-	-	
Foregut empty (kg)	5	.59	.52	.32	.33	.61	.58	.42	.36	
	6	.50	.37	.03	.07	.14	.20	-.03	.03	
	3	.49	.25	-.51	-.36	-	-	-	-	
	5	.26	.10	-.03	.05	.06	.09	.06	-.04	
	6	.64	.24	-.10	.15	.28	.29	.10	-.29	
	Intestines	3	.36	-.15	-.35	-.12	-	-	-	-
5		.07	-.31	-.45	-.46	-.34	-.37	-.41	-.46	
6		.48	-.25	-.16	-.23	-.02	-.16	-.04	-.46	
Liver weight	3	.44	.30	-.10	.01	-	-	-	-	
	4	.27	-	-.06	-.07	-	-	-	-	
	5	.18	-.02	-.11	-.13	-.11	-.04	-.09	.01	
Heart weight	6	.76	.12	.06	.13	.11	.13	.14	-.12	
	3	.17	.07	.04	-.03	-	-	-	-	
	4	.25	-	-.42	-.40	-	-	-	-	
Kidney weight	5	.35	-.20	-.45	-.22	-.21	-.18	-.22	-.18	
	6	.53	.17	-.44	-.14	-.10	-.14	-.43	-.41	
	3	.33	-.16	-.33	-.06	-	-	-	-	
	4	.20	-	-.12	-.11	-	-	-	-	
	5	.48	-.26	-.15	-.03	.01	.10	.13	.10	
	6	.27	-.27	-.28	-.18	.10	.18	.15	.07	

For N=64: P<0.05 when r>.25 and P<0.01 when r>.33 (Experiments 1 and 2).

For N=30: P<0.05 when r>.35 and P<0.01 when r>.45 (Experiment 3).

For N=18: P<0.05 when r>.44 and P<0.01 when r>.56 (Experiment 4).

For N=24: P<0.05 when r>.39 and P<0.01 when r>.50 (Experiments 5 and 6).

For definitions of abbreviations see Table 4-1.

C, J, S2, GR, LG and L2 see Table 3-3 and Figure 3-3.

shoulder. The correlations between depth, width, and area of M. longissimus with fatness were also examined. Higher levels of fatness were associated with increased M. longissimus depth (B), inconsistent changes in M. longissimus width (A) and increased M. longissimus area.

The correlation coefficients between the weights of non-carcass components and fatness were generally low and non-significant.

4-4-3 RELATIONSHIPS BETWEEN THE CELLULARITY OF FIVE FAT DEPOTS AND CARCASS FATNESS

Table 4-51 gives the simple correlation coefficients between fatness measurements and the cellularity characteristics of subcutaneous, intermuscular, omental, mesenteric, and kidney fat depots for three experiments. The weight of fat in the five fat depots, as well as in the total side, was positively correlated with the average number and diameter of adipose cells. Higher correlations were found between each fat depot weight and their average cell diameter than with their average cell number for all three experiments. As expected, positive correlation coefficients existed between the cellularity characteristics of the five fat depots and fat depth measurements. Across the three experiments, inconsistent relationships were found between the number and average diameter of adipocytes (Table 4-51). Correlations between the diameters of adipocytes from different depots are also shown in Table 4-51.

4-4-4 CORRELATION BETWEEN FATNESS AND MUSCLE FIBRE PARAMETERS

Relationships between fatness measurements and muscle fibre types and diameters from Experiments 5 and 6 are given in Table 4-52 as simple correlation coefficients. The proportion of red muscle fibres was significantly and positively correlated with all fat thickness measurements in Experiments 5 and 6 and with total side fat weight in Experiment 5. Also in Experiment 5, a few significant negative correlations were found between fatness and intermediate muscle fibre proportion. Low, negative, and non-significant ($P > 0.05$) correlations were obtained between fatness and white muscle fibre proportion across both experiments. Correlations of measures of fatness with the diameter of the three muscle fibre types were low and non-significant.

Table 4-51. Simple correlation coefficients between various measures of fatness and cellularity characteristics of five adipose tissue depots.

Item	Experiment								Kidney fat	Omental fat	Mesenteric fat	Diameter				
	No.	TSF	C	J	S2	GR	SCF	IMF				SCF	IMF	Kidney	Omental	Mesenteric
IMF diameter	4	-	.65	.55	-	-	.60	.83	.36	.20	-	.26	-	-	-	-
	5	.48	.63	.61	.44	.47	.59	.72	.39	.29	-	.27	-	.16	.25	-
	6	.35	.60	.50	.44	.65	.39	.68	.33	.35	.19	.37	-	.38	.29	.58
IMF number	4	-	.11	.15	-	-	.24	.43	.18	.44	-	.23	.11	-	-	-
	5	.62	.31	.45	.55	.64	.47	.41	.63	.77	-	.32	-.24	.48	.26	-
	6	.50	.18	.26	.24	.35	.38	.63	.37	.48	.18	.12	-.21	.31	.32	-.05
SCF diameter	4	-	.38	.34	-	-	.78	.43	.26	.36	-	-	.26	-	-	-
	5	.59	.57	.64	.60	.66	.80	.56	.39	.43	-	-	.27	.46	.65	-
	6	.42	.36	.54	.47	.50	.67	.48	.42	.33	.26	-	.37	.52	.56	.46
SCF number	4	-	.70	.82	-	-	.45	.54	.16	.46	-	-.23	.06	-	-	-
	5	.76	.66	.73	.68	.73	.62	.70	.74	.65	-	.21	.57	.37	.27	-
	6	.58	.35	.50	.43	.51	.41	.38	.19	.52	.47	.07	.08	.20	.14	.03
Kidney fat diameter	5	.55	.53	.43	.54	.50	.52	.51	.70	.57	-	.46	.16	-	.59	-
	6	.44	.52	.52	.45	.61	.46	.44	.86	.40	.16	.52	.38	-	.42	.65
Kidney fat number	5	.47	.25	.45	.26	.46	.42	.54	.47	.50	-	.08	.28	-.29	.11	-
	6	.41	.11	.33	.11	.31	.38	.38	.45	.42	.24	.04	-.01	.06	.03	-.08
Omental fat diameter	5	.60	.67	.50	.57	.58	.59	.37	.57	.91	-	.65	.25	.59	-	-
	6	.56	.50	.56	.69	.53	.54	.61	.29	.71	.43	.56	.29	.42	-	.38
Omental fat number	5	.62	.40	.54	.47	.62	.58	.77	.50	.41	-	.18	.08	.33	.15	-
	6	.43	.06	.32	.38	.39	.45	.39	.38	.45	.33	-.07	.14	.20	-.29	-.12
Mesenteric fat diameter	6	.37	.52	.53	.49	.54	.50	.47	.19	.38	.59	.46	.58	.65	.38	-
Mesenteric fat number	6	.35	.28	.28	.24	.09	.31	.22	.09	.33	.42	-.13	-.24	.37	.23	-.15

For N=18: P<0.05 when r>.44 and P<0.01 when r>.56 (Experiment 4).

For N=24: P<0.05 when r>.39 and P<0.01 when r>.50 (Experiments 5 and 6).

For definitions of abbreviations see Table 4-1.

C, J, S2, GR see Table 3-3 and Figure 3-3.

Table 4-52. Simple correlation coefficients between various measures of fatness and muscle fibre parameters for two experiments.

Item	Experiment							
	No.	TSF	C	J	S2	GR	LG	L2
Red muscle fibre %	5	.56	.61	.57	.48	.60	.55	.48
	6	.31	.62	.43	.45	.41	.40	.39
Intermediate %	5	-.47	-.26	-.39	-.40	-.50	-.35	-.30
	6	-.22	-.21	-.22	-.21	-.28	-.26	-.25
White fibre %	5	-.02	-.12	-.19	-.08	-.10	-.17	-.08
	6	-.05	-.07	-.05	-.02	-.06	-.10	-.01
Red fibre diameter	5	.28	.37	.33	.29	.30	.23	.21
	6	.15	.24	.32	.07	.27	.24	.17
Intermediate diameter	5	-.02	-.11	-.19	-.09	-.05	.04	.17
	6	-.29	-.15	-.08	-.33	-.23	.11	.38
White fibre diameter	5	-.01	-.12	-.16	.08	.06	.02	.03
	6	-.08	-.16	-.17	.12	-.14	-.03	-.26

For N=24: $P < 0.05$ when $r > .39$ and $P < 0.01$ when $r > .50$ (Experiments 5 and 6).

For definitions of abbreviations see Table 4-1.

C, J, S2, GR, LG, L2 see Table 3-3 and Figure 3-3.

4-4-5 CORRELATIONS BETWEEN CARCASS FATNESS MEASUREMENTS AND MEAT QUALITY PARAMETERS

Simple correlation coefficients between fatness and meat quality parameters including shear force values, sarcomere lengths, percent cooking losses, pH values, expressed juice, and reflectance values are recorded in Table 4-53 for M. semitendinosus, M. semimembranosus, M. biceps femoris and M. longissimus. Low and non-significant correlation coefficients between meat quality parameters across all four muscles and fatness within the six experiments were obtained. However, the correlation coefficients between sarcomere lengths from the left side of M. longissimus and fat depths C and J (Table 4-53) were found to be significantly positive for Experiment 5. The same Table shows that the relationships between fatness and meat quality in general, were higher for Experiments 1 and 2 than for the other experiments. These differences were most evident in the case of the correlations between fatness and percent cooking losses.

Interrelationships between various meat quality parameters within each muscle are shown in Tables 4-54, 4-55, 4-56 and 4-57 for M. semitendinosus, M. semimembranosus, M. biceps femoris and M. longissimus, respectively. These results show that higher pH values were associated with decreased shear force values and expressed juice, and that higher percent cooking losses were associated with increased expressed juice, particularly in Experiment 6. A few correlations between sarcomere lengths and shear force values were negatively significant for M. semitendinosus and M. longissimus. The reflectance values at different wavelengths were negatively correlated with numerous meat quality characteristics, but most were not significant. Across muscles and experiments low and non-significant correlations were found between different muscles within each experiment, so these data are not presented.

Table 4-53. Simple correlation coefficients showing the relationships between various measures of fatness and parameters of objective quality assessment for four muscles from five experiments.

Item	Experiment No.	M. semitendinosus ¹				M. semimembranosus ²				M. biceps femoris ³				M. longissimus ⁴			
		TSF	C	J	GR	TSF	C	J	GR	TSF	C	J	GR	TSF	C	J	GR
Shear force value:																	
left side	1	-	-.22	-.13	-.18	-	-.13	-.19	-.15	-	-.01	-.02	-.06	-	-.22	-.28	-.31
	2	-	-	-	-	-	-.07	-.21	-.19	-	-.14	-.08	-.13	-	-	-	-
	4	-	-.10	-.15	-	-	-.10	-.12	-	-	-.16	-.20	-	-	-.21	-.29	-
	5	-.14	-.04	-.03	-.03	-.32	-.30	-.32	-.36	-.24	-.02	-.06	-.14	-.02	-.09	-.15	-.09
right side	6	-.11	-.13	-.03	-.04	-.14	-.12	-.04	-.06	-.35	-.05	-.10	-.20	-.17	-.13	-.28	-.31
	5	-	-	-	-	-.04	-.08	-.13	-.14	-.10	-.10	-.08	-.02	-.12	-.04	-.01	-.02
	6	-	-	-	-	-.12	-.19	-.25	-.18	-.07	-.10	-.09	-.05	-.09	-.09	-.13	-.27
Sarcomere length:																	
left side	5	-	-	-	-	-	-	-	-	.25	.30	.32	.28	.33	.40	.45	.38
	6	-.03	-.01	-.05	-.08	-	-	-	-	.30	.36	.37	.29	.28	.36	.23	.26
right side	5	-	-	-	-	-	-	-	-	.10	.15	.18	.13	.05	.03	.17	.13
	6	-.17	-.02	-.04	-.14	-	-	-	-	.20	.19	.15	.12	.02	.10	.04	.10
Cooking loss %:																	
left side	1	-	.23	.21	.23	-	.21	.16	.19	-	.32	.29	.28	-	.32	.30	.31
	2	-	-	-	-	-	.16	.20	.21	-	.46	.48	.45	-	-	-	-
	4	-	.15	.13	-	-	.16	.22	-	-	.10	.10	-	-	.17	.15	-
	5	.10	.38	.14	.09	.04	.13	.07	.04	.20	.15	.19	.21	.16	.26	.14	.09
right side	6	.01	.02	.26	.19	.04	.20	.04	.13	.45	.18	.33	.41	.22	.26	.19	.19
	5	-	-	-	-	.10	.05	.01	.03	.10	.17	.17	.14	-.28	-.21	-.14	-.21
	6	-	-	-	-	.10	.18	.22	.19	.28	.21	.29	.05	-.05	.11	.12	.01
pH value:																	
left side	1	-	-.15	-.14	-.23	-	-.21	-.18	-.20	-	-.31	-.27	-.31	-	-.16	-.04	-.15
	2	-	-	-	-	-	-.11	-.04	-.04	-	-.03	-.01	-.02	-	-	-	-
	4	-	-.23	-.18	-	-	-.25	-.41	-	-	-.21	-.16	-	-	.06	.01	-
	5	-.05	-.07	-.11	-.04	-.02	-.07	-.07	-.09	-.26	-.04	-.21	-.23	-.36	-.38	-.23	-.28
right side	6	-.04	-.04	-.01	-.03	-.29	-.31	-.02	-.01	-.38	-.25	-.37	-.38	-.21	-.24	-.19	-.24
	5	-	-	-	-	.06	.04	.03	.01	-.19	-.21	-.16	-.16	-.33	-.38	-.15	-.23
	6	-	-	-	-	-	-	-	-	-.23	-.01	-.19	-.17	-.18	-.29	-.10	-.16
Expressed juice:																	
left side	4	-	-	-	-	-	-.26	-.33	-	-	.25	.23	-	-	-	-	-
	5	-	-	-	-	-.12	.09	-.03	-.18	.25	.08	.11	.12	.43	.27	.42	.39
right side	6	-	-	-	-	-.14	-.19	-.21	-.05	.28	.34	.38	.18	.20	.22	.26	.24
	5	-	-	-	-	-	-	-	-	.20	.17	.02	.09	-	-	-	-
	6	-	-	-	-	-	-	-	-	.32	.32	.36	.30	.31	.09	.05	.26
Reflectance value:																	
left side	474 nm	4	-	-	-	-	.03	.10	-	-	.15	.20	-	-	.12	.30	-
		5	-	-	-	-.20	.13	.34	.23	-.16	.20	.20	.12	-.12	.13	.15	.10
		6	.12	.03	.12	.05	.38	.37	.30	.52	.21	.32	.35	.23	.15	.12	.07
525 nm		4	-	-	-	-	.05	.16	-	-	.13	.28	-	-	.13	.16	-
		5	-	-	-	-.30	.20	.20	.29	.13	.12	.10	.19	.21	.19	.17	.20
		6	.03	.12	.08	.05	.48	.37	.32	.44	.31	.27	.27	.23	.26	.27	.20
572 nm		4	-	-	-	-	.25	.33	-	-	.04	.06	-	-	.19	.22	-
		5	-	-	-	-.29	.15	.32	.21	.05	.03	.11	.12	.32	.15	.18	.31
		6	.17	.36	.25	.31	.51	.17	.38	.31	.14	.08	.09	.12	.48	.29	.27
630 nm		4	-	-	-	-	.14	.18	-	-	.15	.15	-	-	.24	.18	-
		5	-	-	-	-.22	.16	.12	-	.38	.12	.29	.29	.10	.20	.18	.13
right side		6	.18	.12	.10	.03	.31	.19	.24	.22	.21	.23	.36	.16	.03	.34	.09
474 nm		5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	-	-	-	-	-	-	-	-.19	.14	.12	.10	-	-	-	-
525 nm		5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	-	-	-	-	-	-	-	.13	.11	.14	.07	-	-	-	-
572 nm		5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	-	-	-	-	-	-	-	.11	.35	.12	.09	-	-	-	-
630 nm		5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	-	-	-	-	-	-	-	.19	.13	.18	.14	-	-	-	-

For N=64: P<0.05 when r>.25 and P<0.01 when r>.33 (Experiments 1 and 2). For N=30: P<0.05 when r>.35 and P<0.01 when r>.45 (Experiment 3).

For N=18: P<0.05 when r>.44 and P<0.01 when r>.56 (Experiment 4). For N=24: P<0.05 when r>.39 and P<0.01 when r>.50 (Experiments 5 and 6).

For definitions of abbreviations see Table 4-1.

C, J, GR see Table 3-3 and Figure 3-3.

1 The meat samples from the left side were left with the carcass for 24 h at +10°C, while the meat samples from the right side were placed on ice at 35±2 min postmortem and at about 60-90 min postmortem were transferred to liquid nitrogen for 15 min and finally kept at -30°C for 24 h.

2 For the left and right M. semimembranosus see Section 3-2-1-5.

3 For the left and right M. biceps femoris see Section 3-2-1-4.

4 For the left and right M. longissimus see Section 3-2-1-3.

Table 4-54. Simple correlation coefficients between shear force values, percent cooking losses, pH values, sarcomere lengths, and reflectance values for *M. semitendinosus* from four experiments. The numbers along the top of the Table correspond to the numbered variables listed on the left-hand side.

Item	Variable No.	Experiment No.	Experiment								
			9	8	7	6	5	4	3	2	
<u>Shear force value:</u>											
left side ¹	1	1	-	-	-	-	-	-	-	-.16	.13
		4	-	-	-	-	-	-	-	-.02	-.20
		5	-	-	-	-	-	-	-	-.37	-.33
		6	-.10	-.45	-.54	-.39	-.38	-.43	-.32	-.22	
<u>Cooking loss %:</u>											
left side	2	1	-	-	-	-	-	-	-	-.12	
		4	-	-	-	-	-	-	-	-.22	
		5	-	-	-	-	-	-	-	-.18	
		6	-.10	-.42	-.32	-.21	-.26	-.31	-.01		
<u>pH value:</u>											
left side	3	6	-.04	-.14	-.22	-.29	-.11	-.02			
<u>Sarcomere length:</u>											
left side	4	6	-.15	-.31	-.48	-.25	-.08				
right side ²	5	6	.16	.27	.18	.06					
<u>Reflectance value:</u>											
left side											
474 nm	6	6	.29	.52	.85						
525 nm	7		.37	.62							
572 nm	8		.55								
630 nm	9		-								

For N=64: P<0.05 when r>.25 and P<0.01 when r>.33 (Experiment 1).

For N=18: P<0.05 when r>.44 and P<0.01 when r>.56 (Experiment 4).

For N=24: P<0.05 when r>.39 and P<0.01 when r>.50 (Experiments 6 and 6).

1, 2: The meat samples from the left side were left with the carcass for 24 h at $1\pm 1^{\circ}\text{C}$, while the meat samples from the right side were placed on ice at 35 ± 2 min postmortem and at about 60-90 min postmortem were transferred to liquid nitrogen for 15 min and finally kept at -30°C for 24 h.

Table 4-55. Simple correlation coefficients between shear force values, percent cooking losses, pH values, expressed juice, and reflectance values for *M. semimembranosus* from five experiments. The numbers along the top of the Table correspond to the numbered variables listed on the left-hand side.

Item	Variable No.	Experiment No.	Experiment										
			11	10	9	8	7	6	5	4	3	2	
<u>Shear force value:</u>													
left side ¹	1	1	-	-	-	-	-	-	-	-.33	-	-.19	-
		2	-	-	-	-	-	-	-	-.25	-	.19	-
		4	-.27	-.11	-.07	-.01	-.21	-	-.08	-	-.27	-	-
		5	.30	.26	-.15	-.15	-.18	-.39	-.02	-.21	-.22	.62	-
		6	-.45	.31	-.14	-.10	-.32	-	-.22	.27	-.25	.48	-
right side ¹	2	5	-.12	.21	-.19	-.31	-.12	-	-.15	-.25	-.29	-	
		6	.19	.13	-.25	-.22	.23	-.28	.04	-.14	.24	-	
<u>Cooking loss %:</u>													
left side	3	1	-	-	-	-	-	-	-.01	-	-	-	
		2	-	-	-	-	-	-	-.35	-	-	-	
		4	-.03	.40	-.17	-.01	-.08	-	-.23	-	-	-	
		5	-.09	.10	.14	.10	.07	-	.05	.54	-	-	
		6	-.08	.17	.29	.19	.55	-.15	-.34	.71	-	-	
right side	4	5	.07	.31	.40	.33	-.01	-	.05	-	-		
		6	.03	.27	.43	.41	-.32	.10	.10	-	-		
<u>pH value:</u>													
left side	5	4	-.26	-.33	-.18	-.27	.31	-	-	-	-		
		5	-.15	-.33	-.31	-.13	-.19	-	-	-	-		
		6	-.26	-.22	-.11	-.01	-.49	.74	-	-	-		
right side	6	5	-.33	-.30	-.35	-.15	-.27	-	-	-			
<u>Expressed juice:</u>													
left side	7	4	.15	-.29	-.21	.32	-	-	-	-	-		
		5	.17	.01	-.17	.08	-	-	-	-	-		
		6	-.05	.06	-.11	.02	-	-	-	-	-		
<u>Reflectance value:</u>													
left side 474 nm	8	4	.39	.49	.81	-	-	-	-	-	-		
		5	.14	.32	.48	-	-	-	-	-	-		
		6	.16	.17	.52	-	-	-	-	-	-		
525 nm	9	4	.42	.50	-	-	-	-	-	-	-		
		5	.29	.61	-	-	-	-	-	-	-		
		6	.45	.38	-	-	-	-	-	-	-		
572 nm	10	4	.01	-	-	-	-	-	-	-	-		
		5	.30	-	-	-	-	-	-	-	-		
		6	.1	.3	-	-	-	-	-	-	-		
630 nm	11	4	-	-	-	-	-	-	-	-	-		
		5	-	-	-	-	-	-	-	-	-		
		6	-	-	-	-	-	-	-	-	-		

For N=64: P<0.05 when r>.25 and P<0.01 when r>.33 (Experiments 1 and 2).

For N=18: P<0.05 when r>.44 and P<0.01 when r>.56 (Experiment 4).

For N=24: P<0.05 when r>.39 and P<0.01 when r>.50 (Experiments 6 and 6).

Left and right side see Section 3-2-1-5.

Table 4-56. Simple correlation coefficients between shear force values, percent cooking losses, pH values, expressed juice, sarcomere lengths and reflectance values for *M. biceps femoris* from five experiments. The numbers along the top of the Table correspond to the numbered variables listed on the left-hand side.

Item	Variable No.	Experiment No.	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	
Shear force value:																				
left side ¹	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	.10	-	-.06	-	
		2	-	-	-	-	-	-	-	-	-	-	-	-	-	-.37	-	.08	-	
		4	-	-	-	-	-.10	-.22	-.34	-.41	-	-	-	-	-.14	-	-.52	-	.02	-
		5	-	-	-	-	.11	-.26	-.40	-.30	-.15	-.01	-.10	-.37	-.25	-.16	-.12	.18	.75	-
right side ²	2	5	-	-	-	.01	-.35	-.31	-.16	-.10	.02	-.21	-.31	-.29	-.35	.07	-.09	-	-	
		6	.11	-.14	.08	.08	.02	-.39	-.33	-.05	-.07	-.13	-.03	.01	-.16	.02	.30	.05	-	-
Cooking loss %:																				
left side	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	.08	-	-	-	
		2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-.39	-	-	-
		4	-	-	-	-	.42	.01	.13	.04	-	-	-	-	.22	-	-.21	-	-	-
		5	-	-	-	-	.12	.19	.25	.07	.09	.13	.09	.05	.01	-.32	.42	-	-	-
right side	4	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
		6	.19	-.21	-.36	-.30	.16	.14	.26	.05	.04	.27	.11	.12	.14	-.19	.34	-	-	-
pH value:	5	4	-	-	-	-	-.05	-.14	-.13	-.25	-	-	-	-.40	-	-	-	-	-	
		5	-	-	-	-	-.30	-.25	-.17	-.10	.19	.16	-.44	-.33	-.54	-	-	-	-	-
		6	.30	-.10	-.06	-.21	-.26	-.27	-.05	-.06	.14	.25	.08	-.46	.20	-	-	-	-	-
Expressed juice:	7	5	-	-	-	-	-.20	.28	.01	.06	-	-	-	-	-	-	-	-	-	
		6	.01	.23	.15	.25	.30	.26	.27	.34	-.05	.14	.35	-	-	-	-	-	-	-
Sarcomere length:	9	5	-	-	-	-	.15	.13	.31	.17	.78	-	-	-	-	-	-	-	-	
		6	-.19	.04	-.04	-.23	.12	.03	.24	.14	.45	-	-	-	-	-	-	-	-	-
Reflectance value:	11	4	-	-	-	-	.25	.83	.91	-	-	-	-	-	-	-	-	-	-	
		5	-	-	-	-	.27	.06	.25	-	-	-	-	-	-	-	-	-	-	
		6	.31	.25	.35	.20	.27	.50	.73	-	-	-	-	-	-	-	-	-	-	-
525 nm	12	4	-	-	-	-	.29	.77	-	-	-	-	-	-	-	-	-	-	-	
		5	-	-	-	-	.18	.46	-	-	-	-	-	-	-	-	-	-	-	-
		6	.27	.16	.18	-.04	.22	.82	-	-	-	-	-	-	-	-	-	-	-	-
572 nm	13	4	-	-	-	-	.14	-	-	-	-	-	-	-	-	-	-	-	-	
		5	-	-	-	-	.04	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	.16	.25	.21	.05	.15	-	-	-	-	-	-	-	-	-	-	-	-	-
630 nm	14	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
		5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	-.10	-.04	-.01	-.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-
right side	15	6	.77	.51	-.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
		6	.66	.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

For N=64: P<0.05 when r>.25 and P<0.01 when r>.33 (Experiments 1 and 2).
 For N=30: P<0.05 when r>.35 and P<0.01 when r>.45 (Experiment 3).
 For N=18: P<0.05 when r>.44 and P<0.01 when r>.56 (Experiment 4).
 For N=24: P<0.05 when r>.39 and P<0.01 when r>.50 (Experiments 5 and 6).
 1, 2 Left and right sides for Experiments 5 and 6 see Section 3-2-1-4.

Table 4-57. Simple correlation coefficients between shear force values, percent cooking losses, pH values, expressed juice, sarcomere lengths and reflectance values for *M. longissimus* from five experiments. The numbers along the top of the Table correspond to the numbered variables listed on the left-hand side.

Item	Variable No.	Experiment No.	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2
Shear force value:																			
left side (rack)	1	1	-	-	-	-	-	-	-	-	-	-	-	.10	-	-	-.01	-	-
		4	-	-	-	-	-	-	-	-	-	-	-	-.40	-	-	-.29	-	-
		5	-.09	-.30	-.17	-.30	-.43	-.55	-	-	-.30	-.29	-.21	-.10	.02	-.12	-.06	.74	.77
left side ¹ (loin)	2	5	.13	-.31	-.20	-.35	-.41	-.43	-	-	-.27	-.14	-.01	.13	.05	.03	-.10	.91	-
		6	.08	-.22	-.27	-.43	-.07	-.30	-.18	-.01	-	.13	-.15	-	.08	.37	-	.86	-
right side ² (loin)	3	5	.15	-.16	-.27	-.37	-.24	-.30	-	-	-.07	-.12	-.03	.13	-.03	-.03	-.07	-	-
		6	.12	-.13	-.31	-.45	-.05	-.40	-.10	-.01	-	.03	-.27	-	.23	.39	-	-	-
Cooking loss %:																			
left side (rack)	4	1	-	-	-	-	-	-	-	-	-	-	-	-.05	-	-	-	-	-
		4	-	-	-	-	-	-	-	-	-	-	-	-.40	-	-	-	-	-
		5	.10	.14	.13	.20	.05	.03	-	-	.19	.30	-.39	-.40	.49	.42	-	-	-
left side (loin)	5	5	.05	-.21	-.15	-.11	.07	-.17	-	-	.20	-.03	-.13	-.42	.34	-	-	-	-
		6	.01	-.13	-.21	-.21	.10	-.39	.10	-.44	-	-.21	-.12	-	.36	-	-	-	-
right side (rack)	6	5	.07	.09	.17	.09	.19	-.05	-	-	-.06	-.31	-.29	-.49	-	-	-	-	-
		6	.12	.18	.16	.14	-.01	-.15	.10	-.11	-	-.13	-.28	-	-	-	-	-	-
pH value:																			
left side (rack)	7	5	-.15	-.13	-.09	-.35	-.05	-.16	-	-	-.15	.13	.33	-	-	-	-	-	-
left side (loin)	8	5	-.29	-.25	-.01	-.01	.25	-.09	-	-	.18	.90	-	-	-	-	-	-	-
		6	-.24	-.14	-.02	-.03	-.03	.14	.23	-.15	-	.74	-	-	-	-	-	-	-
right side (loin)	9	5	-.20	-.36	-.25	-.13	.31	.23	-	-	.22	-	-	-	-	-	-	-	-
		6	-.15	-.31	-.18	-.10	-.21	-.25	-.22	-.37	-	-	-	-	-	-	-	-	-
Expressed juice:																			
left side (rack)	10	5	.14	.04	.13	.10	.15	-	-	-	-	-	-	-	-	-	-	-	-
left side (loin)	11	5	.26	-.19	.21	.15	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	.19	-.24	.11	.03	-.01	.04	.33	-	-	-	-	-	-	-	-	-	-
right side (loin)	12	5	.30	.27	.09	.17	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	.27	.32	.15	.13	.38	.43	-	-	-	-	-	-	-	-	-	-	-
Sarcomere length:																			
left side (loin)	13	5	.35	.38	.35	.01	.60	-	-	-	-	-	-	-	-	-	-	-	-
		6	.25	.34	.31	.25	.41	-	-	-	-	-	-	-	-	-	-	-	-
right side (loin)	14	5	.33	-.11	.27	.15	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	.34	-.18	.21	.11	-	-	-	-	-	-	-	-	-	-	-	-	-
Reflectance value:																			
left side																			
474 nm	15	5	.38	.52	.87	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	.38	.42	.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-
525 nm	16	5	.28	.62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	.30	.41	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
572 nm	17	5	.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
630 nm	18	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

For N=64: P<0.05 when r>.25 and P<0.01 when r>.33 (Experiment 1).
 For N=18: P<0.05 when r>.44 and P<0.01 when r>.56 (Experiment 3).
 For N=24: P<0.05 when r>.39 and P<0.01 when r>.50 (Experiments 5 and 6).
 Left and right sides for Experiments 5 and 6 see Section 3-2-1-3.

CHAPTER 5. DISCUSSION

5-1 INTRODUCTION

The major purpose of this study was to provide information on carcass and meat quality of sheep from two genetic lines slaughtered at approximately the same ages and weights. It should be noted that for the experiments involving Southdown rams (Experiments 3, 4, 5, and 6), the animals used were not strictly random selections of the fat and meaty lines, because rams to be used as sires (2 per line per year) had already been removed, and some culling on the basis of animal size and weight-corrected ultrasonic fat-depth measurements had taken place (see Section 3-1-3). Thus, reference to line effects and responses to selection in this Chapter do not necessarily indicate totally genetic effects.

Little information is available on the effects of selection for or against fatness on carcass and meat quality in sheep or on the phenotypic and genetic correlations among carcass characteristics in sheep. Because of the lack of information on sheep selected for or against fatness this Section will be largely concerned with information from groups of sheep that differed in fatness for reasons other than genetic selection (particularly from different genotypes), or from genetic lines which have been selected on the basis of fatness, but which are of species other than the ovine. The results of selection against fatness in pigs are particularly relevant to the present study, and so will be discussed in some detail. On the other hand, comparisons of selection results reported herein with those of pig experiments are only of limited validity. Many selection experiments reported in the literature have been carried out under different environments, utilising different selection procedures. In addition, many pig selection experiments have had as their objective the improvement of a group of traits in an index rather than a single trait (Table 5-1). Many early selection experiments aimed at reducing the depth of backfat utilised "probing" or direct measurement of the animal's backfat, while more recent studies have used ultrasonic procedures.

Table 5-1. Results from experiments in which sheep, pigs, chickens, or mice have been selected for and/or against fatness.

Selection criterion	Animals	No. generations	Measurement			Comment	Reference	
Low and high backfat	Duroc pig	16		<u>Lean</u>	<u>Control</u>	<u>Fat</u>	At the same live weight. Fat depth was an average of five sites	Hetzer and Miller (1973)
			Fat depth (mm)	-15	00	30		
			Ham fat %	- 6	00	20		
	Yorkshire pig	14						
			Fat depth (mm)	-10	00	25		
			Ham fat %	- 8	00	6		
Selection index (high growth rate, high food efficiency and low backfat)	Pig	7		<u>Selection</u>	<u>Control</u>		At similar carcass weight	Chadwick (1977)
			No. animals	20	20			
			Fat depth C (mm)	13.4	18.3			
			Carcass fat %	24.3	28.1			
Selection index (high growth rate, high food efficiency and low backfat)	Large White pig	10		<u>Selection</u>	<u>Control</u>		At the same side weight (21.26 kg)	Wood et al. (1983b)
			No. animals	8	8			
			Fat depth C (mm)	13.2	17.4			
			Side fat weight (kg)	6.42	6.97			

Table 5-1 (continued)

Selection criterion	Animals	No. generations	Measurement			Comment	References
Low backfat and high growth rate	Pig	8	No. animals	<u>Lean</u>	<u>Fat</u>	At 90 kg live weight	Standal (1979)
			Fat depth C (mm)	-	-		
			Carcass fat %	18 mm difference between the two lines	17.3		
Low backfat	Large White pig	10	No. animals	<u>Selection</u>	<u>Control</u>	At the same live weight	Henderson <u>et al.</u> (1983)
			Fat depth C (mm)	40	39		
			Carcass fat %	18.6	21.8		
Low backfat	Pig	9	No. animals	<u>Selection</u>	<u>Control</u>	At 90 kg live weight. Fat depth was the sum of three fat depths	Fredeen and Mikami (1986)
			Fat depth (mm)	-	-		
			Ham lean weight	-24.6	00		
Low and high abdominal fat	White Rock type chicken	3	No. animals	<u>Low</u>	<u>High</u>	At 28 d of age with no difference in body weight	Leclercq <u>et al.</u> (1980)
			Abdominal fat (g)	30	30		
			Abdominal fat to body weight ratio	10.1	16.7		
				2.77	1.78		

Table 5-1 (continued)

Selection criterion	Animals	No generations	Measurement			Comment	Reference
Low and high abdominal fat	Chicken	4	No. animals	<u>Low</u> 8	<u>High</u> 8	At 52 days of age with no difference in body weight	Ricard <u>et al.</u> (1983)
			Abdominal fat depot (g/kg body wt.)	6.4	25.5		
			Subcutaneous fat (g/kg body wt.)				
			Thigh + drumstick	2.7	7.3		
			Neck	2.4	5.6		
			Remaining carcass	4.2	13.0		
			Total carcass fat	9.3	26.0		
Low and high abdominal fat	Chicken	3	No. animals	<u>Low</u> 9	<u>High</u> 9	At 9 weeks of age with no difference in body weight (male only)	Cahaner <u>et al.</u> (1986)
			Mean relative weight (g/100 g) body weight of:				
			Abdominal fat	0.74	1.67		
			Gizzard fat	0.21	0.52		
			Sartorial fat	0.16	0.32		
			Neck fat	0.34	0.70		
			Mesenteric fat	0.22	0.25		

Table 5-1 (continued)

Selection criterion	Animals	No generations	Measurement		Comment	Reference												
Low and high ratios of gonadal fat pad weight (GFPW) to body weight	Mice	9	No. animals Gonadal fat pad (mg) GFPW/body wt. (mg/g)	<table border="0"> <tr> <td></td> <td style="text-align: center;"><u>Low</u></td> <td style="text-align: center;"><u>High</u></td> </tr> <tr> <td></td> <td style="text-align: center;">176</td> <td style="text-align: center;">159</td> </tr> <tr> <td></td> <td style="text-align: center;">264</td> <td style="text-align: center;">634</td> </tr> <tr> <td></td> <td style="text-align: center;">8.4</td> <td style="text-align: center;">18.7</td> </tr> </table>		<u>Low</u>	<u>High</u>		176	159		264	634		8.4	18.7	At 10 weeks of age (male) with no difference in body weight	Sharp <i>et al.</i> (1984)
	<u>Low</u>	<u>High</u>																
	176	159																
	264	634																
	8.4	18.7																
Low and high backfat	Sheep		No. animals Fat depth C (mm)	<table border="0"> <tr> <td></td> <td style="text-align: center;"><u>Low</u></td> <td style="text-align: center;"><u>Control</u></td> <td style="text-align: center;"><u>Fat</u></td> </tr> <tr> <td></td> <td style="text-align: center;">-</td> <td style="text-align: center;">-</td> <td style="text-align: center;">-</td> </tr> <tr> <td></td> <td style="text-align: center;">1.86</td> <td style="text-align: center;">3.01</td> <td style="text-align: center;">5.10</td> </tr> </table>		<u>Low</u>	<u>Control</u>	<u>Fat</u>		-	-	-		1.86	3.01	5.10	At 34 kg live weight ewe lambs After 5 years of selection	Fennessy <i>et al.</i> (1987)
	<u>Low</u>	<u>Control</u>	<u>Fat</u>															
	-	-	-															
	1.86	3.01	5.10															

5-2 CARCASS QUALITY CHARACTERISTICS

5-2-1 LIVE WEIGHT, CARCASS WEIGHT AND DRESSING-OUT PERCENT

Muscle mass and fat deposition are classified as highly and moderately heritable, respectively (Wilson, 1975). Growth rate is also moderately heritable, and positively correlated genetically with reduced body fat content and total muscle mass. Their heritability estimates indicate that continued genetic progress can be made toward increased carcass leanness by selection of individuals on their own phenotypes. In the present study, data on average daily gain from birth to slaughter weight in Experiments 5 and 6, and from weaning to slaughter weight in Experiments 1, 2, 3 and 4 were analysed to evaluate the correlated responses of this trait to selection for high and low backfat thickness of sheep. For both pre- and post-weaning growth there were no differences between the two selection lines, but the meaty line usually had slightly higher growth rates than the fat line. This indicates that selection for leanness, although effective in reducing fat content, has not brought about a commensurate increase in growth rate. These findings are consistent with the results of Scott et al. (1981), who found no differences in growth rates between obese and lean pigs from birth until 6 months of age. Wood et al. (1983b) concluded that 10 generations of selection for an index combining growth rate, backfat thickness, and feed conversion had resulted in negligible changes in growth rate. A contemporary study (Henderson et al., 1983) involving large numbers from these same lines did reveal significant line differences in growth rate with the selected line growing faster than the control line. Low and negative phenotypic and genetic correlations between fat depth C and average daily gain have been reported for sheep (Table 5-2), for cattle (Shelby et al., 1963; Dunn et al., 1970; Dinkel and Busch, 1973; Wilson et al., 1976b; Koch et al., 1982) and for pigs (Fahmy and Bernard, 1970; Young et al., 1978; Bereskin and Frobish, 1982; David et al., 1983; Gogue and Gueblez, 1983; David, 1984; Bereskin, 1986; Sang et al., 1986). Steine (1982) concluded from analyses of Norwegian data that the genetic correlations between carcass fatness in sheep and growth rate was zero. Bowman and Hendy (1972) suggested that selection to decrease backfat thickness would be effective, and would most probably result in a reduction in the age at a fixed

slaughter weight and an increase in growth rate to slaughter. Fennessy (1985) indicated that selection against fatness within the Coopworth breed had led to increased growth rates. The latter conclusion was in contrast with the results of the present study, but is supported by those from pig selection lines (Pond et al., 1981; Bereskin and Hetzer, 1986; Tess et al., 1986). These workers concluded that their lean pigs grew faster than the obese pigs. Hetzer and Miller (1972) found a reduction in growth rate arising from selection against fatness in Yorkshire pigs, but an increase in growth rate in Durocs. Levels of fatness in the Durocs were high, and selection could be expected to improve efficiency and growth rate; whereas in the much leaner Yorkshire pigs selection against fatness could lead to reduced appetites and growth rates (Hetzer and Miller, 1973). These results are of interest in the context of our selection programme where the reduction in fatness has been quite marked, and no significant change in growth rate has as yet been observed. Moreover, Bereskin et al. (1974) presented evidence suggesting that pigs from the low fat lines were better mothers as measured by piglet weight at weaning. Table 5-3 shows the results of some studies in which comparisons were made of the growth rates of genotypes of sheep that differed in fatness. Inconsistent differences between the fatter and leaner genotypes make a firm interpretation difficult. However, in most situations the leaner genotypes grew faster than the fatter genotypes. When comparison are made at the same weight, genotypes which are heavier at maturity generally grow faster and contain less fat in their bodies and carcasses than do animals of smaller mature size (McClelland et al., 1976; Searle and Griffiths, 1976; Thompson et al., 1979a; Wood et al., 1980).

Table 5-2. Estimates of phenotypic and genetic correlations between backfat thickness and several characteristics in sheep, including measures of growth rate, dressing-out percent, carcass linear measurements, M. longissimus area, and carcass composition.

Trait	No. animals	No. sires	No. breeds	Data adjusted for	Correlation with fat depth		Reference
					Genetic	Phenotypic	
Average	218	40	4	age	-0.41	-0.09	Al-Barhawe (1966)
daily	802	58	3	weight	0.07	-0.12	Botkin <u>et al.</u> (1971)
gain	178	18	1	weight	-0.20	-	Bowman and Hendy (1972)
	167	17	2	cross weight	-0.09	-	Bradford and Spurlock (1972)
	2585	102	6	weight	0.08	-0.30	Wolf <u>et al.</u> (1981)
Live	1826	216	-	age	0.32	-0.19	Thorsteinsson and Bjornsson (1982)
weight	1600	51	4	age	-	0.21	Bennett <u>et al.</u> (1982/1983)
	850	51	1	age	-	0.18	Clarke <u>et al.</u> (1984/1985)
	1431	110	4	age	0.47	0.39	Parratt <u>et al.</u> (1987)
Carcass	120	-	2	-	0.17	-	Boylan and Searle (1965)
weight	218	40	4	age	-1.26	0.11	Al-Barhawe (1966)
	802	58	3	weight	0.22	0.42	Botkin <u>et al.</u> (1971)
	178	18	1	weight	0.36	-	Bowman and Hendy (1972)
	474	12	1	age	0.04	0.42	Mohamed (1976)
	584	85	7	age	0.37	-0.08	Olson <u>et al.</u> (1976b)
	1637	8 to 12	2	cross age	-	0.71	Bennett <u>et al.</u> (1981/1982)
	1637	8 to 12	2	cross age	-	-0.03	Bennett <u>et al.</u> (1981/1982)
	1826	216	-	age	0.43	0.22	Thorsteinsson and Bjornsson (1982)
	1600	51	4	age	0.53	0.16	Bennett <u>et al.</u> (1982/1983)
	850	51	1	age	-	0.15	Clarke <u>et al.</u> (1984/1985)
	1431	110	4	age	0.45	0.41	Parratt <u>et al.</u> (1987)

Table 5-2 (continued)

Trait	No. animals	No. sires	No. breeds	Data adjusted for	Correlation with fat depth		Reference
					Genetic	Phenotypic	
Dressing-out %	120	-	2	-	0.19	0.13	Boylan and Seale (1965)
	802	58	3	weight	-0.10	-0.18	Botkin <i>et al.</i> (1971)
	167	17	2	cross weight	0.14	-	Bradford and Spurlock (1972)
	584	85	7	age	0.23	-0.08	Olson <i>et al.</i> (1976b)
Carcass length	802	58	3	weight	-0.10	-0.18	Botkin <i>et al.</i> (1971)
	474	12	1	age	-0.14	-0.19	Mohamed (1976)
	1826	216	-	age	-0.20	-0.25	Thorsteinsson and Bjornsson (1982)
	1600	51	4	age	-0.28	-0.12	Bennett <i>et al.</i> (1982/1983)
	1600	51	4	weight	-0.25	-0.31	Bennett <i>et al.</i> (1982/1983)
	850	51	1	age	-	0.12	Clarke <i>et al.</i> (1984/1985)
Tibia and tarsus length	474	12	1	age	-0.10	-0.23	Mohamed (1976)
	1826	216	-	age	-0.18	-0.25	Thorsteinsson and Bjornsson (1982)
Leg length	474	12	1	age	-0.29	-0.36	Mohamed (1976)
	1826	216	-	age	-0.22	-0.24	Thorsteinsson and Bjornsson (1982)
Depth of thorax	474	12	1	age	0.16	0.46	Mohamed (1976)
	1826	216	-	age	-0.14	-0.35	Thorsteinsson and Bjornsson (1982)

Table 5-2 (continued)

Trait	No. animals	No. sires	No. breeds	Data adjusted for	Correlation with fat depth		Reference
					Genetic	Phenotypic	
Width of gigot	474	12	1	age	-0.95	-0.07	Mohamed (1976)
	1826	216	-	age	-0.12	-0.14	Thorsteinsson and Bjornsson (1982)
Width of chest	474	12	1	age	0.22	0.27	Mohamed (1976)
	1826	216	-	age	0.18	0.00	Thorsteinsson and Bjornsson (1982)
Circum- ference of chest	1826	216	-	age	-0.02	-0.24	Thorsteinsson and Bjornsson (1982)
Maximum shoulder width	474	12	1	age	0.27	-0.51	Mohamed (1976)
Maximum width behind shoulder	474	12	1	age	0.45	0.45	Mohamed (1976)
Metacarpal weight	474	12	1	age	-0.38	-0.66	Mohamed (1976)
	1826	216	-	age	-0.24	-0.42	Thorsteinsson and Bjornsson (1982)

Table 5-2 (continued)

Trait	No. animals	No. sires	No. breeds	Data adjusted for	Correlation with fat depth		Reference
					Genetic	Phenotypic	
Metacarpal length	474	12	1	age	-0.29	-0.31	Mohamed (1976)
	1826	216	-	age	-0.16	-0.04	Thorsteinsson and Bjornsson (1982)
Metacarpal circumference	1826	216	-	age	-0.13	-0.16	Thorsteinsson and Bjornsson (1982)
<u>M. longis-</u> <u>simus</u> <u>area</u>	120	-	2	cross weight	-0.16	-0.37	Boylan and Seale (1965)
	218	40	4	age	-1.07	-0.15	Al-Barhawe (1966)
	802	58	3	weight	-0.24	0.11	Botkin <u>et al.</u> (1971)
	178	18	1	weight	-0.05	-	Bowman and Hendy (1972)
	167	17	2	cross weight	-0.26	-0.32	Bradford and Spurlock (1982)
	1884	79	6	weight	0.05	-0.47	Wolf <u>et al.</u> (1981)
	1637	8 to 12	2	cross age	-	0.45	Bennett <u>et al.</u> (1981/1982)
	1637	8 to 12	2	cross weight	-	0.17	Bennett <u>et al.</u> (1981/1982)
850	51	1	age	-	-0.25	Clarke <u>et al.</u> (1984/1985)	
<u>M. longis-</u> <u>simus</u> <u>width (A)</u>	474	12	1	age	-0.45	-0.28	Mohamed (1976)
	1826	216	-	age	-0.18	0.01	Thorsteinsson and Bjornsson (1982)
	850	51	1	age	-	0.01	Clarke <u>et al.</u> (1984/1985)
<u>M. longis-</u> <u>simus</u> <u>depth (B)</u>	474	12	1	age	-0.12	-0.19	Mohamed (1976)
	1826	216	-	age	-0.10	-0.39	Thorsteinsson and Bjornsson (1982)
	850	51	1	age	-	-0.03	Clarke <u>et al.</u> (1984/1985)

Table 5-2 (continued)

Trait	No. animals	No. sires	No. breeds	Data adjusted for	Correlation with fat depth		Reference
					Genetic	Phenotypic	
Shoulder %	120	-	2	weight	-0.42	-0.41	Boylan and Seale (1965) Bowman and Hendy (1972)
	178	18	1	weight	0.08	-	
Leg %	120	-	2	weight	-0.56	-0.56	Boylan and Seale (1965) Bowman and Hendy (1972)
	178	18	1	weight	-0.54	-	
Best end %	178	18	1	weight	-0.51	-	Bowman and Hendy (1972)
Loin %	120	-	2	weight	0.64	0.64	Boylan and Seale (1965) Bowman and Hendy (1972)
	178	18	1	weight	0.32	-	
Rack %	120	-	2	weight	0.30	-0.27	Boylan and Seale (1965)
Muscle weight	1431	110	4	age	0.20	0.30	Parratt <u>et al.</u> (1987)
Muscle %	944	65	6	weight	-0.61	-0.80	Wolf <u>et al.</u> (1981)
	850	51	1	age	-	-0.75	Clarke <u>et al.</u> (1984/1985)
	1431	110	4	age	-0.58	-0.41	Parratt <u>et al.</u> (1987)

Table 5-2 (continued)

Trait	No. animals	No. sires	No. breeds	Data adjusted for	Correlation with fat depth		Reference
					Genetic	Phenotypic	
Bone weight	802	58	3	weight	-0.22	-0.30	Botkin <u>et al.</u> (1971)
	584	85	7	age	0.22	-0.16	Olson <u>et al.</u> (1976b)
	1431	110	4	age	0.17	0.18	Parratt <u>et al.</u> (1987)
Bone %	584	85	7	age	-0.90	-1.21	Olson <u>et al.</u> (1976b)
	944	65	6	weight	-0.50	-0.14	Wolf <u>et al.</u> (1981)
	850	51	1	age	-	-0.35	Clarke <u>et al.</u> (1984/1985)
	1431	110	4	age	-0.53	-0.40	Parratt <u>et al.</u> (1987)
Muscle: bone ratio	944	65	6	weight	0.12	-0.61	Wolf <u>et al.</u> (1981)
Fat weight	802	58	3	weight	0.51	0.62	Botkin <u>et al.</u> (1971)
	1431	110	4	age	0.83	0.53	Parratt <u>et al.</u> (1987)
Fat %	944	65	6	weight	0.68	0.74	Wolf <u>et al.</u> (1981)
	1637	8 to 12	2 cross	age	-	0.51	Bennett <u>et al.</u> (1981/1982)
	1637	8 to 12	2 cross	weight	-	0.27	Bennett <u>et al.</u> (1981/1982)
	850	51	1	age	-	0.76	Clarke <u>et al.</u> (1984/1985)
	1431	110	4	age	0.81	0.50	Parratt <u>et al.</u> (1987)
Muscle: fat ratio	944	65	6	weight	-0.57	-0.64	Wolf <u>et al.</u> (1981)

Table 5-2 (continued)

Trait	No. animals	No. sires	No. breeds	Data adjusted for	Correlation with fat depth		Reference
					Genetic	Phenotypic	
Subcut- aneous fat	944	65	6	weight	0.69	0.80	Wolf <u>et al.</u> (1981)
	850	51	1	age	-	0.74	Clarke <u>et al.</u> (1984/1985)
Inter- muscular fat	944	65	6	weight	0.43	0.50	Wolf <u>et al.</u> (1981)
	850	51	1	age	-	0.77	Clarke <u>et al.</u> (1984/1985)
Subcut- aneous:intermuscular fat ratio	944	65	6	weight	0.37	0.18	Wolf <u>et al.</u> (1981)
Kidney fat %	584	58	7	age	0.06	-1.47	Olson <u>et al.</u> (1976b)
	1637	8 to 12	2	cross age	-	0.35	Bennett <u>et al.</u> (1981/1982)
	1637	8 to 12	2	cross weight	-	0.01	Bennett <u>et al.</u> (1981/1982)
Kidney fat	1600	51	4	age	0.58	0.49	Bennett <u>et al.</u> (1982/1983)
	1600	51	4	weight	0.39	0.31	Bennett <u>et al.</u> (1982/1983)
weight	850	51	1	age	-	0.49	Clarke <u>et al.</u> (1984/1985)
Caulfat %	1826	216	-	age	0.10	-0.08	Thorsteinsson and Bjornsson (1982)

At the same live weight the fat line had heavier carcass weights and higher dressing-out percents than the meaty line. Positive phenotypic and genetic correlations between carcass weight, dressing-out percent, and backfat thickness have been reported for sheep (Table 5-2), and for cattle (Dinkel and Busch, 1973; Koch et al., 1982), and for pigs (Smith et al., 1962; Smith and Ross, 1965). Their findings imply that an increase in carcass weight and dressing-out percent are associated with an increase in the thickness of backfat. According to Hammond (1932), Seebeck and Tulloh (1966) and Fourie et al. (1970), the degree of fatness of the animal is a very important contributory factor to dressing-out percent, with fatter animals having higher dressing-out percents. Kirton et al. (1984) concluded that fat lambs had heavier carcasses and higher dressing-out percents than lean lambs. Wood et al. (1983a) noted that high correlations between fat thickness measurements C and J and dressing-out percent suggested that fatness had a marked effect on dressing-out percent in sheep. Similar conclusions for cattle were reported by Stringer et al. (1968), Hendrick et al. (1969), Zinn et al. (1970), and Dikeman et al. (1985).

Results from a sample of published studies showing relationships between the level of fatness and dressing-out percent are summarised in Table 5-4. The results in the Table support the generalisation that the fatter breeds have a higher dressing-out percent than the leaner breeds. However, Bennett et al. (1983) reported that live weight and carcass weight were not appreciably different between lambs by fat and meaty sires. The results of the present study for Southdown rams are in good agreement with those of Hetzer and Miller (1973) and Chadwick (1977) with pigs, in that the fatter pigs had higher dressing-out percents than the lean pigs. Furthermore, the effect of selection against fatness on the weights of non-carcass components (Section 5-2-2) is of particular interest in view of their relationship to dressing-out percent. The difference in dressing-out percent between the two genetic lines could be due to the fatness effect, to the greater weight of non-carcass components, or to both these effects. In this respect, work on pigs (Chadwick et al., 1980), cattle (Butler-Hogg and Wood, 1981) and sheep (Wood et al., 1983a) showed that a high dressing-out percent in some breeds was specifically due to low weights of non-carcass components. On the other hand, there were no differences in the dressing-out percents of

progeny of rams from the two selection lines in this present study and this conclusion was consistent with the results of Bennett et al. (1983) who found that the progeny of fat and meaty sires were similar for dressing-out percent.

Table 5-3. Results from several studies in which growth rate differences were reported for genetically distinct groups of sheep that differed in fatness.

Animals	Trait	Group (number)		Comment	Reference
		Fatter	Leaner		
<u>SD (64) R (64)</u>					
Romney (R)					
Southdown (SD)	Carcass fat %	39.3	33.1	The leaner group grew faster	Fourie <u>et al.</u> (1970)
(rams and ewes)	Weight at 80 weeks	56.7	63.4		
<u>BMXM (30) TXM (30)</u>					
Blackhead Mutton					
X Merino (BMXM)	Fat depth C	4.0	2.9	The groups did not differ in growth rate	Osikowski and Borys (1976)
Texel X	Daily gain (g)	208	210		
Merino (TXM) wethers					
<u>SD (209) S (268)</u>					
Southdown (SD)	Fat depth C	7.0	4.0	The leaner group grew faster	Coop <u>et al.</u> (1979)
Suffolk (S)	Weight at 94 d (kg)	24.9	27.1		
<u>SB (4) T (6)</u>					
Scottish	Carcass fat %	21.5	9.9	The leaner group grew faster	Butler-Hogg and Whelehan (1984)
Blackface (SB)	Weight at 6 months	29.21	30.50		
Texel (T)					
<u>CH (104) T (125)</u>					
Charmoise (CH)	Side fat %	32	23	The leaner group grew slightly faster	Cameron and Drury (1985)
Texel (T)	Weight at 16 weeks	31.0	32.4		

Table 5-4. Results from a sample of studies in which dressing-out percent differences were reported for genetically distinct groups of sheep that differed in fatness.

Trait	Group (number)		Comments	Reference
	Fatter	Leaner		
	<u>Southdown (64)</u>	<u>Romney (64)</u>		
Carcass fat %	39.3	33.1	The leaner group had a lower dressing-out %	Fourie <i>et al.</i> (1970)
Dressing-out %	58.6	52.1		
	<u>Southdown (-)</u>	<u>Suffolk (-)</u>		
Carcass fat %	25.5	21.3	The leaner group had a lower dressing-out %	Rattray and Drew (1976)
Dressing-out %	45.8	43.9		
	<u>S.X (FXSD)^a (26)</u>	<u>SXR^b (34)</u>		
Fat depth C	5.4	4.5	The leaner group had a lower dressing-out %	Kemp <i>et al.</i> (1981)
Dressing-out %	51.2	49.8		
	<u>Clun (67)</u>	<u>Suffolk (92)</u>		
Carcass fat %	34.1	29.6	The leaner group had a lower dressing-out %	Wood <i>et al.</i> (1983a)
Dressing-out %	51.7	48.3		
	<u>Scottish</u>			
	<u>Blackface (4)</u>	<u>Texel (6)</u>		
Carcass fat weight (Kg)	2.72	1.24	The leaner group had a lower dressing-out %	Butler-Hogg and Whelehan (1984)
Dressing-out %	43.2	41.0		

Table 5-4 (continued)

Trait	Group (number)		Comments	Reference
	Fatter	Leaner		
	<u>Suffolk (10)</u>	<u>Finnish (10)</u>		
Fat depth C	5.95	3.30	The leaner group	Lirette <u>et al.</u>
Dressing-out %	50.1	47.7	had a lower dressing-out %	(1984)
	<u>Charmoise (258)</u>	<u>Texel (358)</u>		
Fat weight (Kg)	2.5	1.9	The leaner group	Cameron and Drury
Dressing-out %	42.1	41.2	had a slightly lower dressing-out %	(1985)
	<u>H X (FXSD)^c (56)</u>	<u>HX(SXR)^d (57)</u>		
Fat depth C	5.9	4.7	The leaner group	Hawkins <u>et al.</u>
Dressing-out %	52.3	51.0	had a lower dressing-out %	(1985a)

a Suffolk X 1/4 Finnish-Landrace X 1/4 Southdown

b 3/4 Suffolk X 1/4 Rambouillet

c Hampshire X Finnish-Landrace X Southdown

d Hampshire X Suffolk-Rambouillet

5-2-2 NON-CARCASS COMPONENTS

Consistent differences were recorded between rams from the fat and meaty lines in this study for the internal organ weights, with the meaty line animals generally having heavier organs than the fat line after correction for carcass weight differences. In this respect, Davey and Bereskin (1978), Pond et al. (1981), Koong et al. (1983), Pekas et al. (1983), and Tess et al. (1986) found similar results when comparisons were made between fat and lean genetic lines of pigs. Lean pigs had heavier weights of stomach, small intestine, large intestine, liver, kidney, heart, and spleen than the fat pigs. Mersman et al. (1984) suggested that the greater gut mass may provide the mechanism for increased growth in lean compared with obese pigs when feed intakes are similar. Sundstol et al. (1979) reported that the digestibility of crude protein, ether extract, organic matter and dry matter was significantly higher for the lean line pigs. Yen et al. (1983), however, found similar digestibility values for dietary energy and nitrogen in lean and obese pigs.

It should be noted that in the present study, although there were no differences throughout the experiment in average growth rate between the two lines, the digestive organs of the fat line animals weighed less. This implies that sheep from the fat line may have more efficient digestive processes as their smaller alimentary tracts yielded similar growth rates. According to Church et al. (1979) there is a significant correlation between stomach weight and feed ingestion per unit time.

There is evidence that genetic reductions in fatness are associated with increased maintenance feed requirements in sheep (Oithoff et al., 1985) and pigs (Sundstol et al., 1979; Koong et al., 1983; Ferrall et al., 1983; Tess et al., 1984a). Several workers have demonstrated high fractional protein synthetic rates of visceral organ tissues compared with muscle tissue in rats (Nicholas et al., 1977), rabbits (Lobley et al., 1978), pigs (Simon et al., 1982), cattle (Sinnott-Smith et al., 1983), and sheep (Leymaster and Jenkins, 1985), which is consistent with results demonstrating higher energy expenditure by the metabolically active tissues such as the internal organs than with carcass tissues for sheep (Oithoff et al., 1985) and pigs

(Baldwin et al., 1980; Tess et al., 1984a, b). This suggests that reduced body fat may lead to higher maintenance requirements (fasting heat production) per unit of live weight. These findings and interpretations, taken together, suggest that if the same phenomenon existed in the animals of the experiments reported herein, then the variation in the weights of internal organs between the two selection lines may have been associated with corresponding variation in fasting heat production. Additional experimentation is warranted to assess the effect of visceral-organ weights on the efficiency with which feed is converted into edible product by sheep of the two selection lines.

5-2-3 CARCASS LINEAR MEASUREMENTS

The external carcass dimensions (Figure 3-2) are intended to give an indication of shape, since less carcass length in relation to weight and greater carcass depth and width measurements can produce an impression of carcass fatness (Kempster et al., 1982b). The correlations between carcass linear measurements and fatness measures in this study generally confirmed the statement of Kempster et al. (1982b).

It seems likely that the greater carcass length for the meaty line was a consequence of selection for reduced backfat depths. Purchas et al. (1982) compared fat and meaty lines from Southdown and Romney breeds for body length for four successive years. They found that the fat line of both breeds had shorter average body lengths at a set weight than the corresponding meaty line. At the same weight, Kirton (1982) found that lambs from P export grade (moderate to heavy fat cover) had significantly shorter carcasses than those from Y grade (light fat cover). Similarly, Kemp and Barton (1966) found that the carcass length was affected by fatness in sheep. Fennessy et al. (1982) found that the difference in carcass length between the progeny of the lean and fat Coopworth sires failed to reach significance, but the lean lambs had slightly longer carcasses. Negative genetic correlations between carcass length and average backfat thickness at a constant weight have been reported for sheep by Thorsteinsson and Bjornsson (1982) and Bennett et al. (1982/1983), while Clarke et al. (1984/1985) found a low positive correlation between the two variables (Table 5-2), but this was at a constant age. On the other hand, the

cannon bone has been used as a selection criterion for meat quality improvement in sheep because of its association with other carcass measurements, internal and external (Thorsteinsson and Bjornsson, 1982). These authors provided evidence that cannon bone weight was strongly negatively related to fat thickness (Table 5-2). The circumference of the cannon bone was weakly negatively related to fat thickness. In this respect, Purser (1980) selected sheep for long or short cannon bones and found that long-cannon-bone lambs were leaner at a constant weight. Good et al. (1961) reported that at equal live weight, cattle having a large cannon bone circumference had a larger M. longissimus area and less fat thickness at position C. Furthermore, relationships between the fat depth C and certain linear measurements from a sample of studies in the literature (Table 5-5) generally support our results, although in some of these cases, the selection was carried out for both characters. Also the results of selection for or against fatness in pigs have been consistent with our results. Thus MacIver (1971), Hetzer and Miller (1973), Wood et al. (1983b), Kuhlbers et al. (1984) and Mersmann et al. (1984) reported that at the same weight the length of pig carcasses selected for reduced backfat thickness was greater, whilst Duckworth and Holmes (1968), who selected pigs for increased carcass length, reported a reduction in backfat thickness. Kersey DeNise et al. (1983) concluded that selection for increased muscle percent in pigs was associated with a reduction in backfat thickness and increased carcass length after five generations. In cattle, Colomer-Rocher et al. (1980) and Andersen and Ingovartsen (1984) suggested that lower degrees of fatness were related to longer carcasses at similar carcass weights. In pigs, Enfield and Whatley (1961), Smith et al. (1962), Smith and Ross (1965), Duckworth and Holmes (1968), Fahmy and Bernard (1970), Bereskin and Frobish (1982), Gogue and Gueblez (1983), and Fredeen and Mikami (1986) reported negative genetic correlations between the average backfat thickness and carcass length at a constant weight or age. It appears that genetic selection for increased weight-adjusted carcass length would have a favourable genetic outcome on carcass fat depth.

Table 5-5. A summary of some sheep studies in which linear carcass measurements (mm) and the cross-sectional area (cm²) of M. longissimus were compared between groups of carcasses which differed in level of fatness. Measurements were either adjusted to a constant carcass weight or were made at approximately the same carcass weight. Abbreviations used are explained in Table 3-3.

Experimental group (No. animals in parentheses)	Fat depth C	Carcass length	Leg length	Gigot	Width behind shoulder	M. longissimus			Reference
						area	width (A)	depth (B)	
Blocky conformation (-)	5.05	536	166	221	175	-	51.4	31.2	Barton <u>et al.</u> (1949)
Leggy conformation (-)	3.95	538	175	218	170	-	51.6	29.5	
Fatter grades (14)	4.80	550	213	223	179	11.61	49.1	29.0	Kemp and Barton (1966)
Leaner grades (14)	2.90	580	249	226	169	9.87	51.4	25.0	
Blocky confor- mation (15)	5.00	-	161	-	-	9.16	-	-	Kirton and Pickering (1967)
Leggy confor- mation (15)	2.30	-	183	-	-	9.29	-	-	
Good confor- mation (-)	5.20	680	300	-	-	13.9	-	-	Jackson and Mansour (1974)
Poor confor- mation (-)	4.00	690	310	-	-	13.2	-	-	

Table 5-5 (continued)

Experimental group (No. animals in parentheses)	Fat depth C	Carcass length	Leg length	Gigot	Width behind shoulder	M. longissimus			Reference
						area	width (A)	depth (B)	
Finnish (42)	-	977	282	-	-	12.3	-	-	Hanrahan <u>et al.</u> (1978)
Galway (44)	-	985	280	-	-	13.7	-	-	
Clun (73)	4.30	521	265	-	-	15.9	55.9	28.4	Wood <u>et al.</u> (1980)
Colbred (102)	3.30	563	279	-	-	16.1	58.0	27.7	
SX(FXSD) ^a (26)	5.40	-	-	213	183	13.9	53.8	29.0	Kemp <u>et al.</u> (1981)
SXR ^b (34)	4.50	-	-	210	175	14.2	55.8	28.9	
P carcass grade (-)	2.55	-	-	-	-	8.26	46.7	25.9	Kirton (1982)
Y carcass grade (-)	1.33	-	-	-	-	7.94	47.9	24.6	
Good muscling (7)	4.10	-	167	-	-	9.54	50.8	25.5	Kirton <u>et al.</u> (1983)
Poor muscling (7)	1.80	-	186	-	-	7.74	50.1	22.7	
HX(FXSD) ^c (56)	5.90	-	-	211	186	14.1	54.2	31.6	Hawkins <u>et al.</u> (1985a)
HX(SXR) ^d (57)	4.70	-	-	212	179	14.8	55.7	31.8	

a 1/2 Suffolk (1/4 Finnish Landrace X 1/4 Southdown)

c Hampshire X Finnish Landrace-Southdown

b 3/4 Suffolk X 1/4 Rambouillet

d Hampshire X Suffolk-Rambouillet

One of the interesting points of the present study was that the carcasses from the fat line had a greater width behind the shoulder (WTh), but not at other sites than those from the meaty line. Since the thickness of fat behind the shoulder region will be included in that measurement of body width, a positive correlation was to be expected (see Figure 5-1). In accordance with these results, King (1957) reported positive phenotypic correlations between the width of the body (WTh), and measurements of backfat thickness. Depth of carcass would similarly be expected to be affected by fat deposition in the thorax region. This appears to be the case from the positive phenotypic and genetic correlations between fat depth measurements and depth of carcass reported at constant weight by Smith *et al.* (1962). These results support those of Kemp and Barton (1966) and are shown in Table 5-5.

The cross-sectional area of the M. longissimus did not show any significant selection effects at equal carcass weight in any of the experiments. Comparing obese and lean pigs at equal weight (Buhlinger *et al.*, 1978) obtained similar results. After adjusting to the same weight, Kemp and Barton (1966) found that the longissimus area was not affected by fatness in sheep, while Mersmann *et al.* (1984) showed that M. longissimus area was larger in lean pigs than obese pigs. However, most investigators have shown that the area of M. longissimus is negatively correlated (phenotypically or genetically) to measurements of fatness in sheep (see Table 5-2), for cattle (Shelby *et al.*, 1963; Cundiff *et al.*, 1964; Dinkel and Busch, 1973; Koch *et al.*, 1982; Heidari and Vogt, 1983; Heidari, 1985) and for pigs (Enfield and Whatley, 1961; Smith *et al.*, 1962; Smith and Ross, 1965; Isler and Swiger, 1969; Bereskin and Frobish, 1982; Gogue and Gueblez, 1983; Sandu *et al.*, 1985; Fredeen and Mikami, 1986). In contrast, Jensen *et al.* (1967) provided evidence which suggested that there was no relationship between the two traits at the genetic or the phenotypic levels in pigs. Although difference in M. longissimus area failed to reach significance between the two selection lines, the width (A) was generally smaller and the depth (B) generally greater for the fat line. In this respect, Butterfield (1965) suggested that the M. longissimus area was influenced by skeletal length, with longer carcasses having smaller muscle areas. A similar conclusion was reached by Kirton and Pickering (1967), with the leaner longer



Figure 5-1. Ram carcasses of the same weight from the fat (on left) and meaty (on right) groups of Experiment 3, showing typical differences in carcass shape and appearance (Purchas, 1981).

carcasses having slightly smaller M. longissimus areas. The negative phenotypic correlations between fat depth of sheep and both depth and width of M. longissimus (Table 5-2) indicate that improvement in the width of eye muscle could be greater than improvements in depth with selection aimed at reducing carcass fatness. On the other hand, the negative genetic correlations between the M. longissimus dimensions and fat depth indicate that both width and depth of eye muscle should be improved by selection against fatness. These results are in accordance with those of Wood et al. (1983b), which showed that selection for decreased backfat thickness in pigs resulted in wider (A) (86.6 vs 80.7 mm) but not deeper (B) (43.0 vs 44.0 mm), cross-sections of M. longissimus. In sheep, similar conclusions were reported by Kemp and Barton (1966), with fatter carcasses tending to have deeper M. longissimus (B) than the leaner carcasses (Table 5-5).

5-2-4 CUT WEIGHT DISTRIBUTION

Where this trait was assessed, the fat-line side had a higher proportion of weight in the rack cut. although some line differences were found in the proportions of the other three cuts, these were not as marked as for the rack cut. In general, the sides from the fat line had a higher proportion of the fatter cuts such as the rack and loin and those from the meaty line had a higher proportion of the leaner cuts such as the leg and shoulder. Boylan and Seale (1965) reported significantly positive genetic correlations between backfat thickness and the proportions of the loin and rack cuts, but negative correlations with the proportion of leg and shoulder cuts. They concluded that the positive correlations between rack and loin cuts with fatness are to be expected, as an increase in the amount of fat in the animal would result in greater deposition in the loin cut relative to the rest of the carcass, while the presence of the kidney knob in the loin, with its association of fat, may have contributed markedly to the correlation. The negative correlation with the leg cut was also expected following the same line of argument. This must largely be due to the negative relationship known to exist between carcass fatness and carcass muscle content (Clarke et al., 1984/1985). Similar results were reported by Bowman and Hendy (1972) for the phenotypic correlations between backfat thickness and cut weight distribution (Table 5-2). In pigs, highly negative phenotypic and

genetic correlations between backfat thickness and percent lean cuts (hams, loins and shoulders) were reported by Jensen et al. (1967) and Isler and Swiger (1969). Further studies showing that fatter groups of sheep have higher proportions of the loin and rack cuts and lower proportions of the leg and shoulder cuts are summarised in Table 5-6.

These variations between the two lines were as expected, because the rack and loin cuts contained more fat (Figures 4-3 and 4-4). The loin had a big part of the flank while the rack had a thick layer of subcutaneous fat in the lower part of the rib. Shoulder weight, however, tended to be heavier in the meaty line because it contained a higher proportion of bone (Figures 4-3 and 4-4). The above conclusion can also be explained by the findings of Fourie (1965) that the superfluous fat is mainly laid down around the later-maturity abdominal muscles and muscles of the shoulder and thorax and will be slightly higher in the loin and rack cuts as a proportion of the carcass. Similar conclusions were drawn by Luitingh (1962) for cattle and Kirton et al. (1967b) for lambs, with the proportion of valuable cuts decreasing as the proportion of fat increased in the carcasses. In lambs, Boylan and Seale (1965) reported that the percents of leg and shoulder and M. longissimus area decreased with an increase in fatness, but that the percents of loin and rack increased.

Table 5-6. A summary of some sheep studies in which proportions of the leg, loin, rack and shoulder cuts were compared in carcasses from groups of animals which differed in levels of fatness. Measurements were either adjusted to a constant carcass weight or were made at approximately the same carcass weight.

Experimental group (No. animals in parentheses)	Fat depth C (mm)	Cut (% of carcass)				Reference
		Leg	Loin	Rack	Shoulder	
Fatter grades (14)	4.80	31.1	10.0	8.1	24.4	Kemp and Barton (1966)
Leaner grades (14)	2.90	31.2	9.4	7.5	24.8	
Blocky confor- mation (15)	5.00	31.1	11.4	12.0	21.2	Kirton and Pickering (1967)
Leggy confor- mation (15)	2.30	33.0	11.0	10.5	21.5	
Perendale (-)	2.90	32.5	11.4	10.6	22.4	Kirton <u>et al.</u> (1974)
Merino (-)	0.66	33.5	10.6	10.0	21.6	
Dorset Down (-)	2.44	33.3	12.2	10.2	19.9	Kirton <u>et al.</u> (1978)
Suffolk (-)	1.83	34.3	11.5	9.9	20.8	
SX(FXSD) ^a (26)	5.40	29.4	10.5	7.8	23.8	Kemp <u>et al.</u> (1981)
SXR ^b (34)	4.50	30.4	10.1	7.7	23.3	
Suffolk (10)	6.00	33.0	-	8.1	30.5	Lurette <u>et al.</u> (1984)
Finnish (10)	3.30	33.8	-	7.1	30.8	
HX(FXSD) ^c (56)	5.90	29.9	10.5	8.4	23.4	Hawkins <u>et al.</u> (1985a)
HX(SXR) ^d (57)	4.70	31.2	10.2	8.3	23.3	

a 1/2 Suffolk (1/4 Finnish Landrace X 1/4 Southdown)

b 3/4 Suffolk X 1/4 Rambouillet

c Hampshire X Finnish Landrace-Southdown

d Hampshire X Suffolk-Rambouillet

5-2-5 CARCASS COMPOSITION

Correlations between ultrasonic fat depth measurements at position C and carcass fat depth C ranged from 0.91 to 0.97 indicating that carcass backfat thickness can be predicted satisfactorily on the live animals. Published estimates of the level of precision in measuring subcutaneous fat ultrasonically in sheep generally support this conclusion (Purchas and Beach, 1981; Fennessy et al., 1982, 1987; Bennett et al., 1983). Selection experiments with pigs have shown that backfat thickness can be successfully changed by basing selection on live measurements of fat depth (Hetzer and Miller, 1973; Standal, 1979; Henderson et al., 1980, 1981; Wood et al., 1983b; Fortin and Elliot, 1985; Fredeen and Mikami, 1986).

Most of the variation in body composition of sheep appears to be associated with the amount of fat (Tulloh, 1964; Coop et al., 1979; Black, 1983). Fat thickness C at 13th rib is currently used as an index of fat deposition because of its high positive association with the total fat in the carcass (Kempster and Cuthbertson, 1977; Thompson and Atkins, 1980; Table 5-1). Furthermore, genetic correlations reported between backfat thickness and carcass composition (e.g. carcass fat, subcutaneous fat, intermuscular fat, bone, and muscle) in sheep have been moderately high (Table 5-2). The effectiveness of the selection for reduced backfat thickness in the meaty line found in this study supports such estimates of genetic correlations and suggest that significant progress in selection can be made.

The reduction in backfat thickness was accompanied by an increase in weight of muscle at the same side weight. Fennessy et al. (1982) found that lambs from the lean sires tended to have less fat than those from the fat sires with the difference in the fat thickness measurements C and S2 being significant, but the differences in GR and chemical fat failing to reach significance. Our results are partially in agreement with those of Fennessy et al. (1982). Bennett et al. (1983) showed that ultrasonic selection for loin fat depth in 6 to 18 month-old sheep resulted in lambs that differed favourably at position C, but the differences between the progeny of the two sires for GR and kidney fat were small. Similar observations were made for two lines of pigs (Henderson et al., 1980, 1981) who reported that selection had

little effect on the overall carcass composition despite a significant reduction in backfat thickness. Wood et al. (1983b) found that after 10 generations, selection for low backfat thickness shifted sites of fat deposition within the subcutaneous fat depot slightly and was associated with slight increases in muscle weight. Moreover, Tess et al. (1986) reported that selection for low backfat thickness decreased total empty body fat and increased the protein content. Ellis et al. (1983) showed that Large White pigs from a line selected for decreased backfat thickness contained more protein and less fat than the controls. Fredeen and Mikami (1986) reported that after nine generations of selection against fat, the selected pigs had significantly less backfat and greater lean content than the control pigs. These differences were consistent within dissected fractions corresponding to those used by Tess et al. (1986) and in general, support our results. Furthermore, results from broilers selected against weight of abdominal fat (Ricard et al., 1983; Cahaner and Nitsan, 1985; Cahaner et al., 1985, 1986) and in mice selected against weight of gonadal fat pad (Sharp et al., 1984), have shown that differences in carcass fatness can be successfully achieved by selection.

Although an increase in weight of muscle tissue occurred in the meaty line, this was accompanied by an increase in bone weight. Indeed, considering the role of the skeleton as a supporting framework for the musculature, some increase in bone weight with increasing muscle weight might be expected in order to maintain the functional stability of the animal (Fowler, 1968). Similarly, if selection for reduced subcutaneous fat produced a later-maturing sheep then more bone might be expected in the meaty line animals due to them being less mature than the fat line at a fixed slaughter weight. However, higher mature weights are usually associated with higher average daily gains, but the results in the present study indicated that the two lines did not differ in this respect, so difference in bone weight, due to this effect, can be discounted. However, the carcass weights from the fat line were heavier than those from the meaty line, and according to the findings of Fourie et al. (1970), the muscle to bone ratios increased with increasing carcass weight. It would appear, therefore, that muscle to bone ratio has not been improved in the meaty line relative to the fat line by selection for reduced subcutaneous fat depth, and in fact may have been slightly reduced. In

sheep, Wolf et al. (1981) found a negative genetic correlation (-0.61) between muscle to bone ratio and backfat thickness. Comparing two groups of sheep Kirton et al. (1983) revealed that the fatty group had a higher muscle to bone ratio than the leaner group at the same weight. Furthermore, Russel and Barton (1967) and Kemp and Barton (1966) investigated data resulting from the complete dissection of lamb carcasses into fat, muscle and bone. These data covered the normal range of carcass weights and grades found in New Zealand, and as was the case with our results, the fatty carcasses had higher muscle to bone ratios than those from the leaner carcasses. Similar conclusions were reached by Butler-Hogg and Whelehan (1984) for comparisons of fatter and leaner genotypes of sheep. Butterfield et al. (1983a) found that a small strain of Merino (fatter) had a higher muscle to bone ratio than a large strain of Merino (leaner) at a constant weight. Comparing two lines of selected pigs Wood et al. (1983b) found no difference in muscle to bone ratios. Vos and Sybesma (1971) and Martin and Fredeen (1974b) have suggested that fat depth and muscle to bone ratio are only weakly related in pigs, while a significantly negative phenotypic correlation (-0.42) between fat depth and muscle to bone ratio was found in pigs by Edwards et al. (1980).

The term muscularity can be defined as a visual assessment of muscle to bone ratio (Anon., 1982) as mentioned above. Kempster et al. (1982a) defined muscularity as the thickness of muscle in relation to skeletal size. The latter authors concluded that fatness is positively related to muscle to bone ratio and muscle thickness when adjustments for carcass weight and subcutaneous fat have been made. A similar finding was reached by Colomer-Rocher et al. (1980) and Bass et al. (1984) who concluded that selection against fatness resulted in a decrease in muscularity. The present study confirms their conclusion. Purchas (1986) noted that improvements in muscularity are usually associated with increased muscle to bone ratios. In the present study, at constant side muscle plus bone weight, the ratios of individual muscle weights to adjacent bone lengths were higher in carcasses from the fat line. Furthermore, the ratios of side muscle to body length and total leg muscle to femur plus tibia length were higher in the fat line. This indicates that in relation to the dimensions of the muscles at constant side muscle plus bone weight, fat

carcasses were associated in this study with shorter and thicker muscles. In accordance with these results, Colomer-Rocher et al. (1980) found for beef that fat carcasses tended to have relatively short, thick muscles, whereas lean carcasses tended to have long, thin muscles when compared at the same carcass weight.

5-2-6 PARTITIONING AND DISTRIBUTION OF CARCASS FAT

It was of particular interest in the present study, to find significant line differences in the partitioning of fat within carcass depots such that, at the same total side fat, sides from the fat line had a greater proportion of subcutaneous fat and a lower proportion of intermuscular fat. This difference suggests that selection on subcutaneous fat depth had resulted in the proportional relocation of fat from the intermuscular fat to the subcutaneous fat depots, although the effect could have been due to differences in stage of maturity between the two lines. Subcutaneous to intermuscular fat ratio would be expected to be higher in fatter, early-maturing animals as subcutaneous fat is a late-developing depot relative to total fat (Thompson et al., 1979a; Kempster, 1980; Butterfield et al., 1985). In pigs, Duniec et al. (1961) suggested that subcutaneous fat and intermuscular fat deposition were relatively independent genetically, while Rook et al. (1987) expressed the view that selection for reduced backfat thickness in pigs might lead to an increase in intermuscular fat. Furthermore, the two fat depots have different physiological functions; with subcutaneous fat acting primarily as an energy store, whilst intermuscular fat fulfils the role of a lubricant between muscles (Chadwick, 1977). They also have differences in fatty acid composition (Purchas et al., 1986).

When adjusted to the same side weight, intermuscular fat weight was higher for the sides from the fat line as might be expected in view of the high genetic correlation reported between subcutaneous and intermuscular fat depots for sheep (Wolf et al., 1981; Clarke et al., 1984/1985). The ratio of subcutaneous fat to intermuscular fat was reduced at the same side weight for the meaty line. In pigs, at the same side weight, Wood et al. (1983b) found no significant differences in the weight of dissected subcutaneous and intermuscular fat depots between the selection line and control line. However, their sample

population was small, with only two pigs from each of their selected and control lines being slaughtered at eight live weights ranging from 15 to 120 kg. Kempster and Evans (1979) showed a lower ratio of subcutaneous fat to intermuscular fat in commercial hybrids with a particularly high lean content. Similar results were reported by Lister (1976) with cattle. It seems that genetic factors leading to increased fat will tend to result in a greater ratio of subcutaneous fat to intermuscular fat. Such results are compatible with the fact that subcutaneous fat is later developing than intermuscular fat (Butler-Hogg, 1984b). The results in the present study differ from those for pigs reported by Wood et al. (1983b), where selection over 10 generations had no effect on the partitioning of fat between the subcutaneous and intermuscular depots of lean and obese carcasses at the same total fat weight. Chadwick (1977) found that whilst the proportion of subcutaneous fat was lower in the lean line, no line difference was found in the proportion of intermuscular fat. The difference between our results and those with pigs may be a species difference, as clear species differences have been reported for the ratio of subcutaneous to intermuscular fat. Thus Kempster et al. (1982a) reported that the ratios of subcutaneous to intermuscular fat were 3.67 and 1.10 for pigs and sheep, respectively. In sheep, at a similar percent of total body fat, Perry et al. (1986) found that the Border Leicester rams had a higher proportion of subcutaneous fat than did Poll Dorset and Suffolk rams. They concluded that breed variation in fat partitioning in mature animals indicates that it may be possible to manipulate carcass fatness at the same proportion of mature body weight. Butler-Hogg and Whelehan (1984) compared Texel rams (leaner) with Scottish Blackface (fatter) for carcass fat partitioning. They found that the carcasses from Scottish Blackface rams had a higher proportion of subcutaneous fat, kidney and channel fat (KKCF), and caul fat, but less intermuscular fat and mesenteric fat than those from Texel rams. Butler-Hogg (1984b) reported breed differences in fat partitioning with Clun lambs (leaner) depositing proportionately more body fat intra-abdominally compared with Southdown lambs (fatter). Butterfield et al. (1985) showed differences in subcutaneous and intermuscular fat partitioning between Dorset Horn rams and wethers, with the wethers (fatter) having significantly more subcutaneous fat and less intermuscular fat than the rams (leaner).

Results from the present study demonstrated that selection against fatness has brought about limited relocation of body fat from the subcutaneous fat to the internal fat depots (omental, kidney and mesenteric fat depots). This conclusion is consistent with the results of Wood et al. (1983b), and Fortin and Elliot (1985) for pigs, although for the present studies at the same carcass weight the weight of these depots was lower in the meaty line. Our results are supported by the positive genetic correlations between backfat thickness and internal fat depots in sheep (Table 5-2) reported by Wolf et al. (1981), Bennett et al. (1981/1982), and Clarke et al. (1984/1985). These workers found that a decrease in the subcutaneous fat depth of the carcass was associated with decreases in the internal fat depots. Butterfield et al. (1985) found a similar partitioning for the internal fat depots between Dorset Horn rams (leaner) and wethers (fatter), despite a large difference between the two sexes in extramuscular fat partitioning, except that the mesenteric fat depot was heavier in rams than in wethers.

Subcutaneous and intermuscular fat weight distribution between the four anatomical cuts (see Section 3-2-2-2, and Figure 3-5), were similar in the two selection lines, except that carcasses from the fat line had a greater proportion of subcutaneous fat in the loin cut.

Wood et al. (1983b) obtained similar results when comparing six anatomical regions from lines of pigs selected against fatness. In sheep, breed differences in the distribution of subcutaneous and intermuscular fat depots at constant weight of fat depots were presented by Seebeck (1968). He concluded that the proportion of the total subcutaneous fat was higher in the loin and flank regions and lower in the thorax region in fatter than leaner animals, while the intermuscular fat was higher in the neck and loin and flank regions and lower in the thorax region in fatter than in leaner animals. Gaili (1978) reported significant differences between the Dorset Horn, Clun, and Hampshire breeds in intermuscular fat distribution, while Thompson et al. (1979b) were unable to detect a significant effect of breed on the distribution of either subcutaneous or intermuscular fat. Results from the MLC ram breed comparison showed relatively little variation between breeds in this characteristic (Kempster, 1980). Wolf and Smith (1983) reported results which were in good agreement with those

of Kempster (1980) in showing only small effects of breed on the distribution of both subcutaneous and intermuscular fat at a constant weight of total fat. Results from Jackson and Mansour (1974) also support our findings, with litter variation in fat distribution between groups of good or poor conformation. A similar conclusion was reported by Butterfield et al. (1984) and Butler-Hogg et al. (1984) for different sexes.

Fat partitioning between depots shows genetic variation and substantial differences have arisen during the evolution of domestic breeds (Kempster, 1980). Fat distribution within depots on the other hand, follows a more closely defined pattern, so that at equal depot weights, breed differences in fat distribution are small. Berg and Butterfield (1976) suggested that differences in fat distribution could be explained in terms of lines of least resistance. They hypothesised that the muscles and body shape create variable pressures and that growth of the hindquarter intermuscular fat meets with more resistance than in the forequarter, resulting in a shift forward of intermuscular fat as fattening progresses. Subcutaneous fat expands under the skin in the least resistant areas, gradually resulting in the overall smooth appearance of very fat animals. Such a hypothesis may explain why relatively little variation exists in fat distribution within a fat depot at the same level of fatness. Similar observations for intermuscular fat deposition were found in the present study. Whilst dissection techniques employed were detailed and anatomically based, only the major individual muscles and muscle groups were separated in detail. These observations imply that for more precise measurement of intermuscular fat content detailed muscle-by-muscle dissection techniques should be employed. The measurement of intermuscular fat in this study, therefore, may be associated with some error with some of the intermuscular fat remaining with the muscle, particularly in the case of the shoulder and rack cuts.

5-2-7 MUSCLE AND BONE DISTRIBUTION

There were only small differences in muscle weight distribution among the anatomical cuts between the fat and meaty lines. It therefore seems that when genetic selection produces the relatively big changes in fatness that have been achieved in this case, the effects

on muscle and bone tissue distribution are likely to be small. Results from comparisons of two genetic lines in pigs (Wood et al., 1983b) and two conformation groups in sheep (Jackson and Mansour, 1974; Butler-Hogg and Whelehan, 1987) support our conclusion. In cattle, the muscle distribution of improved British and Brahman cattle was compared with that of unimproved Shorthorns by Butterfield (1964, 1965). He found that no changes had occurred in muscle weight distribution as a result of selection based on conformation. Furthermore, the results of the present study are in agreement with the view of a general anatomical harmony in muscle tissue distribution, with small differences between breeds when comparisons have been made at a constant weight of total muscle (see Section 2-2-6-1). Jury et al. (1977), Bergstrom (1978), Taylor et al. (1980) and Cameron and Drury (1985) concluded that the small but significant differences which exist between breeds in muscle distribution are probably genetic and could possibly be exploited. Muscle distribution in small (fatter) and large (leaner) mature-sized Merinos studied by Butterfield et al. (1983b) showed that the small strain had a lower proportion of muscle in the proximal and distal hind limbs, but a higher proportion in the abdominal wall, neck to forelimb, and thorax than in the large strain. Butler-Hogg and Whelehan (1984) found small differences in muscle distribution between Texel rams (leaner) and Scottish Blackface rams (fatter). They concluded that the proportion of muscle in the high-value cuts was 1.8% higher for the Texel. Kempster et al. (1983) concluded from the MLC's ram breed evaluation that the range of differences between sire breeds in the distribution of total muscle between various joints was small but significant. They found that Texel crosses (the leanest) had a lower proportion of lean in the loin than Southdown crosses (the fattest). It is clear, however, from these observations that any selection accompanying breed formation in sheep, cattle and pigs has had little influence on muscle distribution. Wolf (1982) found that adjustment to an equal stage of maturity (between breeds) generally tended to reduce the variation between breeds in muscle distribution. He concluded, however, that differences between sheep breeds for muscle weight distribution at constant weight of total muscle could not be explained entirely in terms of differences in stage of maturity.

Carcasses from animals selected for increased or decreased fatness in the present study showed only slight differences in bone weight distribution, which is in agreement with the results presented by Wood et al. (1983b) and Rook et al. (1987) for pigs selected against fatness. However, breed differences in bone distribution at constant total bone were reported for cattle (Kempster et al., 1977; Jones et al., 1978; Berg et al., 1978; Kempster, 1978), and pigs (Davies, 1975; Richmond et al., 1979). It is possible that these differences are to some extent a reflection of mature size, the larger breeds having more of their bone in the earlier-developing leg cut at a constant total bone weight.

5-2-8 FAT CELLULARITY CHARACTERISTICS

Cellularity studies on selected adipose tissue depots of sheep (Merkel et al., 1973; Burton et al., 1974; Hood and Thornton, 1979; Broad et al., 1980; Butler-Hogg and Wood, 1983; Thornton et al., 1984; Vigneron et al., 1984; Thompson and Butterfield, 1987; Thompson et al., 1987b), cattle (Robelin, 1981; Cianzio et al., 1985) and pigs (Anderson, 1972; Anderson and Kauffman, 1973; Mersman et al., 1975; Wood et al., 1975; Hood and Allen, 1977) have been reported, and this subject has been reviewed by Allen (1976), Hood (1977, 1982) and Robelin (1986) (see for example Table 5-7). The present results support the general conclusions of all these studies in showing that differences in fatness of meat-producing animals result primarily from hypertrophy rather than hyperplasia of adipose cells.

Table 5-7. Examples of adipose cellularity characteristics in groups which differed in their level of fatness.

Experimental group (No. animals in parentheses)	Fat depot	Adipocyte characteristics			Comment	Reference
		Diameter	Volume	No.		
Hereford X Angus had 12.2 mm fat thickness Holstein had 3.6 mm fat thickness	Subcutaneous	133.3 μm	1.50 $\mu\text{m}^3 \times 10^6$	-	At the same age and weight, the fatter breed had larger but less number of adipocytes	Hood and Allen (1973)
	Kidney	106.9 μm	0.92 $\mu\text{m}^3 \times 10^6$	-		
		138.2 μm	1.68 $\mu\text{m}^3 \times 10^6$	7.44 $\times 10^9$		
		119.5 μm	1.16 $\mu\text{m}^3 \times 10^6$	9.65 $\times 10^9$		
Growth ad libitum had 12.9 mm fat depth C (16) Growth for main- tenance had 7.6 mm fat depth C (16)	Subcutaneous	-	1.10 $\mu\text{m}^3 \times 10^6$	0.96 $\times 10^6$	The fatter group had larger but less number of adipocytes	Haugebak <u>et al.</u> (1974)
	Kidney	-	0.82 $\mu\text{m}^3 \times 10^6$	1.34 $\times 10^6$		
		-	1.56 $\mu\text{m}^3 \times 10^6$	0.77 $\times 10^6$		
		-	0.85 $\mu\text{m}^3 \times 10^6$	1.43 $\times 10^6$		
	Intermuscular	-	0.38 $\mu\text{m}^3 \times 10^6$	2.90 $\times 10^6$		
		-	0.31 $\mu\text{m}^3 \times 10^6$	3.49 $\times 10^6$		
Duroc pigs selected for 18 generations for fatness (10) or for leanness (8)	Subcutaneous	-	2.41 $\mu\text{m}^3 \times 10^6$	1.65 $\times 10^{10}$	The fatter line had more adipocytes	Steele <u>et al.</u> (1974)
		-	0.92 $\mu\text{m}^3 \times 10^6$	0.92 $\times 10^{10}$		

Table 5-7 (continued)

Experimental group (No. animals in parentheses)	Fat depot	Adipocyte characteristics			Comment	Reference
		Diameter	Volume	No.		
Ossabaw pigs selected for fatness (7)	Subcutaneous	118 μm	-	-	The fatter group had larger adipocytes	Etherton (1980)
Yorkshire pigs selected for leanness (7)		88 μm	-	-		
Ossabaw pigs selected for fatness (12)	Subcutaneous	143 μm	-	-	The fatter group larger adipocytes	Hausman and Martin (1981)
Yorkshire pigs selected leanness (12)		97 μm	-	-		
Obese rats selected for fatness (6 to 10)	Subcutaneous	58.5 μm	-	-	At 10 weeks of age the obese rats had larger adipocytes	Smith <u>et al.</u> (1983)
Control rats (6 to 10)		50.7 μm	-	-		
Fat Zucker mice (-)	Subcutaneous	60.9 μm	1.19 $\mu\text{m}^3 \times 10^5$	-	The fatter line had larger and more adipocytes	Rogers <u>et al.</u> (1984)
Lean Zucker mice (-)		52.2 μm	0.76 $\mu\text{m}^3 \times 10^5$	-		

Table 5-7 (continued)

Experimental group (No. animals in parentheses)	Fat depot	Adipocyte characteristics			Comment	Reference
		Diameter	Volume	No.		
Duroc and Yorkshire pigs selected for 18 and 15 generations, respectively, for fatness (20) or leanness (20)	Subcutaneous	88.8 μm	4.94 $\mu\text{m}^3 \times 10^5$	2.63 $\times 10^6$	The fatter line had larger but less adipocytes	Mersman (1985)
		72.0 μm	2.62 $\mu\text{m}^3 \times 10^5$	5.00 $\times 10^6$		
Dorset Horn X Corriedale (106)	Kidney	90.0 μm	-	-	The fatter group had larger adipocytes	Ch'ang <u>et al.</u> (1986)
Dorset Horn X Merino (34)		83.9 μm	-	-		
Duroc X Yorkshire pigs selected for 16 generations for obese (8) lean (8)	Subcutaneous	62.2 μm	1.80 $\mu\text{m}^3 \times 10^5$	-	At 56 days of age obese pigs had larger adipocytes	Mersman (1986)
		55.1 μm	1.22 $\mu\text{m}^3 \times 10^5$	-		

Table 5-7 (continued)

Experimental group (No. animals in parentheses)	Fat depot	Adipocyte characteristics			Comment	Reference	
		Diameter	Volume	No.			
Romney rams selected for fatness (6) or for leanness (6)	Subcutaneous	104.6 μm	-	-	The fatter line had larger adipocytes	Purchas (unpublished data)	
		92.3 μm	-	-			
	Kidney	110.6 μm	-	-			
		100.7 μm	-	-			
	Intermuscular	94.6 μm	-	-			
		81.9 μm	-	-			
	Omental	132.6 μm	-	-			
		113.2 μm	-	-			
Peppin Merino sheep selected for high weaning weight (fatter) (9) low weaning weight (leaner) (13)	Subcutaneous	-	-	-	At the same maturity, hyper- plasia had a greater contribution to increased fat weight	Thompson <u>et al.</u> (1987b)	
		-	9.23 $\mu\text{m}^3 \times 10^5$	6.67 $\times 10^9$			
	Intermuscular	-	9.87 $\mu\text{m}^3 \times 10^5$	5.08 $\times 10^9$			
		-	8.09 $\mu\text{m}^3 \times 10^5$	6.27 $\times 10^9$			
		Kidney	-	8.81 $\mu\text{m}^3 \times 10^5$			4.05 $\times 10^9$
			-	1.74 $\mu\text{m}^3 \times 10^5$			1.51 $\times 10^9$
		Omental	-	1.75 $\mu\text{m}^3 \times 10^5$			1.22 $\times 10^9$
			-	1.99 $\mu\text{m}^3 \times 10^5$			2.21 $\times 10^9$
		Mesenteric	-	2.08 $\mu\text{m}^3 \times 10^5$			1.32 $\times 10^9$
			-	1.21 $\mu\text{m}^3 \times 10^5$			1.22 $\times 10^9$
-	1.18 $\mu\text{m}^3 \times 10^5$	0.93 $\times 10^9$					

Although increased fat cell size in the subcutaneous fat depot was mainly responsible for the increase in adipose tissue mass for the fat line in the present study, the small differences in average adipocyte number between the two selection lines across experiments (particularly in Experiment 5) suggests that adipocyte hypertrophy alone was not the only cause of adipose tissue enlargement in subcutaneous fat as fattening proceeded. Using lambs at birth from the same two selection lines used in this study, Cullen (1985) found a similar number of adipocytes in subcutaneous, intermuscular, cavity, pericardial and omental fat depots. Thus the difference in the size and number of subcutaneous fat adipocytes between the two selection lines in the present study would appear to have arisen during the period from birth until slaughter. The number of recognisable cells in subcutaneous fat is not fixed even in very fat animals and may continue to increase during fattening in sheep (Broad et al., 1980; Thompson and Butterfield, 1987; Thompson et al., 1987b), pigs (Enser et al., 1976), cattle (Roblin, 1981; Truscott et al., 1983b), and rats (Johnson and Hirsch, 1972; Bertrand et al., 1978; Bjorntorp et al., 1979; Klyde and Hirsch, 1979), probably due to new fat cells forming either by hyperplasia or by filling of pre-existing cells with storage lipid. Such events may be triggered by an unknown mechanism where the size of the adipocyte plays a regulatory function (Faust et al., 1978). Allen (1976) suggested that adipocyte number is fixed at some point during growth and that adipocyte volume has some maximum. If this is the case, then fat accretion should plateau as protein accretion does. The fact that it apparently does not suggests that during the initial phase of proliferation a large number of pre-adipocytes are formed, but not all of them fill with lipid at the same time. Greenwood and Hirsch (1974) have criticised the histometric method and the coulter-counting method using osmium-fixed cells employed by other workers on the grounds that both methods fail to include pre-adipocytes and newly-formed adipocytes which have not yet accumulated recognisable deposits of fat. However, no simple method for distinguishing these cells yet exists. The results of the present study for subcutaneous fat are consistent with the above suggestions.

The size of adipocytes taken from the outer and inner layer of subcutaneous fat from both selection lines for Experiment 6 was not different, a similar result to that reported by Anderson et al. (1972)

for very fat pigs. Wood et al. (1975) showed that fat cells increased in size faster in the inner layer of backfat for pigs compared with the outer layer as overall fatness increased.

In the other four fat depots (intermuscular, omental, kidney, and mesenteric) the degree of hypertrophy was the major cellularity difference between rams from the meaty and the fat lines. Inconsistent differences in the number of adipocytes between the two selection lines were found. Larger adipose tissue cells in obese than in lean pigs of the same genetic background have been found (Steele et al., 1974; Allen, 1976; Hausman and Martin, 1981; Scott et al., 1981; Mersman et al., 1984; Mersman, 1985) and also in obese rodents (Johnson and Hirsch, 1972; Trayhurn et al., 1979). Hood and Thornton (1979), however, found a large variation in the size of omental and perirenal adipocytes relative to the weight of fat in these depots. Hood and Allen (1977) indicated that adiposity in the pig is due primarily to cellular hypertrophy, since leaner pigs contained a larger number of adipose cells in both perirenal and extramuscular depots than the fatter pigs. In cattle, the smaller fat depots in Holstein steers has been shown to be due to fewer and smaller adipose cells than in Hereford X Angus steers (Hood and Allen, 1973). A similar conclusion was reported by Cianzio et al. (1985). They suggested that adipocyte hypertrophy was the principal cause for the increase in adipose tissue mass in the bovine. The absence of differences between the two Southdown selection lines in fat cell number may be because, in the meaty line, the majority of fat cells accumulated lipid and enlarged to a moderate size, while in the fat line, the already partially filled cells expanded further, resulting in the observed increase in size, but not in number.

Simple pooled correlations revealed that both mean adipocyte size and number for each adipose tissue depot was significantly positively correlated with backfat thickness. The five fat depot weights and their respective size and number of adipose cells were also significantly associated, but correlations with size were consistently higher. This observation is in agreement with the results of Vigneron et al. (1984) who found a positive association between fat cell size and number in three fat depots and total fat in the side, but only the correlation with size was significant. Similar conclusions were

reported by Haugeback et al. (1974), Ch'ang and Evans (1978/1979), Hood and Thornton (1979), Moody et al. (1980), and Solomon et al. (1981) in sheep, by Hood and Allen (1973) and Cianzio et al. (1985) in cattle, and by Hood and Allen (1977) in pigs.

5-3 PREDICTION OF CARCASS COMPOSITION FROM RACK COMPOSITION

Among the different carcass sample cuts available, those from the rack have frequently been used and have been shown to provide a useful indirect index of carcass composition (Hankins, 1947; Barton and Kirton, 1958a; Field et al., 1963; Timon and Bichard, 1965; Kemp et al., 1970b; Hinks and Prescott, 1974; Kempster et al., 1976, 1986; Hanrahan et al., 1978; Cook et al., 1983; Moran, 1983). However, the approaches of these various workers have varied with regard to the exact nature of the sample cuts and the form of the prediction equations. Furthermore, the extent of variation has ranged widely for the various sets of data and this can have a marked effect on the regression parameter estimates. According to Kempster et al. (1976), the better predictors will be those which give maximum precision in relation to the money and time which can be spent on evaluation, and which are most stable between groups.

In the present study, either the percents or the weights of the physical components of the rack cut were used alone (percents only) or together with side weight in multiple regression equations with corresponding components of the side (percents) as dependent variables. The precision of the three equations used in the present study were compared both in terms of correlations coefficients as well as in their residual standard deviations. No outstanding differences in the usefulness of the simple or multiple prediction equations (as percents) were apparent from the correlations and residual standard deviations. In this respect, Barton and Kirton (1958a) concluded that regression equations based on the weight of muscular tissue in the leg and loin cuts gave no greater accuracy of prediction of total carcass muscular tissue than either cut alone. However, the accuracy of predictions of side components from rack components with or without side weight were improved marginally by using percents rather than absolute weights. Many of the reported studies have used the correlation coefficient and residual standard deviation as a measure of

predictive accuracy, but since the magnitude of the correlation coefficient is influenced by the extent to which the data varies, its use in this context is suspect (Harrington, 1963). According to Kempster *et al.* (1982a) a more meaningful measure of precision is provided by the residual standard deviation. Timon and Bichard (1965) suggested that greatest emphasis should be placed on the residual standard deviation since it is a direct function of the correlation coefficient weighted by the variation in the independent variable. Norton (1968) stated that the correlation coefficient tended to be deceptively meaningful and that the residual standard deviation was relatively meaningless unless the initial standard deviation and the units of measurement are known. Purchas (1977) pointed out that the important distinction between correlation coefficients and residual standard deviations is that the residual standard deviation gives an indication of the absolute amount of variation not accounted for, whereas the correlation coefficient gives an indication of the proportion of variation accounted for. In the present study, the regression equations showed generally higher multiple correlation coefficients for total fat and subcutaneous fat percents than for muscle or bone percents, which was to be expected with the characteristically greater variation in fat tissue content. This generalisation, together with the fact that the rack composition was more effective in terms of correlation coefficients in predicting side fat than muscle or bone supports the findings of Hankins (1947) and Timon and Bichard (1965). Furthermore, the proportion of fat in the rack cut is high in comparison with other cuts and it changes more rapidly than the other parts of the carcass as shown by the allometric growth coefficient values in Appendix 2.

The present study showed that the intercept for muscle or bone percent measurements was not significant between the two lines, so a common intercept was appropriate. On the other hand, the intercept for fat percent measurements was significantly higher for the fat line, probably because of the lack of overlap between the two lines (see Figures 4-12, 4-13 and 4-14). Hence, the total regression equations were found to be the appropriate prediction equations in this study. Although there are many reports of analyses to compare predictors within single groups of lambs (Barton and Kirton, 1958a; Kirton and Barton, 1962; Field *et al.*, 1963; Timon and Bichard, 1965;

Kempster et al., 1976), few workers have examined the same predictors over a series of groups differing in breed or sex to determine the stability of prediction equations. Sample size has generally been too small or the data insufficiently variable in origin to do this (Kempster et al., 1982a). Several trials have, however, provided indirect evidence of instability in prediction relationships. In particular, Kempster et al. (1976) found substantial instability in regression equations between seven breed type groups, particularly for simple linear measurements and visual scores. A similar conclusion has been reached by Hanrahan et al. (1978) who used a rack cut (7th to 12th rib) as a predictor for side composition in three sire breeds (Galway, Fingalway and 1/4 Finn X 3/4 Galway). They found significant heterogeneity among three breeds in the relationship between fat weight in the side and fat in the rack cut. They concluded that considerable bias may result if breed comparisons rely on the composition of a sample cut to estimate the carcass composition unless appropriate prediction equations were derived within breed. More specific indications emerged from a large-scale breed comparison trial carried out in Great Britain by the Animal Breeding Research Organisation in collaboration with MLC (Kempster, 1983). This involved the dissection of 894 crossbred lambs from two dam types by Dorset Down, Ile de France, Oldenburg, Oxford Down, Suffolk and Texel sires. The results indicated that bias between breeds in prediction equations for lean percents from four sample cuts (best-end neck, shoulder, loin, and leg) can still be a problem even when breeds are compared within flock and year. The Texel cross appeared quite different from other breeds in several of the prediction relationships, due largely to their high lean to bone ratio and low percent of perinephric and retroperitoneal fat. A similar conclusion has been reached by Kempster et al. (1986). Moreover, between sexes, Oliver et al. (1968) and Carpenter et al. (1969) suggested the use of different prediction equations for each sex when predicting carcass composition. Similar conclusions were reached by Ledger and Hutchison (1962) with cattle, who found that the prediction of total fat in the carcass from a rack cut was improved by the use of separate prediction equations for steer and cow carcasses. The selection of predictors having stable equations is particularly important in trials without base line evaluation, since no amount of replication will compensate for bias. The occurrence of sample cuts with unstable prediction equations for

total side fat is of particular concern because it means that separate regression equations need to be applied within each line in order to predict fatness differences between carcasses from the fat and meaty lines. However, it is difficult to compare these results with those obtained by other workers because of differences in cuts, breed, sex, and treatments.

5-4 MEAT QUALITY CHARACTERISTICS

5-4-1 INTRODUCTION

Investigations into the feasibility of altering lamb carcass composition genetically by selection has been stimulated in New Zealand by the increasing consumer demand for leaner lamb carcasses. However, the effects of selection for or against fatness on meat quality in sheep have not yet been investigated, although intensive genetic selection programmes in pigs, which began many years ago in order to decrease carcass fatness, have been evaluated for shifts in carcass composition and meat quality. For example, Fredeen and Mikami (1986) showed that selection on the basis of an index combining increased growth rate and reduced backfat in pigs for 12 generations resulted in an improvement in lean content without compromising meat quality attributes such as pH and meat colour. The results of Standal *et al.* (1973) corroborate those of Fredeen and Mikami (1986), in that although increased fat mobilisation occurred in a line of pigs selected for low backfat for four generations, meat colour did not significantly differ from controls. Martin and Fredeen (1974b) also concluded that selection of swine for low backfat thickness and high percent of lean appeared not to affect meat pH, colour, or shear force values. Topel *et al.* (1975) compared a lean and fat line of crossbred pigs from unspecified background, differing by 6.4% lean in the carcass. Small, non-significant differences were found for drip loss from three muscle groups excised from the ham, but in all three groups there was a trend towards higher drip losses in the lean line. Ollivier (1977) reported that nine generations of selection based on an index combining average daily gain and backfat in pigs, resulted in annual decreased of 0.5 mm in carcass backfat thickness, but no evidence was found of any change in the meat quality attributes of pH, colour and water-holding capacity. Similar conclusions were reached by Standal

(1979), who combined backfat thickness and average daily gain as selection criteria for eight generations and showed 18 mm difference in average backfat thickness between the two selection lines.

The results of the present study, where small and non-significant differences were shown between the fat and meaty lines of Southdowns for meat quality characteristics, are consistent with the above findings. Vos and Sybesma (1971) concluded from their studies with pigs that increasing carcass quality by decreasing subcutaneous fat would have less effect on meat quality than selection for extremes of muscling in which case this would have a negative effect on meat quality. Estimates of genetic relationships found in the literature between backfat depth and muscle quality characteristics such as colour, pH, and drip losses in pigs were antagonistic (Chadwick, 1977). In chickens, the amount of fat at different locations of the carcass was significantly different between two selected lines for or against abdominal adipose tissue, but there was no adverse effect on meat quality such as tenderness, juiciness, flavour and cooking loss (Ricard *et al.*, 1983).

5-4-2 pH VALUES

Muscle pH is largely determined by the concentration of lactic acid present (Lawrie, 1985) and as a result can be used as an immediate indicator of the extent of post-mortem glycolysis. According to Dutson (1983) ultimate pH values, as one of the basic biophysical properties of muscle, have an important influence on many muscle characteristics such as colour, water-holding capacity, and tenderness. Several studies have reported effects of pH at specific times during conversion of muscle to meat, as well as the ultimate pH of meat, on the quality of ovine meat (reviewed in Section 2-3-4-5-1). In the present study, across all experiments and muscles tested, ultimate pH values were similar in the two selection lines, but were low in comparison with published values for sheep (Smith *et al.*, 1976; Furnival *et al.*, 1977; Pinkas *et al.*, 1982; Aalhus and Price, 1986). Moreover, the correlations between pH values and certain carcass fatness measurements in this study were not significant. This finding is in accordance with those of Vos and Sybesma (1971) and Wood *et al.* (1986) who reported that there was no relation between pH values and

backfat thickness for pigs. Similarly Purchas and Davies (1974b) reported low correlations between intramuscular fat and pH of beef. In sheep, however, Smith et al. (1976) found that meat from lean carcasses (fat depth C 3.3 mm) had significantly higher pH values than did meat from fat carcasses (fat depth C 7.1 mm). A similar result has been reported by Lochner et al. (1980) who found that M. longissimus from a lean group of cattle (fat depth 5 mm) had higher pH values than those from a fat group (fat depth 26 mm). However, in pigs Martin and Fredeen (1974b) found that ultimate pH was significantly higher for the high fat group than for the low fat group. The comparison of pH values between different experiments, however, is complicated by different times and temperature at post-mortem ageing (Cassens and Newbold, 1966). In the present study, when some of the variable factors were overcome by using animals of similar breeding, comparable ages and reared under identical conditions, the pH measurements did not indicate any significant selection effects.

It was evident in the present study that the conditions of electrical stimulation employed were successful in greatly accelerating the rate of pH fall during post-mortem glycolysis when applied to carcasses at 25 to 30 min after death. This acceleration was particularly marked whilst the current was flowing, but also existed during the post-stimulation phase. The acceleration of pH decline after stimulation reported here was of a similar order as that reported by Shorthose et al. (1986) using a similar stimulation technique for sheep muscles. The different post-mortem muscle glycolytic patterns observed for the electrical stimulation treatment groups between Experiments 5 and 6, could be due to the 5 min greater delay in applying the electrical stimulation to the carcasses in Experiment 6. These results are supported by those of Hagyard et al. (1980), who reported that the pH of M. longissimus at 2 h post-mortem was 5.96 and 6.04 for carcasses stimulated at 25 and 30 min post-mortem, respectively. Although the electrical stimulation treatment brought about more rapid pH decline in these samples during the 6 h period immediately post-stimulation, there were no significant differences in pH value after 24 h when the pH of the unstimulated muscle had fallen to its ultimate level. These results are in accordance with those of McCollum and Hendrickson (1977), Dutson et al. (1982), Martin et al. (1983), McIntyre and Ryan (1984), Takahashi et al. (1984, 1987),

Ledward et al. (1986) and Solomon et al. (1986), who also found no significant differences in the ultimate pH of different muscles following electrical stimulation. The M. biceps femoris placed on ice in the present study had significantly higher ultimate pH values than those held at ambient temperature possibly due to those samples not reaching their ultimate pH values at 24 h as compared with the samples at ambient temperature. Similar results have been reported by Locker and Hagyard (1963), who compared ultimate pH from sternomandibularis muscle of a cow at 2^o and 25^oC. This assumption is supported by the fact that the rate of fall of pH depends upon muscle temperature (Newbold and Harris, 1972; Honikel et al., 1981), and pH fell more rapidly at 0^oC than at 15^oC just during the first few hours post-mortem, while pH fell more rapidly at 15^oC during the following hours post-mortem (Winger et al., 1979; Honikel et al., 1981). The phenomenon of accelerated post-mortem muscle metabolism at lower temperatures is known to be caused by cold-shortening (Hamm, 1981). Rate of pH decline was not determined in the present study, but ultimate pH of M. biceps femoris was highest for both lines from ice treatment. In accordance with these results, Honikel et al. (1981) showed that ultimate pH at 24 h post-mortem from bovine neck muscles kept at 0.5^oC was higher (5.95) than those kept at 14^oC (5.52). Similar results have been obtained by Winger et al. (1979).

The differences in ultimate pH among the five muscles examined in this study are generally consistent with the results reported by Smith et al. (1976), Furnival et al. (1977), Pinkas et al. (1982) and Aalhus and Price (1986), in showing M. longissimus having lower pH values than M. semitendinosus, M. semimembranosus or M. biceps femoris, with M. semitendinosus having the highest pH value. Such differences might be explained by the fact that since muscles differ in their proportion of red and white fibres they might, therefore, differ in their patterns of energy metabolism, both ante- and post-mortem (Beecher et al., 1968; Swatland, 1982; Houlier et al., 1984). Ante- and post-mortem glycolytic rates as related to the proportion of muscle fibre types have been widely investigated (Ashmore, 1974; Laborde et al., 1985). Generally the red muscle fibres would be expected to have higher ultimate pH values because of lower glycogen contents and greater dependence on oxidative metabolism (Cassens and Cooper, 1971). According to Swatland (1982), red muscle fibres derive their energy

aerobically from blood-borne nutrients and oxygen, while white muscle fibres obtain energy anaerobically by utilising their stores of glycogen to produce lactate. In this respect, Solomon et al. (1981) showed that M. longissimus had a lower proportion of red muscle fibres and a higher proportion of white muscle fibres than M. semimembranosus in sheep. In cattle, Johnston et al. (1981) also reported that M. semitendinosus had more red muscle fibres than M. biceps femoris or M. semimembranosus. Suzuki (1971a, b) compared several muscles in sheep and concluded that M. longissimus had more white muscle fibres, but less red muscle fibres than M. semimembranosus. The same author showed that M. longissimus had less white muscle fibres than M. semitendinosus, with no difference in red muscle fibres. However, it should be mentioned that Suzuki (1971a, b) used a different classification system for muscle fibre types than other workers. In the present study, although no significant differences were shown between the two selection lines in ultimate pH or rate of pH decline, the M. semitendinosus from the fat line, which had more red muscle fibres, had lower pH values than those from the meaty line. It is possible that the samples evaluated for pH were from areas of the muscle which were not different for muscle fibre types, or that the small differences in the proportion of red muscle fibres did not have an influence on ultimate pH of the M. semitendinosus. In this respect, Sivachelvan and Davies (1981) reported that samples from the central portion of ovine M. semitendinosus (where samples for fibre evaluation were taken in the current study) contained a higher proportion of red muscle fibre, whereas the superficial portion of the same muscle (where samples for pH evaluation were taken) contained a lower proportion of red muscle fibres.

5-4-3 MUSCLE FIBRE PARAMETERS

In the meaty line, there was a slightly increased occurrence of the intermediate and white muscle fibres in the M. semitendinosus, apparently at the expense of the proportion of red muscle fibres, although only the decrease proportion of red muscle fibres was statistically significant. These findings are supported by those of Beermann et al. (1985) who studied the effects of administration of cimaterol (CL263,780) on tissue repartitioning and muscle metabolism in lambs. They found that a 60% reduction in fat thickness at the

12th rib was accompanied by marked reductions in the proportion of type I (red) fibres in Mm. semitendinosus and longissimus.

It is generally believed that the number of total muscle fibres is set at birth or soon after and does not change during the life of an animal (Ashmore et al., 1972; Stickland et al., 1975; Swatland, 1976; Sivachelvan and Davies, 1986; Seideman et al., 1986). Thus postnatal increases in muscle mass are accomplished by the enlargement of muscle fibres (hypertrophy). Some of the muscle growth is due to the enlargement of all muscle fibres and some is due to the conversion of small red fibres to large white fibres. Furthermore, it has been suggested that unidirectional selection for lean content may produce changes in muscle metabolism (Weiss et al., 1971a, b; Ashmore et al., 1972). The latter authors have suggested that an increase in the degree of muscularity may be achieved by increasing the relative proportions of white muscle fibres. Lax and Pisansarakit (1982) selected mice for high and low 10-week body weight for 27 generations, and found that the high weight line had a significantly higher proportion of white muscle fibres in the M. longissimus. The results of the present study suggest that selection against fatness brought about a transformation of small red fibres to intermediate and large white muscle fibres. In this respect, Kiessling et al. (1982) suggested that as white muscle fibres are thicker than the red muscle fibres, all factors which favour a transformation of red fibres into white fibres should increase the total muscle mass. Results of the present study suggest that in a muscle such as M. semitendinosus, with decreased red fibre occurrence due to selection against fatness, there might be subtle shifts from oxidative metabolism towards glycolytic metabolism, the dominant metabolism of white fibres. Further, if a significant fraction of the musculature has an alteration in fibre type occurrence, it is possible that muscle metabolism as a whole would be slightly altered. However, the extent cannot be determined from the present data since only one muscle has been examined. Similar conclusions were reported by Nostvold et al. (1979), who found that lean pigs had significantly higher proportions of intermediate muscle fibres than fat pigs.

In the present study the white fibres were larger in diameter than intermediate fibres, which were larger than red fibres; a trend

which is consistent with results reported by Padykula and Gauthier (1970), Johnston et al. (1975), May et al. (1977) and Spindler et al. (1980).

There were only slight differences in muscle fibre diameter between selection lines and between treatment groups within lines, with the fat line having a smaller mean diameter for all three muscle fibres than the meaty line, but the differences were not significant. This suggests that selection for high or low fat thickness will not necessarily cause a change in the size of muscle fibres. These findings are in agreement with Nostvold et al. (1979) who used pigs from the eight generations of a selection experiment based on an index incorporating rate of gain and backfat thickness. At approximately 87 Kg live weight, muscle from lean pigs had larger diameters in all muscle fibre types than fat pigs, but the differences were significant only for the white fibres. Staun (1963) showed that there were no significant differences in the diameter of muscle fibres in two selection lines (lean and obese) of Yorkshire and Duroc pigs. In rats, Champion et al. (1984) found that lean rats had larger muscle fibre diameters than obese (ob/ob), while Purchas et al. (1985) reported no differences between the two genetic lines of mice for muscle fibre diameter.

Diameter distribution analysis for the three muscle fibre types in this study revealed no deviations from normality for the two genetic lines, but the meaty line distribution was extended to the right of the corresponding fat line in the ascending part of the distribution. These observations are in accordance with those for pigs reported by Nostvold et al. (1979) who also found that the distribution of the three muscle fibre types from two selection lines was normal, with the muscle fibre distribution curves from the meaty line extending to the right side of the corresponding fat line in both ascending and descending parts of the distribution curve. According to Hegarty (1971), fibre diameter distributions reported in the literature for farm and laboratory animals have been monophasic. However, in beef, Johnston et al. (1975) found that the red muscle fibres did not have a normal distribution for fibre diameter in the M. longissimus, but that the distribution was skewed to the right as a

result of a large number of fibres having diameters three or more standard deviations above the group mean.

The overall muscle fibre diameters found in the present study were larger than comparable values reported in the literature for sheep and lambs. For example, Suzuki (1971a) who used the same muscle and Hight and Barton (1965), Suzuki (1972), White et al. (1978) and Marinova et al. (1984) using different muscles in sheep. This was probably because the samples for fibre evaluation in our study were placed on ice within 35 min of slaughter. This resulted in sarcomere lengths that were 38% shorter than for the contralateral muscle left on the carcass. Such a reduction in sarcomere length would be associated with a 27% increase in diameter if the volume remained constant (Arango et al., 1970; Lewis et al., 1973; Clancy and Herlihy, 1978; Jeremiah et al., 1984).

In our study, the proportion of red muscle fibres was found to be positively correlated to various indices of fat (e.g. total side fat, C, J, S2, GR, LG and L2), while the proportions of intermediate and white fibres showed negative, but low correlations with various indices of fat content. Histochemically, red muscle fibres contain more lipid than white muscle fibres (George and Naik, 1958; Padykula and Gauthier, 1963; Moody and Cassens, 1968; Hunt and Hedrick, 1977; Suzuki et al., 1978) possibly due to the greater mitochondrial content of red fibres and the associated phospholipid in the membrane. Melton et al. (1975) and Calkins et al. (1981) reported that the proportion of red muscle fibres was positively correlated with marbling in steers. Since red muscle fibres have substantially more oxidative metabolic capacity compared with white muscle fibres, which are glycolytic, it is possible that red fibres may be associated with fat deposition because red muscle fibres use lipid as a fuel (Cassens and Cooper, 1971). In the present study, the positive correlations between red muscle fibre diameter and various indices of fat content were similar to those reported by May et al. (1977), Solomon et al. (1981) and Hawkins et al. (1985b). Since red muscle fibres contain numerous lipid droplets and more total intramuscular lipid than other fibre types, a positive association with fatness was expected.

The concept that sensory properties of meat are related to the proportions of muscle fibre types was discussed by Cassens (1977) who concluded that the properties of a muscle, be they visual appearance, physiological parameters or biochemical characteristics, are a reflection of the proportions of types of muscle fibres present within that muscle. In the present study, correlation coefficients between histological characteristics and indices of quality were generally low and non-significant, except for shear force values, in which case the diameter of red muscle fibres was negatively correlated with shear force values in Experiment 6 only (data not presented in tabular form). Although white fibres have been shown to be positively associated with increased amounts of connective tissue (collagen) (Seideman, 1986), red muscle fibres have been shown to be more susceptible to cold-shortening (Cornforth *et al.*, 1980) and to not exhibit post-mortem degradation of Z-lines to the same extent (Gann and Merkel, 1978). However, Locker (1985) stated that the cold shortening response seems to apply in all muscles no matter what the proportions were of the two muscle fibre types. The latter conclusion was inconsistent with other workers (reviewed in Section 2-3-4-1-1). However, the present study failed to confirm Ashmore's suggestion (1974) that the muscle fibre type plays a part, not only in relation to quantity of muscle, but also in relation to sheep meat quality.

5-4-4 REFLECTANCE SPECTROPHOTOMETRY

The major variation in the forms of myoglobin present in meat is first the extent of oxygenation of myoglobin (Mb) to yield oxymyoglobin (MbO₂) and secondly in the level of oxidation yielding metmyoglobin (Mb⁺) (Snyder, 1964). The colour of the meat surface depends not only on the quantity of myoglobin present, but also on the relative proportions of the three main states of myoglobin present at the surface. The concentration of each of these forms (oxymyoglobin, myoglobin and metmyoglobin) in turn is determined by a variety of factors (reviewed in Section 2-3-4-7-2). In the present study, to eliminate the ante- and post-mortem factors which affect the form of myoglobin, all the animals involved were approximately at the same weight and age and were reared together. The only known difference was with respect to fatness. Although not statistically significant, muscles from the fat line had slightly higher reflectance values than

those from the meaty line. These findings support those of Ollivier (1977) who showed that the colour score was not significantly different between lines of pigs selected for backfat thickness and growth rate. Similar conclusions were reached by Fredeen and Mikami (1986), Wood et al. (1986) and Jones et al. (1987). Martin and Fredeen (1974b) reported that there was no correlation between percent transmission and percent intramuscular fat in pigs. Similarly, Martin et al. (1981) showed that fat thickness had little or no relationship with pig colour. In lambs, Hunt et al. (1975) also concluded that degree of marbling in the M. longissimus did not significantly affect any subjective or objective measurements of colour. Jost et al. (1983) collected data from 315 steer and heifer carcasses and found no significant correlations between fat content and colour. Kuhlert et al. (1984) concluded that subjective colour scores for pork were not significantly affected by low or high backfat thickness. The low correlations between certain carcass fat measurements and reflectance values in the present study were in accordance with the above findings. However, Jeremiah et al. (1972) concluded that as fat depth increased from 2.0 to 8.1 mm in lambs the subjective colour scores (9 = greyish or greenish; 1 = very bright) decreased.

It is difficult to compare the present findings with the large number of reports in which both positive and negative effects of electrical stimulation on muscle colour and uniformity of muscle colour have been published. This is because of the wide variety of stimulation techniques that have been applied. The lack of an effect of electrical stimulation on colour reported here supports previous findings that were reviewed in Section 2-3-4-7-2. However, in beef, Savell et al. (1978b, c) and Salm et al. (1981) found that a significant improvement in lean colour occurred when the rate of pH decline was increased by electrical stimulation. In sheep, Riley et al. (1980a, b) reported that the lean colour of electrically-stimulated sides was significantly improved when compared with control sides. A 36 percent improvement in lamb lean colour was also found by Smith et al. (1980). These differences were identified when the carcasses were evaluated within 24 h post-mortem (Savell et al., 1978b); beyond that time no difference in colour of stimulated and unstimulated muscles existed. Bowles et al. (1983) suggested that tenderness improvement and the more rapid pH decline of electrically-stimulated muscle may be

associated with a more open muscle structure, which in turn may result in greater reflectance properties of the muscle causing it to appear lighter. The open structure would also be related to a greater oxygen incorporation by the muscles. On the other hand, Buts et al. (1986) suggested that the effect of electrical stimulation on colour (brightness) was the result of the accelerated denaturation of proteins. However, Breidenstein et al. (1968) reported that large amounts of marbling interfered with colour reflectance measurements and gave lighter colour values. Van Den Oord and Wesdorp (1971) pointed out that a higher fat content results in higher reflectance values between 400 and 700 nm. Similar results were obtained by Elliot (1967) in experiments with meat slices containing cores of fat of varying diameter.

The relationship of ultimate pH to meat colour is well documented with a high pH giving a darker meat colour (reviewed in Section 2-3-4-7-2). In general, the reflectance values in this study for four muscles were not affected significantly by ultimate pH probably because no particularly high pH values were observed.

Among four different muscles in this study the M. semitendinosus had the highest reflectance values and the M. semimembranosus had the lowest values with the M. longissimus and M. biceps femoris intermediate. Jeremiah et al. (1985) also showed that beef M. longissimus had higher reflectance values than did M. semimembranosus. Temperature treatments (on ice vs ambient) had a marked effect on reflectance values for M. biceps femoris. Muscles at ambient temperature in the present work had significantly higher reflectance values than those kept on ice particularly at 630 nm which in this case reflected the relative proportion of oxymyoglobin (MbO₂) on the meat surface. This implies that M. biceps femoris from the ice treatment had a closer muscle structure as a result of contraction of myofibrils which in turn may produce lower reflectance values. Conversely, M. biceps femoris held at ambient temperature had higher reflectance values possibly as a result of an open muscle structure as suggested by Bowles et al. (1983). In this respect, Ledward (1985) suggested that the rate of change of temperature of muscle during post-mortem glycolysis can modify the perceived colour independently of metmyoglobin (MetMb) formation. In addition, the oxygen

consumption rate is likely to be lower in rapidly, as opposed to slowly, chilled meat (Atkinson and Follett, 1973), and this will inhibit the formation of the bright red oxymyoglobin, giving a darker overall appearance. Furthermore, Brown and Dolev (1963) suggested that temperature has a profound effect on oxidative reaction rates. They reported doubling the rates by increasing the temperature from 0°C to 10°C. A similar conclusion has been reached by Snyder and Ayres (1961). In accordance with the present study, Purchas (unpublished data) applied similar post-mortem treatments (on ice vs ambient) for M. longissimus of steers and showed that the samples from ambient temperature had significantly higher reflectance values at 630 nm than those from the cold treatment.

5-4-5 EXPRESSED JUICE

Water retention of meat is supposed to be caused primarily by an immobilisation of tissue water within the myofibrillar system (Hamm, 1981). Offer and Trinick (1983) provided evidence that most of the immobilised water was located within the thick filaments and between the thick and thin filaments of the myofibril. It can be expected by using a press method that a shift of water takes place from the intracellular into the extracellular space and then onto the meat surface as a result of structural alterations at the level of the sarcomeres or of the myofilament structure. In the present study, slight but non-significant differences in expressed juice were found between the two selection lines with the muscles from the fat line having more expressed juice than the muscles from the meaty line. Hawrysh et al. (1975) found that expressed juice levels for fatter beef samples were higher than those from leaner samples which is in agreement with the present results. In contrast, Gaddis et al. (1950) found that the percent of expressed juice became lower with increases in fat content and attributed that to an increase in the percent of fat in expressed water. Satorius and Child (1938) indicated that no relationship existed between fat content and the amount of expressed juice. As an explanation for these differences, Hawrysh et al. (1975) suggested that marbled samples from the fat carcasses were softer, permitting the expressed muscle to slide out and cover a larger area, thus enabling the filter paper to absorb larger amounts of fat. Lin et al. (1985) concluded that expressed juice was the measure for bound

moisture in muscle and was not affected by the differences in fat content in these muscles, but the slightly higher expressed juice for fatter samples probably reflects the increase in percent fat expressed rather than actual increases in juice expressed.

Inconsistent findings have been reported on the effect of electrical stimulation on water-holding capacity of meat samples. However, the present results support the conclusion that no effect exists (reviewed in Section 2-3-4-6-2). Many studies have reported significantly negative correlations between pH and water-holding capacity in meat (reviewed in Section 2-3-4-6-2). This is the expected situation because less expressed juice should be expected as pH rises and moves away from the average isoelectric point. The present results revealed negative correlations between the two variables, but these were generally not significant. The differences in water-holding capacity between three muscles (Mm. semitendinosus, biceps femoris, and semimembranosus) have been reported by Bouton et al. (1971) with M. semitendinosus having the highest water-holding capacity compared to the other two muscles. However, in pigs, Lin et al. (1985) found that the amount of expressed juice of three different muscles was not statistically different between the muscles studied.

The influence of post-mortem temperature of sheep muscles on expressed juice is of practical interest, particularly the effect of low temperatures because under such conditions, not only rigor mortis, but also cold shortening could influence the expressed juice of the meat. However, clear information on the influence of cold shortening on the expressed juice of sheep muscles is not available. In the present study, the M. biceps femoris samples which were held at 0°C had significantly lower expressed juice values than those kept at ambient temperature. Fabiansson et al. (1984) reported that beef meat samples that had been rapidly chilled had a higher water-holding capacity and similarly the myofibrillar protein water-holding capacity was higher, indicating less protein denaturation and probably a pH effect. Their findings are in accordance with those of the present study. In contrast, Bouton et al. (1972a) showed that stretched deep pectoral muscles from ovine (sarcomere length 2.8 to 3.0 μm) had a higher water-holding capacity than its cold-shortened counterpart (sarcomere length 1.3 to 1.5 μm). They concluded that part of the

difference in water-holding capacity between these muscles would be due to the contraction state of the sarcomere and hence to the number of water-holding capacity sites available, but the range of sarcomere length was greater than that of the present study. Honikel et al. (1986) suggested that the close and almost linear relationship between shortening of the sarcomeres in the pre-rigor state and during the onset of rigor mortis and the extent of drip loss during the storage of meat post-rigor is another factor which influences the water-holding capacity of meat. However, Honikel et al. (1981) incubated bovine neck muscles between 0°C and 30°C soon after slaughter for up to 24 h and found that temperature had no effect on water-holding capacity of the muscles. The latter result is also in agreement with the report of Jolley et al. (1980/1981) that post-mortem changes in water-holding capacity measured by a filter-press method of raw intact neck bovine muscle, were not influenced by the range of temperatures from -1°C to 30°C.

5-4-6 PERCENT COOKING LOSSES

Cooking loss values from the muscles tested in this study, when expressed as a percent of initial weight, were slightly, but not significantly higher in the fat line than in the meaty line. The small difference between the percent cooking losses from the meaty and fat lines suggests that there is much less effect of the fat content on the weight loss when an intact muscle sample is presented. Similar results were reported by Riley et al. (1983a) who found that the thickness of backfat did not affect the cooking losses in beef. However, Smith et al. (1976) reported that cooking data from lambs with thick fat depth sustained greater cooking losses than did muscles from lambs with thin fat depths. They suggested that these differences may have reflected the lower pH and thus the lower water-holding capacity of such muscles, or they may have resulted from greater rendering of fat during cooking. Solomon et al. (1980) reported that differences in cooking losses among rib roasts cooked under similar conditions were due primarily to differences in fatness, as leaner roasts had more cooking losses. In beef, Costello et al. (1985) showed that restructured steaks that contained 25% fat had significantly greater cooking losses than steaks with 15% or 20% fat. However, in their

work the fat percent differences were much greater than in the present study.

Numerous reports have also indicated that following electrical stimulation percent cooking losses is either decreased (Elgasim et al., 1981), unchanged (Griffin et al., 1981; Babiker and Lawrie, 1983; Bowles et al., 1983; Wood and Frohlich, 1983), or increased (Savell et al., 1978a; Greathouse et al., 1983; Lewis and Babiker, 1983). However, it is difficult to relate these findings to the results obtained in the present study or to each other, due to the wide variety of stimulation and cooking techniques employed. The results of the present study do, however, support findings from previous work in which sheep were used (Rashid et al., 1983b), and where alterations in cooking loss due to stimulation were not observed.

A reduction in cooking loss percent of M. biceps femoris due to cold shortening in the present study agrees with other results (Locker and Daines, 1975, 1976). However, Locker and Daines (1974) reported that a significant 29% shortening between cold-shortened and control muscles had no effect on cooking loss percent. A similar result was obtained by Honikel et al. (1981). Davey and Gilbert (1975), however, found cooking loss percent increased with degree of cold shortening from thin strips of muscles. According to Locker and Daines (1976) the majority of fibres in cold-shortened meat were crimped, and the effective fibre length was greater for the same length of piece than in unshortened meat. Locker and Daines (1974) suggested that cooking loss percent was positively related to length along the fibre, and since the M. biceps femoris samples on ice for 24 h had significantly shorter sarcomere lengths than those at ambient temperature, so a lower loss on cooking shortened samples would be expected. The significantly higher pH of the M. biceps femoris on ice may have accounted for the greater water-holding capacity.

Bouton et al. (1972a) reported increased cooking loss with ageing and suggested that it was related to the same myofibrillar protein structural changes which produced the improved tenderness associated with the ageing process. However, ageing for 15 days in the present study did not affect the M. semimembranosus cooking losses from the two selection lines. In the present study and across all experiments,

the M. semitendinosus had the highest percent cooking loss while the M. longissimus had the lowest and the other two muscles (Mm. semimembranosus and biceps femoris) were intermediate. Differences in percent cooking losses between different muscles reported by Rashid et al. (1983b) were in contrast with the present study in that M. longissimus had higher values than M. semitendinosus in lambs.

5-4-7 WARNER-BRATZLER SHEAR FORCE VALUES

Reported relationships between fatness and meat tenderness have indicated that increases in subcutaneous fat thickness may improve meat tenderness by decreasing the rate of post-mortem chilling (reviewed in Section 2-3-3-1-2). Therefore, the question of whether selection for or against fatness affected meat tenderness was of particular concern. This question was addressed by electrically stimulating half the carcasses and by applying several treatments to muscles within each carcass, so that the effect of selection line could be evaluated not only on shear force values, but also on the response of shear force values to these treatments. The within-carcass treatments included subcutaneous fat trimming from one side over M. longissimus, ageing of M. semimembranosus for 1 or 15 days and subjecting one M. biceps femoris to cold-shortening conditions.

5-4-7-1 Line Effects

The relationship between fatness and tenderness has been investigated by many workers, and the general conclusion has been that increased subcutaneous fat thickness may improve the tenderness of meat through its effect on the rate of post-mortem chilling. Two possible mechanisms for these observations are first by the prevention of cold shortening and secondly by the acceleration of proteolytic changes (reviewed in Section 2-3-3-1-2). The former mechanism would apply when well-insulated carcasses with a thick layer of subcutaneous fat are compared with those insulated by a thin layer of subcutaneous fat, especially when the carcasses are subjected to fast chilling (Lochner et al., 1980). In the present study, only slight differences were found between the two selection lines for shear force values, with values being non-significantly lower for samples from the fat line. In this respect, Al-Barharwe (1966) reported non-significant

negative genetic and phenotypic correlations between fat thickness and shear force values in sheep. However, in an investigation of the effects of subcutaneous fat depth on lamb tenderness, Smith et al. (1976) showed that tenderness increased significantly with increasing fat cover due to the slower cooling rate. In cattle, a similar conclusion has been reached by Jennings et al. (1978). On the other hand, only slightly shorter sarcomere lengths were shown for muscles from chilled sides of the meaty carcasses as compared to the fat ones in the present study, suggesting that very little cold shortening took place. Moreover, the chilling rates for the meaty line carcasses, although faster, were not significantly different from those of the fat line carcasses, so differences due to insulating effects would not be expected to be very large. These results were possibly due to the fact that all carcasses in this study had a reasonable fat cover, were quite large and were not transferred to the cooler until 100 min post-mortem. In contrast, Smith et al. (1976) used carcasses that were lighter and that had less fat than those in the present study, and they transferred them to the cooler at 1°C within 40 min post-mortem. Temperatures at 4 h post-mortem for the two studies (18° to 25°C vs 3.8° to 7.9°C) provide evidence that the rates of temperature decline were much faster in the study of Smith et al. (1976). Furthermore, a positive correlation between meat tenderness and very early post-mortem temperature in beef has been reported by Lochner et al. (1980), Marsh (1983), and Petaja et al. (1985). Therefore, the 100 min at 18° to 19°C prior to chilling in the present study might have decreased the beneficial effects of subcutaneous fat as an insulator and this could have contributed in part to the non-significant differences in meat tenderness between the fat and meaty carcasses.

5-4-7-2 Line Effects on the Response to Electrical Stimulation

In the present study, electrical stimulation was applied to half the carcasses to test the hypothesis that accelerated carcass conditioning might reduce the beneficial effects of fat as an insulator. The response of both lines to electrical stimulation was an increased rate of pH decline during the first 2 h post-mortem, and a significant decrease in shear force values, but the interactions between stimulation and selection lines were not significant. In beef, Riley et al. (1983b) concluded that a fat thickness of 7.6 mm or more may

minimise the beneficial effects of electrical stimulation. In the present study, the lack of an interaction between fatness and stimulation with respect to tenderness could be due to the level of fat thickness being sufficient to decrease cooling rates for both lines and due to the conditioning which took place during the 100 min prior to chilling. According to Dutson et al. (1982), improvements in meat tenderness do not result from electrical stimulation unless it markedly accelerates post-mortem glycolysis. A similar conclusion has been reported by Wu et al. (1985). In the present study evidence of the effectiveness of the electrical stimulation technique in accelerating glycolysis for both fat and meaty line carcasses was provided by the consistently lower pH values for stimulated samples during the 8 to 10 h period immediately post-mortem. Such findings are in agreement with the reports of Jeremiah et al. (1985), Shorthose et al. (1986) and Solomon et al. (1986). However, Marsh (1983) suggested that the rapid drop in pH associated with electrical stimulation was not entirely responsible for the tenderness improvement, but that electrical stimulation exerted most of its tenderising effects through muscle-fibre disruption. He suggested that slow, rather than rapid glycolysis promoted tenderness and that muscle temperature at 3 h post-mortem was much more critical than muscle pH.

In the present study, muscles from carcasses stimulated at 25 min post-mortem in Experiment 5 were slightly more tender than the same muscles stimulated at 30 min post-mortem from Experiment 6. The 5 min difference in stimulation time also influenced the rate of pH decline. Similarly, Hagyard et al. (1980) showed that muscles from carcasses stimulated 25 min post-mortem were slightly more tender than those stimulated 30 min post-mortem. They concluded that the time of stimulation was very important since with stimulation at later than 25 to 30 min post-mortem the pH at 2 h was significantly above 6. Furthermore, according to Chrystall and Devine (1978) if the delay is protracted, then the muscle pH can have fallen considerably, reducing the magnitude of the pH drop achieved on eventually applying the stimulus. In this respect, linear relationships between time post-mortem at which stimulation takes place and meat tenderness have been shown by Hagyard et al. (1980).

5-4-7-3 Line Effects on the Response to Fat Trimming

M. longissimus from carcasses of the two selection lines did not differ significantly in the extent to which shear force increased and sarcomere length decreased in response to removing the subcutaneous fat from over the muscle. The shorter sarcomere lengths and higher shear values in the M. longissimus from fat-trimmed sides indicated that cold shortening contributed to the tenderness differences. It is interesting to note that the muscle temperature differences between trimmed and untrimmed sides was only about 2°C for the first 8 h from the 24 h chilling period. Yet even such a relatively small difference in temperature apparently caused a significant difference in sarcomere length. In accordance with these results, Smith et al. (1976) reported significant differences between trimmed and untrimmed sides of lamb for internal temperature of the M. longissimus during chilling at 1, 2, and 3 h post-mortem and in tenderness. Similar results were reported in beef by Meyer et al. (1977), and Lochner et al. (1980) stated that in the first few hours after slaughter the temperature of trimmed sides of beef fell more rapidly even if exposed to much milder than cold-chilling conditions. The response of trimmed and untrimmed M. longissimus to electrical stimulation in the present study showed that the treatment brought about a marked improvement in meat tenderness for muscles from both sides, but that the muscles from the trimmed side responded slightly more. These results are in agreement with the suggestion of Savell et al. (1978a) that electrical stimulation will benefit the tenderness of meat from trimmed carcasses more than that from untrimmed carcasses.

5-4-7-4 Line Effects on the Response to Cold-shortening Conditions

A commonly accepted criterion for cold shortening in lambs is that it will occur only if the meat temperature drops below 10°C before the pH has reached 6.2 (Bendall, 1972). In the present study, cold-shortening conditions produced changes in shear force value and sarcomere length for M. biceps femoris which were very similar for the fat and meaty lines. In contrast, Purchas and Davies (1974b) showed significant negative relationships between shear force values and intramuscular fat percent for M. semitendinosus which was permitted to

cold-shorten at 2⁰ to 4⁰C for 24 h. Similar conclusions have been reached by Purchas et al. (1979) with sheep. However, the proportional increase of intramuscular fat percent (1 to 5%) was much greater than the present study (4 to 9%). The results of the present study confirm those of other studies in showing that the extent of shortening during the early post-mortem period decreases tenderness to a remarkable degree (reviewed in Section 2-3-4-3-1).

The generally accepted finding that cold shortening of meat can be reduced by applying electrical stimulation (reviewed in Section 2-3-4-3-2-2) was supported by the results of this study, with the muscles from the unstimulated group having shorter sarcomere lengths and higher shear force values than those from the stimulated group. In accordance with these results, Bouton et al. (1980) suggested that the major effect of electrical stimulation was the prevention of cold shortening; while George et al. (1980) and Martin et al. (1983) reported that very rapid cooling soon after slaughter reduced the electrical stimulation effect to almost zero, noting, therefore, that the extra tenderisation could not be entirely due to muscle damage during stimulation.

5-4-7-5 Line Effects on the Response to Ageing

The ageing treatment in this study showed that M. semimembranosus aged for 1 day was significantly tougher than that aged for 15 days with the shear-force values for both fat and meaty lines showing an average reduction of 28% to 33% between 1 and 15 days ageing for Experiments 5 and 6 respectively. These findings support those of many other workers (reviewed in Section 2-3-4-4-2-1). The shear force of the meaty line samples dropped slightly more between 1 and 15 days ageing than those from the fat line, but the interaction was not significant.

The possibility that electrical stimulation influences the rate of tenderisation during ageing has been the subject of a number of investigations, but the results have been variable. In the present case, electrical stimulation had a much larger and more significant effect on shear force values of M. semimembranosus at 1 day than at 15 days. These results are in good agreement with Moller et al. (1983)

who used similar stimulation techniques and found that stimulation had a significant effect on shear force values from ovine M. semi-membranosus at 1 day but not after 2 weeks ageing at 0^o to 1^oC. Furthermore, Savell et al. (1981) and Martin et al. (1983) reported that electrical stimulation had the greatest impact on beef tenderness if the period of ageing was 6 to 8 days or less. In beef Taylor and Cornell (1985) found that electrical stimulation, ageing for 28 days, and a combination of both treatments resulted in samples that were significantly more tender than the controls, but there were no significant differences in tenderness between the ageing and the electrical stimulation and ageing treatments. These results showed that electrical stimulation decreased the response of tenderness to ageing, a result which is supported by the present study and by that of George et al. (1980) and Moller et al. (1983). Furthermore, Valine et al. (1981) indicated that electrical stimulation per se had no significant effect on the rate of meat ageing, but could perhaps be used to improve the efficiency of meat ageing by reducing the time to reach a set level of tenderness.

5-4-7-6 Between Muscle Comparisons

Differences in shear force values between different muscles that had received the same post-mortem treatment in this study were consistent with those reported by many investigators (Batcher et al., 1962a; Jeremiah et al., 1971; Khan and Voisey, 1973; Purchas et al., 1979; Moller et al., 1983; Rashid et al., 1983b; DeVol et al., 1984; Lin et al., 1985) in showing that M. longissimus samples had shorter sarcomeres and generally lower shear force values than M. semitendinosus samples. The difference in shear values was probably due to the greater connective tissue content of M. semitendinosus (Light et al., 1985), as numerous investigators have reported that longer sarcomeres are associated with more tender meat within a muscle (reviewed in Section 2-3-4-3-1).

CHAPTER 6

CONCLUSIONS

1. The results reported in this thesis have provided further evidence that backfat thickness over M. longissimus at the 12th rib can be accurately measured ultrasonically in live sheep. Therefore, selection on the basis of such measurements after correction for live weight should be effective, as published values for heritabilities of fat depth and genetic correlations among fat depots indicate that improvement would be made.

2. Based entirely on the results obtained with the Southdown sheep and their crossbred progeny used in the present series of experiments, it can be concluded that the decreased fatness of sheep selected against fatness relative to those selected for fatness is likely to be associated with:
 - (a) No change in either pre- or post-weaning growth rates up to 16 to 17 months of age under grazing conditions.
 - (b) An increase in the weight of several non-carcass components including the foregut, intestines, kidneys and heart, but a decrease in the weight of non-carcass fat depots including omental, kidney and mesenteric fat relative to carcass weight.
 - (c) A decrease in dressing-out percent due probably to higher internal organ weights and to lower carcass fat content.
 - (d) A decrease in carcass side fat percent (subcutaneous, intermuscular and intramuscular fat) and a corresponding increase in the proportions of carcass side muscle and bone, in such a way that muscle to bone ratio decreases slightly. For example, in Experiment 5, carcasses from the meaty line, when compared with those from the fat line at the same weight, had fat depth C values that were 51% lower at 4.4 mm, side fat percent values that were 7.0 percent points less at 25.7%, side muscle percent values that were 5.1 percent points higher at 57.6%, and a muscle to bone ratio which was lower by 0.15 at 3.86.
 - (e) Carcasses with larger frames in terms of total carcass length, leg length and the length of certain bones at the same carcass weight.

- (f) Carcasses with lower muscularity scores in terms of muscle weights relative to skeletal size and in terms of shallower, but wider cross-sections of M. longissimus at the 12th rib.
- (g) No change in the distribution of subcutaneous and inter-muscular fat depots among four cuts (shoulder, rack, loin, and leg), but a greater change in fat depth C over M. longissimus at the 12th rib than in other fat depths at the shoulder or the leg.
- (h) A relocation of fat from the subcutaneous fat to the inter-muscular fat and to some extent the relocation of body fat from the subcutaneous fat to the internal fat depots.
- (i) A decrease in the adipocyte size in the subcutaneous, inter-muscular, omental, kidney, and mesenteric fat depots, but little change in the number of adipocytes per depot.
- (j) No change in the distribution of muscle and bone weights amongst the shoulder, rack, loin, and leg cuts, or between several muscles and several bones at the same total side muscle weight and total side bone weight, respectively.
- (k) A change in the relationship between the percent fat in the rack cut and the percent fat in the whole carcass, such that a certain level of fat in the rack cut was associated with lower levels of carcass fat in the leaner carcasses than in the fatter carcasses.
- (l) No change in several meat characteristics which have important implications for meat quality, including ultimate muscle pH, expressed juice values, percent cooking losses, reflectance values, Warner-Bratzler shear force values and sarcomere lengths.
- (m) A decrease in the proportion of red (β R) muscle fibres in M. semitendinosus relative to the proportions of both intermediate (α R) and white (α W) muscle fibres.
- (n) No change in the extent to which electrical stimulation decreased the shear force values for Mm. semitendinosus, semimembranosus, biceps femoris, and longissimus.
- (o) No change in the extent to which ageing for 15 days at $3+1^{\circ}\text{C}$ decreased the shear force values of M. semimembranosus.
- (p) No change in the extent to which trimming the subcutaneous fat over M. longissimus during the first 24 h post-mortem at

0° to 3°C increased the shear force values of M. longissimus.

- (q) No change in the extent to which cold-shortening conditions during the first 24 h post-mortem increased the shear force values of M. biceps femoris.
 - (u) No change in the extent to which electrical stimulation decreased the effect of:
 - (i) Ageing for 15 days at 3+1°C on the shear force values of M. semimembranosus.
 - (ii) Trimming the subcutaneous fat over M. longissimus for the first 24 h post-mortem at 0° to 3°C on the shear force values of M. longissimus.
 - (iii) Cold-shortening for the first 24 h post-mortem on the shear force values of M. biceps femoris.
3. The present results are generally consistent with previously published conclusions with the exception that most of those conclusions have shown that leaner animals grew faster than fat animals, while in the present study no differences in growth rate were found.
 4. Although the present study has described the effects of selection for and against fatness on body composition and meat quality characteristics, there is a need for more fundamental work to evaluate the physiological implications of selection for improved carcass and meat quality. In particular, the endocrinology, and fat enzyme systems of the two lines would merit investigation.
 5. From the New Zealand meat industry's point of view, the present findings provide good grounds for the establishment of a national selection programme for sheep breeders designed to reduce fatness at heavier carcass weights. This programme could make use of the ultrasonic probe. Selection against subcutaneous fat, corrected for live weight differences, will be effective in reducing other body fat depots. It is also important to note, however, that this will be achieved without marked deterioration in muscle quality characteristics.

The importance of meat quality to the consumer is well known and accepted. To meet this demand the sheep producer and the meat processor must be committed to the attainment of consistently high quality standards for meat products. This is especially urgent because of the increasing impact non-meat protein and processed foods are having on red meat consumption.

Appendix 1. Allometric growth coefficients (b) and their standard errors (SE^b) relating weights of non-carcass components to live body weight for Southdown rams of Experiments 3, 4, 5 and 6

Item	Experiment 3			Experiment 4			Experiment 5			Experiment 6		
	b	SE ^b	r ²	b	SE ^b	r ²	b	SE ^b	r ²	b	SE ^b	r ²
Omental fat	1.66	0.98	0.30	2.83	1.04	0.21	2.46	0.79	0.56	2.03*	0.47	0.51
Kidney fat	2.18	1.17	0.18	2.92	1.25	0.22	1.93	0.75	0.57	2.53*	0.71	0.50
Mesenteric fat	-	-	-	-	-	-	-	-	-	1.20	0.40	0.31
Foregut empty	1.14	0.30	0.59	-	-	-	1.71	0.59	0.30	1.25	0.20	0.73
Intestines	1.09	0.38	0.56	-	-	-	1.08	0.26	0.64	1.03	0.27	0.50
Small intestine	-	-	-	-	-	-	-	-	-	1.37	0.50	0.36
Large intestine	-	-	-	-	-	-	-	-	-	0.76	0.50	0.17
Liver	1.17	0.41	0.29	1.79	1.32	0.15	1.37	0.50	0.26	2.17*	0.35	0.66
Heart	0.51	0.68	0.03	1.16	2.09	0.22	0.65	0.23	0.50	0.75	0.27	0.67
Kidneys	0.83	0.38	0.33	0.84	1.43	0.07	0.73	0.20	0.47	1.06	0.25	0.60
Thyroid gland	0.83	0.44	0.08	1.35	2.98	0.10	0.37	0.68	0.05	0.41	0.62	0.18
Adrenal gland	0.86	1.30	0.15	0.97	1.32	0.22	0.67	0.45	0.16	0.61	0.31	0.37
Spleen	-	-	-	-	-	-	0.87	0.43	0.19	0.08	0.27	0.62

* (P<0.05) a coefficient significantly more or less than 1.0.

Appendix 2. Allometric growth coefficients (b) and their standard errors (SE^b) relating the weights of each fat depot, and of depot weights within cuts to total side fat weight for Southdown rams of Experiments 3, 5 and 6.

Item	Experiment 3			Experiment 5			Experiment 6		
	b	SE ^b	r ²	b	SE ^b	r ²	b	SE ^b	r ²
	Total side fat is independent variate								
Omental fat	1.16	0.30	0.61	1.27	0.29	0.66	1.18	0.21	0.63
Kidney fat	0.91	0.33	0.81	1.14	0.26	0.71	1.14	0.37	0.51
Mesenteric fat	-	-	-	-	-	-	0.84*	0.17	0.43
<u>Side:</u>									
Subcutaneous fat	1.22	0.12	0.95	1.05	0.06	0.98	1.10	0.06	0.95
Intermuscular fat	0.71	0.15	0.80	0.90	0.08	0.90	0.85	0.08	0.86
<u>Shoulder:</u>									
Total fat	-	-	-	0.79*	0.07	0.93	0.97	0.08	0.89
Subcutaneous fat	-	-	-	0.82	0.12	0.90	1.27	0.12	0.86
Intermuscular fat	-	-	-	0.76	0.12	0.77	0.75	0.12	0.69
<u>Rack:</u>									
Total fat	1.29	0.28	0.82	1.30*	0.08	0.95	1.22*	0.08	0.94
Subcutaneous fat	1.40	0.47	0.67	1.38*	0.09	0.91	1.29	0.18	0.89
Intermuscular fat	1.14	0.27	0.79	1.18	0.12	0.89	1.19	0.11	0.85
<u>Loin:</u>									
Total fat	-	-	-	1.44	0.13	0.94	1.15	0.08	0.93
Subcutaneous fat	-	-	-	1.49	0.16	0.92	1.32	0.22	0.91
Intermuscular fat	-	-	-	1.33	0.19	0.85	1.08	0.10	0.70
<u>Leg:</u>									
Total fat	-	-	-	0.90	0.12	0.88	0.84	0.10	0.81
Subcutaneous fat	-	-	-	1.04	0.25	0.91	0.95	0.13	0.76
Intermuscular fat	-	-	-	0.91	0.12	0.55	0.61*	0.15	0.54

* (P<0.05) a coefficient significantly more or less than 1.0

Appendix 3. Allometric growth coefficients (b) and their standard errors (SE^b) relating carcass side cuts to side weight and dissectible components to total weight for the whole side, and for each cut of Southdown rams in Experiments 3, 5 and 6.

Item	Experiment 3			Experiment 5			Experiment 6		
	b	SE ^b	r ²	b	SE ^b	r ²	b	SE ^b	r ²
	Side weight as independent variate								
Shoulder	-	-	-	0.82	0.06	0.91	0.89	0.05	0.93
Rack	1.26	0.24	0.57	1.46	0.13	0.89	1.12	0.09	0.89
Loin	-	-	-	1.38	0.12	0.90	1.14	0.13	0.80
Leg	-	-	-	0.87	0.07	0.90	1.05	0.09	0.87
<u>Side tissue components:</u>									
Total muscle	0.94	0.12	0.80	0.89	0.08	0.89	0.77	0.08	0.85
Total fat	1.34	0.40	0.64	1.49	0.17	0.91	1.59	0.16	0.85
Subcutaneous fat	1.64	0.50	0.65	1.61	0.22	0.91	1.73	0.19	0.84
Intermuscular fat	0.95	0.40	0.46	1.34	0.21	0.78	1.38	0.21	0.70
Total bone	0.62	0.33	0.54	0.56	0.10	0.82	0.45	0.15	0.52
	Shoulder weight as independent variate								
<u>Shoulder tissue components:</u>									
Total muscle	-	-	-	0.88	0.09	0.90	0.77*	0.10	0.77
Total fat	-	-	-	1.55*	0.15	0.92	1.53	0.26	0.64
Subcutaneous fat	-	-	-	1.58*	0.22	0.91	1.82*	0.34	0.62
Intermuscular fat	-	-	-	1.49	0.25	0.74	1.34	0.29	0.53
Total bone	-	-	-	0.50	0.11	0.85	0.52*	0.18	0.56
	Rack weight as independent variate								
<u>Rack tissue components:</u>									
Total muscle	0.71	0.16	0.52	0.74	0.08	0.83	0.46**	0.10	0.67
Total fat	1.73*	0.28	0.75	1.39	0.14	0.93	1.79**	0.13	0.93
Subcutaneous fat	1.90*	0.39	0.66	1.41	0.19	0.89	1.73***	0.17	0.88
Intermuscular fat	1.44	0.33	0.56	1.37	0.16	0.88	1.73*	0.17	0.85
Total bone	0.45*	0.17	0.37	0.78	0.12	0.72	0.53	0.14	0.64
	Loin weight as independent variate								
<u>Loin tissue components:</u>									
Total muscle	-	-	-	0.78*	0.09	0.79	0.63**	0.10	0.79
Total fat	-	-	-	1.56**	0.18	0.91	1.50**	0.14	0.89
Subcutaneous fat	-	-	-	1.66**	0.19	0.91	1.67	0.33	0.89
Intermuscular fat	-	-	-	1.34	0.26	0.78	1.44	0.14	0.66
Total bone	-	-	-	0.64**	0.10	0.70	0.51***	0.17	0.66
	Leg weight as independent variate								
<u>Leg tissue components:</u>									
Total muscle	-	-	-	1.02	0.11	0.86	1.04	0.10	0.87
Total fat	-	-	-	1.42	0.34	0.75	1.19	0.22	0.61
Subcutaneous fat	-	-	-	1.45	0.33	0.80	1.36	0.26	0.61
Intermuscular fat	-	-	-	1.42	0.58	0.39	0.69	0.26	0.28
Total bone	-	-	-	0.75	0.21	0.64	0.61	0.22	0.38

* (P<0.05), ** (P<0.01) and *** (P<0.001) a coefficient significantly more or less than 1.0.

Appendix 4. Allometric growth coefficients (b) and their standard errors (SE^b) relating muscle weight of the side, muscle weight of each cut, and the weights of individual muscles to total side muscle weight.

Item	Experiment 3			Experiment 5			Experiment 6		
	b	SE ^b	r ²	b	SE ^b	r ²	b	SE ^b	r ²
Total side muscle as independent variate									
Shoulder total muscle -	-	-	-	0.82*	0.07	0.91	0.88	0.09	0.85
<u>M. infraspinatus</u>	-	-	-	0.99	0.32	0.25	1.07	0.20	0.69
<u>M. supraspinatus</u>	-	-	-	1.19	0.18	0.76	1.30	0.20	0.60
<u>M. triceps</u>	-	-	-	0.87	0.13	0.69	0.97	0.19	0.64
Rack total muscle	1.19	0.24	0.54	0.76*	0.09	0.76	0.73*	0.12	0.74
<u>M. longissimus</u>	-	-	-	1.00	0.23	0.45	1.06	0.26	0.51
Loin total muscle	-	-	-	1.28	0.12	0.85	0.93	0.18	0.67
<u>M. longissimus</u>	-	-	-				1.08	0.24	0.61
Leg total muscle	-	-	-	1.04	0.09	0.88	1.33	0.17	0.76
<u>M. semitendinosus</u>	-	-	-	0.85	0.26	0.43	0.98	0.20	0.54
<u>M. semimembranosus</u>	-	-	-	0.94	0.16	0.66	0.88	0.19	0.53
<u>M. biceps femoris</u>	-	-	-	1.13	0.13	0.81	1.10	0.15	0.76

* (P<0.05) a coefficient significantly more or less than 1.0.

Appendix 5. Allometric growth coefficients (b) and their standard errors (SE^b) relating bone weights of the cuts, and individual bone weights to total side bone weight.

Item	Experiment 3			Experiment 5			Experiment 6		
	b	SE^b	r^2	b	SE^b	r^2	b	SE^b	r^2
Total side bone as independent variate									
<u>Shoulder cut:</u>									
Total bone	-	-	-	0.75*	0.17	0.80	0.81	0.12	0.88
Humerus	0.75*	0.11	0.84	0.90	0.17	0.88	0.63*	0.14	0.78
Radius and ulna	0.72	0.22	0.57	0.85	0.16	0.82	0.60*	0.17	0.71
Metacarpal bone	0.59*	0.18	0.49	0.41	0.38	0.22	0.40*	0.16	0.57
<u>Rack cut:</u>									
Total bone	0.67	0.19	0.42	0.78	0.15	0.75	0.66	0.12	0.71
<u>Loin cut:</u>									
Total bone	-	-	-	0.78	0.61	0.16	0.68	0.27	0.56
<u>Leg cut:</u>									
Total bone	-	-	-	1.10	0.22	0.77	1.36	0.22	0.73
Femur	0.68**	0.11	0.81	0.90	0.15	0.89	0.80	0.16	0.76
Tibia and fibula	0.69*	0.12	0.75	0.97	0.55	0.59	0.78	0.16	0.67

* ($P < 0.05$) a coefficient significantly more or less than 1.0.

Appendix 6. Allometric growth coefficients (b) and their standard errors (SE^b) relating weights of individual muscles and muscle groups to total side muscle weight for Southdown rams of Experiment 3.

Muscle	b	SE ^b	r ²
<u>M. rhomboideus</u> (g)	0.84	0.56	0.09
<u>M. trapezius</u> (g)	1.59*	0.28	0.60
<u>M. brachiocephalicus</u> (g)	1.53	0.66	0.23
<u>M. latissimus dorsi</u> (g)	1.30	0.19	0.74
<u>M. serratus ventralis</u> (g)	0.94	0.22	0.52
<u>M. pectoralis</u>	0.83	0.23	0.48
Abdominal muscles	1.35	0.28	0.54
<u>M. longissimus</u>	1.25	0.20	0.74
<u>M. splenius</u>	1.12	0.17	0.62
<u>M. spinalis</u>	0.92	0.17	0.58
Brachial muscles	0.63	0.19	0.37
Antebrachial muscles	0.86	0.25	0.39
<u>M. cutaneus</u>	1.48	0.40	0.41
<u>M. tensor fasciae latae</u>	1.36	0.31	0.66
<u>M. gracilis</u>	0.60	0.23	0.31
<u>M. gluteobiceps</u>	1.16	0.26	0.53
<u>M. semitendinosus</u>	1.08	0.27	0.43
<u>M. semimembranosus</u>	0.99	0.19	0.58
<u>M. adductor</u>	1.39	0.38	0.40
<u>M. gluteus medius</u>	1.10	0.21	0.57
Sublumbar muscles	1.21	0.19	0.64
<u>M. quadriceps femoris</u>	0.59**	0.15	0.48
Deep hip muscles	0.81	0.44	0.35
Crural muscles	0.67	0.20	0.40

*, ** see Table 4-1.

REFERENCES

- AALHUS, J.L. and PRICE, M.A. (1986). Post-mortem pH and temperature decline in endurance-exercised sheep. In: 65th Annual Feeders' Day Report. University of Alberta, Canada, pp. 40-42.
- ABBAN, A.R., STOUFFER, J.R. and WESTERVELT, R.G. (1975). Pre-rigor mechanical tensioning of lamb carcasses to improve tenderness. Journal of Food Science 40: 1214-1216.
- ABBOT, J.A. (1972). Sensory assessment of food texture. Food Technology 26: 40-49.
- ABERLE, E.D. and STEWART, T.S. (1983). Growth of fiber types and apparent fiber number in skeletal muscle of broiler- and layer-type chickens. Growth 47: 135-144.
- ADAMS, J.R. and HUFFMAN, D.L. (1972). Effect of controlled gas atmospheres and temperature on quality of packaged pork. Journal of Food Science 37: 869-872.
- AHMAD, N.A. and DAVIES, H.L. (1986). Effect of sex and dietary energy concentration on feed conversion ratio, growth and carcass characteristics in Merino X Border Leicester lambs. Proceedings of the Australian Society of Animal Production 16: 119-122.
- AL-BARHAWE, A.S. (1966). Estimates of Phenotypic and Genetic Parameters of Lamb Growth and Carcass Traits. Master thesis, Texas A & M University, U.S.A.
- ALLEN, C.E. (1976). Cellularity of adipose tissue in meat animals. Federation Proceedings 35: 2302-2307.
- ALLEN, C.E., BEITZ, D.C., CRAMER, D.A. and KAUFFMAN, R.G. (1976). Biology of Fat in Meat Animals. North Central Regional Research Publication No. 234. Research Division, College of Agricultural and Life Science, University of Wisconsin-Madison, U.S.A.
- ANDERSON, D.B. (1972). The cellular development of adipose tissue. Proceedings of the 25th Annual Reciprocal Meat Conference, pp. 9-39.
- ANDERSON, D.B. and KAUFFMAN, R.G. (1973). Cellular and enzymatic changes in porcine adipose tissue during growth. Journal of Lipid Research 41: 160-168.
- ANDERSEN, H.R. and INGVARSTEN, K.L. (1984). Influence of energy level, weight at slaughter and castration on carcass quality in cattle. Livestock Production Science 11: 571-586.

- ANDREWS, R.P. and ORSKOV, E.R. (1970). The nutrition of the early weaned lamb. II. The effect of dietary protein concentration, feeding level and sex on body composition at two live weights. Journal of Agricultural Science, Cambridge 75: 19-26.
- ANDREWS, R.P., KAY, M. and ORSKOV, E.R. (1969). The effect of different dietary energy concentration on the voluntary intake and growth of intensively fed lambs. Animal Production 11: 173-185.
- ANON. (1982). Lamb grading review draft discussion paper. New Zealand Meat Producers Board, Wellington, New Zealand, p. 25. (Cited by Kirton et al., 1983).
- A.O.A.C. (1980). Official Methods of Analysis, 13th ed. Association of Official Agricultural Chemists, Washington, D.C., U.S.A.
- APRIL, E.W., BRANDT, P.W. and ELLIOT, G.F. (1972). The myofilament lattice: Studies on isolated fibres. II. The effects of osmotic strength, ionic concentration, and pH upon the unit-cell volume. Journal of Cell Biology 53: 53-65.
- ARNOLD, G.W., GHARAYBEH, H.R., DUDZINSKI, M.L., McMANUS, W.R. and AXELSEN, A. (1969). Body composition of young sheep. II. Effect of stocking rate on body composition of Dorset Horn cross lambs. Journal of Agricultural Science, Cambridge 72: 77-84.
- ARANGO, T.C., SMITH, G.C., CARPENTER, Z.L. and CROSS, H.R. (1970). Physical methods for tenderizing bovine carcasses. Journal Animal Science 31: 180 (abstract).
- ASGHAR, A. and YEATES, N.T.M. (1977). Correlations between physiochemical and organoleptic of lamb L. dorsi muscle. Journal of the Science of Food and Agriculture 28: 1-10.
- ASGHAR, A. and YEATES, N.T.M. (1978). The mechanism for the promotion of tenderness in meat during post-mortem ageing process. Critical Reviews in Food Science and Nutrition 10: 115-145.
- ASGHAR, A. and YEATES, N.T.M. (1979). Muscle characteristics and meat quality of lambs, grown on different nutritional planes. I. Effect on carcass morphology. Agricultural and Biological Chemistry 43: 429-436.
- ASGHAR, A. and PEARSON, A.M. (1980). Influence of ante- and post-mortem treatments upon muscle composition and meat quality. Advance in Food Research 26: 53-213.
- ASGHAR, A. and HENRICKSON, R.L. (1982). Chemical, biochemical, functional and nutritional characteristics of collagen in food systems. Advance in Food Research 28: 231-272.

- ASHMORE, C.R. and DOERR, L. (1971). Comparative aspects of muscle fibre types in different species. Experimental Neurology 31: 408-418.
- ASHMORE, C.R. and ADDIS, P.B. (1972). Prenatal development of muscle fibre types in domestic animals. Proceedings of the 25th Annual Reciprocal Meat Conference, pp. 211-230.
- ASHMORE, C.R., TOMPKINS, G. and DOERR, L. (1972). Postnatal development of muscle fibre types in domestic animals. Journal of Animal Science 34: 37-41.
- ASHMORE, C.R. (1974). Phenotypic expression of muscle fibre type and some implications to meat quality. Journal of Animal Science 38: 1158-1164.
- ATKINSON, J.L. and FOLLETT, M.J. (1973). Biochemical studies on the discoloration of fresh meat. Journal of Food Technology 8: 51-58.
- ATTREY, D.P., RAMANATHAN, L.A., RADHAKRISHNA, K. and SHARMA, T.R. (1982). Time course of rigor mortis in sheep muscle with a new apparatus. Indian Journal of Animal Science 52: 67-71.
- BABIKER, S.A. and LAWRIE, R.A. (1983). Post-mortem electrical stimulation and high temperature ageing of hot-deboned beef. Meat Science 8: 1-20.
- BABIKER, S.A. (1985). Effect of electrical stimulation, high temperature conditions and ageing on muscle myofibrillar proteins. Meat Science 14: 83-90.
- BABIKER, S.A. and MERKEL, R.A. (1985). The effects of carcass ageing temperature on proteinase activity and tenderness of beef longissimus muscle. Journal of Animal Science 61: 272 (abstract). Supplement 1.
- BAILEY, A.J. (1972). The basis of meat texture. Journal of the Science of Food and Agriculture 23: 995-1007.
- BALDWIN, R.L., SMITH, N.E., TAYLOR, J. and SHARP, M. (1980). Manipulating metabolic parameters to improve growth rate and milk secretion. Journal of Animal Science 51: 1416-1428.
- BARTLETT, J.E., GUETHER, J.J., NOVOTNY, K.K. and MORRISON, R.D. (1980). Myofiber number and type in twenty-five-day-old beef calves as influenced by breed type. Animal Science Research Report. Oklahoma Agricultural Experimental Station, U.S.A., pp. 42-44.
- BARTON, R.A., PHILIPS, T.O. and CLARKE, E.A. (1949). Influence of sire on fat lamb quality. Proceedings of the New Zealand Society of Animal Production 9: 66-72.

- BARTON, R.A. and KIRTON, A.H. (1958a). The leg and the loin as indices of the composition of New Zealand lamb and mutton carcasses. New Zealand Journal of Agricultural Research 1: 783-789.
- BARTON, R.A. and KIRTON, A.H. (1958b). Carcass weight as an index of carcass components with particular reference to fat. Journal of Agricultural Science, Cambridge 50: 331-334.
- BARTON, R.A. and ULYATT, M.J. (1963). Pasture type in relation to live-weight gain, carcass composition, iodine nutrition and some rumen characteristics of sheep. II. Carcass composition and the non-carcass components of live weight. Journal of Agricultural Science, Cambridge 61: 191-195.
- BARTON, R.A. (1981). The new Southdown. Flock and Herd, No. 5: 18-21.
- BASS, J.J., WOOD, E.G. and PAULSEN, W.D. (1982). A comparison of three ultrasonic machines (Danscan AIDD (NZ) and body composition meter) and subjective fat and conformation scores for predicting chemical composition of live sheep. Journal of Agricultural Science, Cambridge 99: 529-532.
- BASS, J.J., CARTER, W.D., WOODS, E.G. and MOORE, R.W. (1984). Evaluation of the ability of two carcass conformation systems to predict carcass composition of sheep. Journal of Agricultural Science, Cambridge 103: 421-427.
- BATCHER, O.M. and DAWSON, E.H. (1960). Consumer quality of selected muscle of raw and cooked pork. Food Technology 14: 69-73.
- BATCHER, O.M., BRANT, A.W. and KUNZE, M.S. (1969). Sensory evaluation of lamb and yearling mutton flavors. Journal of Food Science 34: 272-274.
- BATCHER, O.M., DAWSON, E.H., POINTER, M.T. and GILPIN, G.L. (1962a). Quality of raw and cooked lamb meat as related to fatness and age of animal. Food Technology 16: 102-110.
- BATCHER, O.M., DAWSON, E.H., GILPIN, G.L. and EISEN, J.M. (1962b). Quality and physical composition of various cuts of raw and cooked pork. Food Technology 16: 104-109.
- BEATTY, C.H., BASINGER, G.M., DULLY, C.C. and BOCEK, R.M. (1966). Comparison of red and white voluntary skeletal muscles of several species of primates. Journal of Histochemistry and Cytochemistry 14: 590-600.

- BEDI, K.S., MAHON, M. and SMART, J.L. (1978). A quantitative light microscopical study of muscle from adult rats previously undernourished in early life. Proceedings of the Nutrition Society 37: 59A.
- BEECHER, G.R., CASSENS, R.G., HOEKSTRA, W.G. and BRISKEY, E.J. (1965). Red and white fibre content and associated post-mortem properties of seven porcine muscles. Journal of Food Science 30: 969-976.
- BEECHER, G.R., KASTENSCHMIDT, L.L., CASSENS, R.G., HOEKSTRA, W.G. and BRISKEY, E.J. (1968). A comparison of the light and dark portions of a striated muscle. Journal of Food Science 33: 84-88.
- BEERMAN, D.H., CAMPION, D.R. and DALRYMPLE, R.H. (1985). Mechanisms responsible for partitioning tissue growth in meat animals. Proceedings of the 38th Annual Reciprocal Meat Conference, pp. 105-114.
- BEIKEN, S.L., BOUTON, P.E. and HARRIS, P.V. (1986). Some effects on the mechanical properties of meat produced cooking by cooking at temperatures between 50°C and 60°C. Journal of Food Science 51: 791-796.
- BENDALL, J.R. (1972). The influence of rate of chilling on the development of rigor "cold-shortening". Proceedings of the Meat Research Institute Symposium No. 2. Meat Chilling: Why and How? ... Bristol 1.3 - 3.6.
- BENDALL, J.R. (1973). Post-mortem changes in muscle. In: Bourne, G.H. (ed.) The Structure and Function of Muscle, 2nd ed. Vol. 2, pp. 243-309. New York, U.S.A.: Academic Press.
- BENDALL, J.R. (1975). Cold-contraction and ATP-turnover in the red and white musculature of the pig post-mortem. Journal of the Science of Food and Agriculture 26: 55-71.
- BENDALL, J.R. (1976). Electrical stimulation of rabbit and lamb carcasses. Journal of the Science of Food and Agriculture 27: 819-826.
- BENDALL, J.R. and RHODES, D.N. (1976). Electrical stimulation of beef carcasses and its practical application. Proceedings of the 22nd European Meeting of Meat Research Workers Vol. 1, B2: 3-2:4.
- BENDALL, J.R., KETTERIDGE, C.C. and GEORGE, A.R. (1976). The electrical stimulation of beef carcasses. Journal of the Science of Food and Agriculture 27: 1123-1231.

- BENNETT, G.L., JOHNSON, D.L. and KIRTON, A.H. (1981/1982). Genetic variation of Southdown lamb carcass traits. New Zealand Ministry of Agriculture and Fisheries, Agricultural Research Division Annual Report, p. 33.
- BENNETT, G.L., MEYER, H.H. and KIRTON, A.H. (1983). Ultrasonic selection for divergence in loin fat depth in Southdowns and Suffolks. Proceedings of the New Zealand Society of Animal Production **43**: 115-117.
- BENNETT, G.L., RAE, A.L., CLARKE, J.N. and KIRTON, A.H. (1982/1983). Research studies for development of a large lean sheep breed. New Zealand Ministry of Agriculture and Fisheries, Agricultural Research Division Annual Report, p. 43.
- BERESKIN, B., HETZER, H.O., PETERS, W.H. and NORTON, H.W. (1974). Genetic and maternal effects on pre-weaning traits in crosses of high and low fat lines of swine. Journal of Animal Science **39**: 1-10.
- BERESKIN, B. and FROBISH, L.T. (1982). Carcass and related traits in Duroc and Yorkshire pigs selected for sow productivity and pig performance. Journal of Animal Science **55**: 554-564.
- BERESKIN, B. (1986). A genetic analysis of feed conversion efficiency and associated traits in swine. Journal of Animal Science **62**: 910-917.
- BERESKIN, B. and HETZER, H.O. (1986). Genetic and maternal effects on pig weights, growth and probe backfat in diallel crosses of high and low fat lines of swine. Journal of Animal Science **63**: 395-408.
- BERG, R.T. and BUTTERFIELD, R.M. (1966). Muscle:bone ratio and fat percentage as measures of beef carcass composition. Animal Production **8**: 1-11.
- BERG, R.T. and BUTTERFIELD, R.M. (1976). New Concepts of Cattle Growth. Sydney, Australia: University of Sydney Press.
- BERG, R.T., ANDERSEN, B.B., and LIBORIUSSEN, T. (1978). Growth of bovine tissues. II. Genetic influences on muscle growth and distribution in young bulls. Animal Production **27**: 51-61.
- BERGSTROM, P.L. (1978). Sources of variation in muscle weight distribution. In: De Boer, H. and Martin, J. (eds.), Patterns of Growth and Development in Cattle. The Hague/Boston/London: Martinus Nijhoff, pp. 91-132.
- BERMAN, M.C., McINTOSH, D.B. and KENCH, J.E. (1977). Proton inactivation of Ca transport by sarcoplasmic reticulum. Journal of Biological Chemistry **252**: 994-1001.

- BERRY, B.W., SMITH, G.C. and CARPENTER, Z.L. (1974). Relationships of certain muscle, cartilage and bone traits to tenderness of the beef longissimus. Journal of Food Science **39**: 819-824.
- BERTRAND, H.A., MASORO, E.J. and YU, B.P. (1978). Increasing adipocyte number as the basis for perirenal depot growth in adult rats. Science **201**: 1234-1235.
- BJORNTORP, P., KARLSSON, M., GUSTAFSSON, L., SMITH, U., SJOSTROM, L., CIGOLINI, M., STORCK, G. and PETTERSON, P. (1979). Quantitation of different cells in the epididimal fat pad of the rat. Journal of Lipid Research **20**: 97-106.
- BLACK, J.L. (1974). Manipulation of body composition through nutrition. Proceedings of the Australian Society of Animal Production **10**: 211-218.
- BLACK, J.L. (1983). Growth and development of lambs. In: Haresign, W. (ed.), Sheep Production. University of Nottingham. London, England: Butterworths, pp. 21-58.
- BLUMER, T.N. (1963). Relationship of marbling to the palatability of beef. Journal of Animal Science **22**: 771-777.
- BOTKIN, M.P., FIELD, R.A., RILEY, M.L., NOLAN, J.C. Jr. and ROEHRKASSE, G.P. (1969). Heritability of carcass traits in lambs. Journal of Animal Science **29**: 251-255.
- BOTKIN, M.P., RILEY, M.L., FIELD, R.A., JOHNSON, C.L. and ROEHRKASSE, G.P. (1971). Relationship between productive traits and carcass traits in lambs. Journal of Animal Science **32**: 1057-1061.
- BOUTON, P.E. and SHORTHOSE, W.R. (1969). Correlation between ultimate pH and some quality traits of sheep meat. Proceedings of the 15th European Meeting Meat Research Workers, pp. 78-83.
- BOUTON, P.E., HARRIS, P.V. and SHORTHOSE, W.R. (1971). Effect of ultimate pH upon the water-holding capacity and tenderness of mutton. Journal of Food Science **36**: 435-439.
- BOUTON, P.E. and HARRIS, P.V. (1972). The effects of cooking temperature and time on some mechanical properties of meat. Journal of Food Science **37**: 140-144.
- BOUTON, P.E., HARRIS, P.V. and SHORTHOSE, W.R. (1972a). The effects of ultimate pH on ovine muscle: water-holding capacity. Journal of Food Science **37**: 351-355.
- BOUTON, P.E., HARRIS, P.V. and SHORTHOSE, W.R. (1972b). The effects of ultimate pH on ovine muscle: Mechanical properties. Journal of Food Science **37**: 356-360.

- BOUTON, P.E., CARROLL, F.D., HARRIS, P.V. and SHORTHOSE, W.R. (1973a). Influence of pH and fibre contraction state upon factors affecting the tenderness of bovine muscle. Journal of Food Science 38: 404-407.
- BOUTON, P.E., CARROLL, F.D., FISHER, A.L., HARRIS, P.V. and SHORTHOSE, W.R. (1973b). Effect of altering ultimate pH on bovine muscle tenderness. Journal of Food Science 38: 816-820.
- BOUTON, P.E., HARRIS, P.V., SHORTHOSE, W.R. and BAXTER, R.I. (1973c). A comparison of the effects of ageing, conditioning and skeletal restraint on the tenderness of mutton. Journal of Food Science 38: 932-937.
- BOUTON, P.E., FISHER, A.L., HARRIS, P.V. and BAXTER, R.I. (1973d). A comparison of the effects of some post-slaughter treatments on the tenderness of beef. Journal of Food Technology 8: 39-49.
- BOUTON, P.E., HARRIS, P.V., SHORTHOSE, W.R. and SMITH, M.G. (1974). Evaluation of methods affecting mutton tenderness. Journal of Food Technology 9: 31-41.
- BOUTON, P.E., FORD, A.L., HARRIS, P.V. and RATCLIFF, D. (1975a). Objective-subjective assessment of meat tenderness. Journal of Texture Studies 6: 315-328.
- BOUTON, P.E., FORD, A.L., HARRIS, P.V. and RATCLIFF, D. (1975b). Objective assessment of meat juiciness. Journal of Food Science 40: 884-885.
- BOUTON, P.E., FORD, A.L., HARRIS, P.V. and SHAW, F.D. (1980). Electrical stimulation of beef sides. Meat Science 4: 145-155.
- BOUTON, P.E. and HARRIS, P.V. (1981). Changes in the tenderness of meat cooked at 50-65°C. Journal of Food Science 46: 475-478.
- BOUTON, P.E., HARRIS, P.V., MacFARLANE, J.J. and SHORTHOSE, W.R. (1982a). Influence of pH on the Warner-Bratzler shear properties of mutton. Meat Science 6: 27-36.
- BOUTON, P.E., HARRIS, P.V. and SHORTHOSE, W.R. (1982b). The effect of temperature and ultimate pH on the increase in meat toughness resulting from restraint during cooking. Meat Science 6: 235-241.
- BOWLES AXE, J.E., KASTNER, C.L., DIKEMAN, M.E., HUNT, M.C., KROPF, D.H. and MILLIKEN, G.A. (1983). Effects of beef carcass electrical stimulation, hot boning, and ageing on unfrozen and frozen longissimus dorsi and semimembranosus steaks. Journal of Food Science 48: 332-336.

- BOWLING, R.A., SMITH, G.C., CARPENTER, Z.L., DUTSON, T.R. and OLIVER, W.M. (1977). Comparison of forage-finished and grain-finished beef carcasses. Journal of Animal Science 45: 209-215.
- BOWLING, R.A., SMITH, G.C., DUTSON, T.R. and CARPENTER, Z.L. (1978). Effects of pre-rigor conditioning treatments on lamb muscle shortening, pH, and ATP. Journal of Food Science 43: 502-507 and 514.
- BOWMAN, J.C. and HENDY, C.R.C. (1972). A study of retail requirements and genetic parameters of carcass quality in Polled Dorset Horn sheep. Animal Production 14: 189-198.
- BOYLAN, W.J. and SEALE, M.E. (1965). Relationships and variation among certain lamb carcass traits. Canadian Journal of Animal Science 45: 37-42.
- BOYLAN, W.J., BERGER, Y.M. and ALLEN, C.E. (1976). Carcass merits of Finn sheep crossbred lambs. Journal of Animal Science 42: 1413-1420.
- BRADFORD, G.E. and SPURLOCK, G.M. (1964). Effects of castrating lambs on growth and body composition. Animal Production 6: 291-299.
- BRADFORD, G.E. and SPURLOCK, G.M. (1972). Selection for meat production in sheep:- results of a progeny test. Journal of Animal Science 34: 737-745.
- BRADY, P.L. and PENFIELD, M.P. (1982). Effects of heating system, temperature and rate of heating on sensory characteristics of beef. Journal of Food Science 47: 1783-1792.
- BRADY, P.L. and HUNECKE, M.E. (1985). Correlations of sensory and instrumental evaluations of roast beef texture. Journal of Food Science 50: 300-303.
- BRAMBELTT, V.D., HOSTETLER, R.L., VAIL, G.E. and DRAUDT, H.N. (1959). Qualities of beef as affected by cooking at very low temperatures for long periods of time. Food Technology 13: 707-711.
- BRATZLER, L.J. (1971). Palatability factors and evaluations. In: Price, J.F. and Schweigert, B.S. (eds.), The Science of Meat and Meat Products. San Francisco, California, U.S.A.: W.H. Freeman and Company, pp. 328-363.
- BRAY, A.R., MOSS, R.A., BURTON, R.N. and TAYLOR, A.G. (1985). Leanness of lamb carcasses following restricted feeding and shearing. Proceedings of the New Zealand Society of Animal Production 45: 89-91.

- BRAY, R.W. (1966). Pork quality - definition, characteristics and significance. Journal of Animal Science 25: 839-842.
- BREIDENSTEIN, B.B., COOPER, C.C., CASSENS, R.G., EVANS, G. and BRAY, R.W. (1968). Influence of marbling and maturity on the palatability of beef muscle. I. Chemical and organoleptic conditions. Journal of Animal Science 27: 1532-1541.
- BRIGGS, C.B. and BROWN, A.J. (1985). The effect of carcass weight on the proportional distribution of intermuscular fat in lamb shoulder joints. Animal Production 40: 564 (abstract).
- BRISKEY, E.J., BRAY, R.W., HOEKSTRA, W.G., PHILLIPS, P.H. and GRUMMER, R.H. (1959). The chemical and physical characteristics of various pork ham muscle classes. Journal of Animal Science 18: 146-152.
- BRISKEY, E.J., SAYRE, R.N. and CASSENS, R.G. (1962). Development and application of an apparatus for continuous measurement of muscle extensibility and elasticity before and during rigor mortis. Journal of Food Science 27: 560-566.
- BRISKEY, E.J. and KAUFFMAN, R.G. (1971). Quality characteristics of muscle as a food. In: Price, J.F. and Schweigert, B.S. (eds.), The science of Meat and Meat Products. San Francisco, California, U.S.A.: W.H. Freeman and Company, pp. 367-401.
- BROAD, T.E., DAVIES, A.S. and TAN, G.Y. (1980). Pre- and post-natal study of the carcass growth of sheep. II. The cellular growth of adipose tissues. Animal Production 31: 73-79.
- BROOKE, M.H. (1970). Some comments on neural influence on the two histochemical types of muscle fibers. In: Briskey, E.J., Cassens, R.G. and Marsh, B.B. (eds.), Physiology and Biochemistry of Muscle as a Food. Madison, Wisconsin, U.S.A.: University of Wisconsin Press, pp. 131-153.
- BROWN, A.J. and WILLIAMS, D.R. (1979). Sheep Carcass Evaluation Measurement of Composition Using a Standardized Butchery Method. Agricultural Research Council, Meat Research Council, Langford, Bristol, England. Memorandum No. 38.
- BROWN, W.D. and DOLEV, A. (1963). Autoxidation of beef and tuna oxymyoglobins. Journal of Food Science 28: 207-210.
- BUEGE, D.R. and STOUFFER, J.R. (1974). Effects of pre-rigor tension on tenderness of intact bovine and ovine muscle. Journal of Food Science 39: 396-401.

- BUHLINGER, C.A., WANGSNES, P.J., MARTIN, R.J. and ZIEGLER, J.H. (1978). Body composition, in vitro lipid metabolism and skeletal muscle characteristics and fast-growing, lean and in slow-growing obese pigs at equal age and weight. Growth 42: 225-236.
- BURTON, J.H. and REID, J.T. (1969). Interrelationships among energy input, body size, age and body composition of sheep. Journal of Nutrition 96: 517-524.
- BURTON, J.H., ANDERSON, M. and REID, J.T. (1974). Some biological aspects of partial starvation. The effect of weight loss and regrowth on body composition in sheep. British Journal of Nutrition 32: 515-524.
- BUSBOOM, J.R., MILLER, G.J., FIELD, R.A., CROUSE, J.D., RILEY, M.L., NELMS, G.E. and FERRELL, C.L. (1981). Characteristics of fat from heavy ram and wether lambs. Journal of Animal Science 52: 83-92.
- BUSH, W.A., STROMER, M.H., GOLL, D.E. and SUZUKI, A.J. (1972). Ca-specific removal of Z-lines from rabbit skeletal muscle. Journal of Cell Biology 52: 367-381.
- BUTLER-HOGG, B.W. and WOOD, J.D. (1981). Growth and development of internal organs in Friesian and Jersey steers. Animal Production 32: 380 (abstract).
- BUTLER-HOGG, B.W. and WOOD, J.D. (1983). Adipose tissue cellularity in Clun and Southdown lambs. British Society of Animal Production, 21-23 March. Paper No. 95.
- BUTLER-HOGG, B.W. (1984a). Growth patterns in sheep: changes in the chemical composition of the empty body and its consistent parts during weight loss and compensatory growth. Journal of Agricultural Science, Cambridge 103: 17-24.
- BUTLER-HOGG, B.W. (1984b). The growth of Clun and Southdown sheep: body composition and the partitioning of total body fat. Animal Production 39: 405-411.
- BUTLER-HOGG, B.W. and WHELEHAN, D.P. (1984). Fat partitioning and muscle distribution in Texel and Scottish Blackface rams. Paper presented at 35th meeting EAAP, 6-9 August 1984, The Hague, Netherlands.
- BUTLER-HOGG, B.W., FRANCOMBE, M.A. and DRANSFIELD, E. (1984). Carcass and meat quality of ram and ewe lambs. Animal Production 39: 107-113.
- BUTLER-HOGG, B.W. (1985). Muscle weight distribution in ram and ewe lambs of the same carcass weight. Proceedings of the British Society of Animal Production. Animal Production 40: 564 (Abstract).

- BUTLER-HOGG, B.W. and WHELEHAN, D.P. (1987). Muscle growth and distribution of muscle weight in Clun and Southdown sheep. Animal Production 44: 133-142.
- BUTS, B., CASTEELS, M., CLAEYS, E. and DEMEYER, D. (1986). Effects of electrical stimulation, followed by moderate cooling on meat quality characteristics of veal longissimus dorsi. Meat Science 18: 271-279.
- BUTTERFIELD, R.M. (1964). Relative growth of the musculature of the ox. In: Tribe, D.E. (ed.), Carcass Composition and Appraisal of Meat Animals. Technical Conference, University of Melbourne, 1963. East Melbourne, Australia: CSIRO, pp. 7.1-7.14.
- BUTTERFIELD, R.M. (1965). Practical implications of anatomical research in beef cattle. Proceedings of the New Zealand Society of Animal Production 25: 152-163.
- BUTTERFIELD, R.M. and BERG, R.T. (1966). A classification of bovine muscles, based on their relative growth patterns. Research Science 7: 326-332.
- BUTTERFIELD, R.M. (1976). Growth and development of beef cattle and its influence on carcass composition. Proceedings of the Carcass Classification Symposium B: 1-12.
- BUTTERFIELD, R.M., GRIFFITHS, D.A., THOMPSON, J.M., ZAMORA, J. and JAMES, A.M. (1983a). Changes in body composition relative to weight and maturity in large and small strains of Australian Merino rams. I. Muscle, bone and fat. Animal Production 36: 29-37.
- BUTTERFIELD, R.M., ZAMORA, J., JAMES, A.M., THOMPSON, J.M. and WILLIAMS, J. (1983b). Changes in body composition relative to weight and maturity in large and small strains of Australian Merino rams. II. Individual muscles and muscle groups. Animal Production 36: 165-174.
- BUTTERFIELD, R.M. and THOMPSON, J.M. (1983). Changes in body composition relative to weight and maturity of large and small strains of Australian Merino rams. IV. Fat depots and bones. Animal Production 37: 423-431.
- BUTTERFIELD, R.M., ZAMORA, J., THOMPSON, J.M., REDDACLIFF, K.J. and GRIFFITHS, D.A. (1984). Changes in body composition relative to weight and maturity of Australian Dorset Horn rams and wethers. I. Carcass muscle, fat and bone and body organs. Animal Production 39: 251-258.

- BUTTERFIELD, R.M., THOMPSON, J.M. and REDDACLIFF, K.J. (1985). Changes in body composition relative to weight and maturity of Australian Dorset Horn rams and wethers. III. Fat partitioning. Animal Production 40: 129-134.
- CAHANER, A. and NITSAN, Z. (1985). Evaluation of simultaneous selection for live body weight and against abdominal fat in broilers. Poultry Science 64: 1257-1263.
- CAHANER, A., KRINSKY, M. and NITSAN, Z. (1985). The response to one cycle of divergent selection for abdominal fat in broilers raised under different conditions. Poultry Science 64: 1813-1820.
- CAHANER, A., NITSAN, Z. and NIR, I. (1986). Weight and fat content of adipose and nonadipose tissues in broilers selected for or against abdominal adipose tissue. Poultry Science 65: 215-222.
- CALKINS, C.R., SAVELL, J.W., SMITH, G.C. and MURPHEY, G.E. (1980). Quality-indicating characteristics of beef as affected by electrical stimulation and postmortem chilling time. Journal of Food Science 45: 1330-1332.
- CALKINS, C.R., DUTSON, T.R., SMITH, G.C., CARPENTER, Z.L. and DAVIS, G.W. (1981). Relationship of fiber type composition to marbling and tenderness of bovine muscle. Journal of Food Science 46: 708-710.
- CAMERON, N.D. and DRURY, D.J. (1985). Comparison of terminal sire breeds for growth and carcass traits in crossbred lambs. Animal Production 40: 315-322.
- CAMPION, D.R., FIELD, R.A., RIELY, M.L. and SMITH, G.M. (1976). Effect of weight on carcass merit of very heavy market ram lambs. Journal of Animal Science 43: 1218-1224.
- CAMPION, D.R., PURCHAS, R.W., MERKEL, R.A. and ROMSOS, D.R. (1984). Genetic obesity and the muscle satellite cell (41854). Proceedings of the Society for Experimental Biology and Medicine 176: 143-147.
- CAPORASO, F., SINK, J.D., DIMICK, P.S., MUSSINAN, C.J. and SANDERSON, A. (1977). Volatile flavour constituents of ovine adipose tissue. Journal of Agriculture and Food Chemistry 25: 1230-1234.
- CARPENTER, Z.L., KAUFFMAN, R.G., BRAY, R.W., BRISKEY, E.J. and WECKEL, K.G. (1963). Factors influencing quality in pork. A. Histological observations. Journal of Food Science 28: 467-471.

- CARPENTER, Z.L., KING, G.T., ORTS, F.A. and CUNNINGHAM, N.L. (1964). Factors influencing retail carcass value of lambs. Journal of Animal Science 23: 741-745.
- CARPENTER, Z.L., KAUFFMAN, R.G., BRAY, R.W. and WECKEL, K.G. (1965). Interrelationships of muscle color and other pork quality traits. Food Technology 19: 115-118.
- CARPENTER, Z.L., KING, G.T., SHELTON, M. and BUTLER, O.D. (1969). Indices for estimating cutability of wether, ram and ewe lamb carcasses. Journal of Animal Science 28: 180-186.
- CASSENS, R.G. and NEWBOLD, R.P. (1966). Effects of temperature on post-mortem metabolism in beef muscle. Journal of the Science of Food and Agriculture 17: 254-256.
- CASSENS, R.G. and NEWBOLD, R.P. (1967). Temperature dependence of pH changes in ox muscle post-mortem. Journal of Food Science 32: 13-14.
- CASSENS, R.G. and COOPER, C.C. (1971). Red and white muscle. Advance in Food Research 19: 1-74.
- CASSENS, R.G. (1977). Muscle biochemistry: The importance of myofibre type. Food Technology 31: 76-81.
- CHADWICK, J.P. (1977). Selection for Economy of Production and Carcass Lean Content in Large White Pigs and its Influence on Meat Quality Characteristics. Ph.D. Thesis, University of Newcastle-upon-Tyne, England.
- CHADWICK, J.P., BICHARD, M., COATES, A. and ROPER, T.M. (1980). Offal and other carcass components in four lines of pigs. Animal Production 30: 463 (Abstract).
- CH'ANG, T.S. and EVANS, R. (1978/1979). Genetic variation in carcass fatness. CSIRO Sheep and Wool Report, pp. 74-75.
- CH'ANG, T.S., HOOD, R.L. and EVANS, R. (1986). Heterosis and breed effect on carcass traits of rams. II. Carcass adiposity traits. Australian Journal of Agricultural Research 37: 89-97.
- CHENG, C.S. and PARRISH, F.C. Jr. (1977). Effect of Ca on changes in myofibrillar proteins of bovine skeletal muscle. Journal of Food Science 42: 1621-1626.
- CHENG, C.S. and PARRISH, F.C. Jr. (1978a). Effects of postmortem storage conditions on myofibrillar ATPase activity of porcine red and white semitendinosus muscle. Journal of Food Science 43: 17-21.

- CHENG, C.S. and PARRISH, F.C. Jr. (1978b). Molecular changes in the salt-soluble myofibrillar proteins of bovine muscle. Journal of Food Science **43**: 461-463 and 487.
- CHENG, C.S. and PARRISH, F.C. Jr. (1979). Heat-induced changes in myofibrillar proteins of bovine longissimus muscle. Journal of Food Science **44**: 22-24.
- CHRYSTALL, B.B. and HAGYARD, C.J. (1976). Electrical stimulation and lamb tenderness. New Zealand Journal of Agricultural Research **19**: 7-11.
- CHRYSTALL, B.B. (1978). Electrical stimulation, refrigeration and subsequent meat quality. Proceedings of the 24th European Meat Research Workers: 7.3.
- CHRYSTALL, B.B. and DEVINE, C.E. (1978). Electrical stimulation, muscle tension and glycolysis in bovine sternomandibularis. Meat Science **2**: 49-58.
- CHRYSTALL, B.B. (1982). Low voltage electrical stimulation of lamb and beef. Twenty-second Meat Industry Research Conference, Hamilton, New Zealand, pp. 33-36.
- CHRYSTALL, B.B. and DEVINE, C.E. (1983) Electrical stimulation of deer carcasses. New Zealand Journal of Agricultural Research **26**: 89-92.
- CHURCH, D.C., RANDALL, R.P. and ORTEGA, E. (1979). Relationship between eating rate and gastro-intestinal tract fill within animal performance in sheep. Journal of Animal Science **49**: 362, Supplement 1.
- CIANZIO, D.S., TOPEL, D.G., WHITEHURST, G.B., BEITZ, D.C. and SELF, H.L. (1985). Adipose tissue growth and cellularity: changes in bovine adipocyte size and number. Journal of Animal Science **60**: 970-976.
- CLANCY, M.J. and HERLIHY, P.D. (1978). Assessment of changes in myofibre size in muscle. In: De Boer, H. and Martin, J. (eds.), Patterns of Growth and Development in Cattle. The Hague/Boston/London, pp. 203-218.
- CLARKE, J.N., JOHNSON, D.L., BENNETT, G.L., KIRTON, A.H. and RAE, A.L. (1984/1985). Genetic variation and relationships among carcass traits of lambs. Ruakura Animal Research Station Genetic Section Annual Report, pp. 32-33.
- CLAUS, J.R., KROPF, D.H., HUNT, M.C., KASTNER, C.L. and DIKEMAN, M.E. (1985). Effects of beef carcass electrical stimulation and hot boning on display color of unfrozen vacuum packaged steaks. Journal of Food Science **50**: 881-883.

- CLEMENTS, B.W., THOMPSON, J.M., HARRIS, D.C. and LANE, J.G. (1981). Prediction of carcass fat depth in live lambs: a comparison of techniques. Australian Journal of Experimental Agriculture and Animal Husbandry 21: 566-569.
- CLIPLEF, R.L. and STRAIN, J.H. (1976). Tenderness and related organoleptic characteristics of beef carcass as affected by post-mortem chilling temperature. Canadian Journal of Animal Science 56: 417-423.
- CLOSE, R.I. (1972). Dynamical properties of mammalian skeletal muscle. Physiological Reviews 52: 129-197.
- COLOMER-ROCHER, F., BASS, J.J. and JOHNSON, D.L. (1980). Beef carcass conformation and some relationships with carcass composition and muscle dimensions. Journal of Agricultural Science, Cambridge 94: 697-708.
- CONTRERAS, S. and HARRISON, D.L. (1981). Electrical stimulation and hot boning: color stability of ground beef in a model system. Journal of Food Science 46: 464-467.
- COOK, G.L., JONES, D.W. and KEMPSTER, A.J. (1983). A note on a simple criterion for choosing among sample joints for use in double sampling. Animal Production 36: 493-495.
- COOP, I.E., CLARK, V.R. and JAY, N.P. (1979). Fat content of heavy-weight lamb carcasses of several breeds and crosses. New Zealand Journal of Experimental Agriculture 7: 103-106.
- COOPER, C.C., BREIDENSTEIN, B.B., CASSENS, R.C., EVAN, G. and BRAY, R.W. (1968). Influence of marbling and maturity on the palatability of beef muscle. II. Histological considerations. Journal of Animal Science 27: 1542-1546.
- CORNFORTH, D.P., SCHWARTZ, W.C. and CRAMER, D.A. (1973). Growth and differentiation of muscle fibres in cattle. Journal of Animal Science 36: 1196-1197 (Abstract).
- CORNFORTH, D.P., PEARSON, A.M. and MERKEL, R.A. (1980). Relationship of mitochondria and sarcoplasmic reticulum to cold shortening. Meat Science 4: 103-121.
- COSTELLO, C.A., PENFIELD, M.P. and RIEMANN, M.J. (1985). Quality of restructured steaks: Effects of days on feed, fat level and cooking method. Journal of Food Science 50: 685-688.
- COTTERILL, P.P. and ROBERTS, E.M. (1976). Preliminary heritability estimate of some lamb carcass traits. Proceedings of the Australian Society of Animal Production 11: 53-56.

- COVER, S., BUTLER, O.D. and CARTWRIGHT, T.C. (1956). The relationship of fatness in yearling steers to juiciness and tenderness of broiled and braised steaks. Journal of Animal Science 15: 464-472.
- COVER, S. and HOSTETLER, R.L. (1960). An examination of some theories about beef tenderness by using new methods. Texas Agriculture Experiment Station Bulletin 542. (Cited by Smith and Carpenter, 1970.)
- COVER, S., RITCHEY, S.J. and HOSTETLER, R.L. (1962a). Tenderness of beef. I. The connective-tissue component of tenderness. Journal of Food Science 27: 469-475.
- COVER, S., RITCHEY, S.J. and HOSTETLER, R.L. (1962b). Tenderness of beef. II. Juiciness and softness components of tenderness. Journal of Food Science 27: 476-482.
- COVER, S., RITCHEY, S.J. and HOSTETLER, R.L. (1962c). Tenderness of beef. III. The muscle fibre components of tenderness. Journal of Food Science 27: 483-488.
- COVER, S., HOSTETLER, R.L. and RITCHEY, S.J. (1962d). Tenderness of Beef. IV. Relations of shear force and fiber extensibility to juiciness and six components of tenderness. Journal of Food Science 27: 527-536.
- COVINGTON, R.C., TUMA, H.J., GRANT, D.L. and DAYTON, A.D. (1970). Various chemical and histological characteristics of beef muscle as related to tenderness. Journal of Animal Science 30: 191-197.
- CRESSWELL, E., ASH, R.W., BOYNE, A.W. and GILL, J.C. (1964a). Some effects of "partial" castration compared with full castration on lamb growth and on the development of male characteristics. The Veterinary Record 76: 646-650.
- CRESSWELL, E., ASH, R.W., BOYNE, A.W. and GILL, J.C. (1964b). The growth and carcass characteristics of entire cross-bred lambs compared with lambs "partially" or "fully" castrated. The Veterinary Record 76: 1472-1474.
- CROSS, H.R., SMITH, G.C. and CARPENTER, Z.L. (1972). Palatability of individual muscle from ovine leg steaks as related to chemical and histological traits. Journal of Food Science 37: 282-285.
- CROSS, H.R., CARPENTER, Z.L. and SMITH, G.C. (1973). Effects of intramuscular collagen and elastin on bovine muscle tenderness. Journal of Food Science 38: 998-1003.
- CROSS, H.R. and STANFIELD, M.S. (1976). Consumer evaluation of restructured beef steaks. Journal of Food Science 41: 1257-1258.

- CROSS, H.R., WEST, R.L. and DUTSON, T.R. (1980/1981). Comparisons of methods for measuring sarcomere length in beef semitendinosus muscle. Meat Science 5: 261-266.
- CROSS, H.R., CROUSE, J.D. and MacNEIL, M.D. (1984). Influence of breed, sex, age and electrical stimulation on carcass and palatability traits of three bovine muscles. Journal of Animal Science 58: 1358-1365.
- CROSTON, D., JONES, D.W. and KEMPSTER, A.J. (1979). A comparison of the performance and carcass characteristics of lambs by nine sire breeds. Animal Production 28: 456-457 (Abstract).
- CROUSE, J.D., FIELD, R.A., CHANT, Jr. C.L., FERRELL, C.L., SMITH, G.M. and HARRISON, V.L. (1978). Effect of dietary energy intake on carcass composition and palatability of different weight carcasses from ewe and ram lambs. Journal of Animal Science 47: 1207-1218.
- CROUSE, J.D., BUSBOOM, J.R., FIELD, R.A. and FERRELL, C.L. (1981). The effects of breed, diet, sex, location and slaughter weight on lamb growth, carcass composition and meat flavour. Journal of Animal Science 53: 376-386.
- CROUSE, J.D., FERRELL, C.L., FIELD, R.A., BUSBOOM, J.R. and MILLER, G.J. (1982). The relationship of fatty acid composition and carcass characteristics to meat flavour in lamb. Journal of Food Quality 5: 203-214.
- CROUSE, J.D., SEIDEMAN, S.C. and CROSS, H.R. (1983). The effects of carcass electrical stimulation and cooler temperature on the quality and palatability of bull and steer beef. Journal of Animal Science 56: 81-90.
- CULLEN, G.D. (1985). The Cellularity of Adipose Tissue in Newborn Lambs. B.Phil. Thesis, Massey University, Palmerston North, New Zealand.
- CULLER, R.D., PARRISH, F.C.J., SMITH, G.C. and CROSS, H.R. (1978). Relationship of myofibril fragmentation index to certain chemical, physical and sensory characteristics of bovine longissimus muscle. Journal of Food Science 43: 1177-1180.
- CULP, G.R., CARPENTER, Z.L., SMITH, G.C. and DAVIS, G.W. (1973). Post-rigor ageing effects on beef tenderness. Journal of Animal Science 37: 258 (Abstract).
- CUNDIFF, L.V., CHAMBERS, D., STEPHENS, D.F. and WILLHAM, R.L. (1964). Genetic analysis of some growth and carcass traits in beef cattle. Journal of Animal Science 23: 1133-1138.
- CURRIE, R.W. and WOLF, F.H. (1980). Rigor related changes in mechanical properties (tensile and adhesive) and extra-cellular space in beef muscle. Meat Science 4: 123-143.

- DAVEY, C.L. and GILBERT, K.V. (1969). Studies in meat tenderness. VII. Changes in the fine structure of meat during ageing. Journal of Food Science 34: 69-74.
- DAVEY, C.L. and DICKSON, M.R. (1970). Studies in meat tenderness. VIII. Ultra-structural changes in meat during ageing. Journal of Food Science 35: 56-60.
- DAVEY, C.L. and CURSON, P. (1971). Interim studies in lamb tenderness. I. Evaluation of high temperature conditioning and ageing of lamb. II. The effect of carcass posture on tenderness of lamb muscles. Meat Industry Research Institute of New Zealand Publication No. 215.
- DAVEY, C.L. and GILBERT, K.V. (1973). The effect of carcass posture on cold, heat and thaw shortening in lamb. Journal of Food Technology 8: 445-451.
- DAVEY, C.L. and GILBERT, K.V. (1974). Temperature-dependent cooking toughness in beef. Journal of the Science of Food and Agriculture 25: 931-938.
- DAVEY, C.L. and GILBERT, K.V. (1975). Cold shortening and cooking change in beef. Journal of the Science of Food and Agriculture 26: 761-767.
- DAVEY, C.L. and GILBERT, K.V. (1976). The temperature coefficient of beef ageing. Journal of the Science of Food and Agriculture 27: 244-250.
- DAVEY, C.L., GILBERT, K.V. and CARSE, W.A. (1976). Carcass electrical stimulation to prevent cold shortening toughness in beef. New Zealand Journal of Agricultural Research 19: 13-18.
- DAVEY, C.L. and GARNETT, K.J. (1980). Rapid freezing, frozen storage and the tenderness of lamb. Meat Science 4: 319-322.
- DAVEY, C.L. (1983). Post-mortem chemical changes in muscle meat ageing. Proceedings of the 36th Annual Reciprocal Meat Conference, pp. 108-115.
- DAVEY, R.J. and BERESKIN, B. (1978). Genetic and nutritional effects on carcass chemical composition and organ weights of market swine. Journal of Animal Science 46: 992-1000.
- DAVID, P.J., JOHNSON, R.K. and SOCHA, T.E. (1983). Genetic and phenotypic parameters estimated from Nebraska specific-pathogen-free swine field records. Journal of Animal Science 57: 1117-1123.
- DAVID, P.J. (1984). Analysis of Nebraska swine field records: selection practices and genetic trends. Animal Breeding Abstract 52: 340.

- DAVIES, A.S. and GUNN, H.M. (1972). Histochemical fibre types in the mammalian diaphragm. Journal of Anatomy 112: 41-60.
- DAVIES, A.S. (1975). A comparison of tissue development in Pietrain and Large White pigs from birth to 64 Kg liveweight. III. Growth changes in bone distribution. Animal Production 20: 45-49.
- DAVIES, P.J.A., WALLACH, D., WILLINGHAM, M.C., PASTAN, I., YAMAGUCHI, M. and ROBSON, R.M. (1978). Filamin-actin interaction. Dissociation of binding from gelatin by Ca activated proteolysis. Journal of Biological Chemistry 253: 4036-4042.
- DAVIS, C.E., BIRTH, G.S. and TOWNSEND, W.E. (1978). Analysis of spectral reflectance for measuring pork quality. Journal of Animal Science 46: 634-638.
- DAVIS, G.W., SMITH, G.C., CARPENTER, Z.L., DUTSON, T.R. and CROSS, H.R. (1979). Tenderness variation among beef steaks from carcasses of the same USDA quality grade. Journal of Animal Science 49: 103-114.
- DEVINE, C.E., CHRYSTALL, B.B. and DAVEY, C.L. (1979). Studies in electrical stimulation: effect of neuromuscular blocking agents in lamb. Journal of the Science of Food and Agriculture 30: 1007-1011.
- DeVOL, D.L., McKEITH, F.K., BECHTEL, P.J. and VANDERWERT, W. (1984). Chemical, physical and sensory properties of thirteen major muscles from Angus steers. Journal of Animal Science 59: 238 (Abstract).
- DIKEMAN, M.E., KEMP, K.E. and CROUSE, J.D. (1979). Composition and meat sensory evaluation characteristics of carcasses in the five USDA yield grades, five fatness categories and five marbling categories. Journal of Animal Science 49: 217 (Abstract). Supplement 1.
- DIKEMAN, M.E., DAYTON, A.D., HUNT, M.C., KASTNER, C.L., AXE, J.B. and IIG, H.J. (1985). Conventional versus accelerated beef production with carcass electrical stimulation. Journal of Animal Science 61: 573-583.
- DINKEL, C.A. and BUSCH, D.A. (1973). Genetic parameters among production, carcass composition and carcass quality traits of beef cattle. Journal of Animal Science 36: 832-846.
- DOLEZAL, H.G., SMITH, G.C., SAVELL, J.W. and CARPENTER, Z.L. (1982). Comparison of subcutaneous fat thickness, marbling and quality grade for predicting palatability of beef. Journal of Food Science 47: 397-401.

- DRANSFIELD, E. and RHODS, D.N. (1975). Texture of beef M. semitendinosus heated before, during and after development of rigor mortis. Journal of the Science of Food and Agriculture 26: 483-491.
- DRANSFIELD, E. (1977). Intramuscular composition and texture of beef muscles. Journal of the Science of Food and Agriculture 28: 833-842.
- DRANSFIELD, E. (1981). Eating quality of DFD beef. In: Hood, D.E. and Tarrant, P.V. (eds.), The Problem of Dark Cutting in Beef. Current Topics in Veterinary Medicine and Animal Science Vol. 10. The Hague/Boston/London: Martinus, Nijhoff Publishers, pp. 344-358.
- DRANSFIELD, E. and LOCKYER, D.K. (1985). Cold-shortening toughness in excised pork M. longissimus dorsi. Meat Science 13: 19-32.
- DREW, K.R. (1973). Changes in whole body and carcass composition in young sheep during weight loss and subsequent regrowth. Proceedings of the New Zealand Society of Animal Production 33: 184-190.
- DREYER, J.H., NAUDE, R.T., HENNING, J.W.N. and ROSSOUW, E. (1977). The influence of breed, castration and age on muscle fibre type and diameter in Friesland and Afrikaner cattle. South African Journal of Animal Science 7: 171-180.
- DUCKWORTH, J.E. and HOLMES, W. (1968). Selection for carcass length in large white pigs. Animal Production 10: 359-371.
- DUNCAN, W.R.H., LOUGH, A.K., GARTON, G.A. and BROOKS, P. (1974). Characterization of branched chain fatty acids from subcutaneous triacylglycerols of barley-fed lambs. Lipids 9: 669-673.
- DUNIEC, H., KIELANOWSKI, T. and OSINSKA, Z. (1961). Heritability of chemical fat content in the loin muscle of baconers. Animal Production 3: 195-198.
- DUNN, R.J., MAGEE, W.T., GREGORY, K.E., CUNDIFF, L.V. and KOCH, R.M. (1970). Genetic parameters in straightbred and crossbred beef cattle. Journal of Animal Science 31: 656-663.
- DUTSON, T.R. and LAWRIE, R.A. (1974). Release of lysosomal enzymes during postmortem conditioning and their relationship to tenderness. Journal of Food Technology 9: 43-50.
- DUTSON, T.R., SMITH, G.C., HOSTETLER, R.L. and CARPENTER, Z.L. (1975). Postmortem carcass temperature and beef tenderness. Journal of Animal Science 41: 289 (Abstract).

- DUTSON, T.R., YATES, L.D., SMITH, G.C., CARPENTER, Z.L. and HOSTETLER, R.C. (1977). Rigor onset before chilling. Proceedings of the 30th Annual Reciprocal Meat Conference, pp. 79-86.
- DUTSON, T.R., SMITH, G.C. and CARPENTER, Z.L. (1980). Lysosomal enzyme distribution in electrically stimulated ovine muscle. Journal of Food Science 45: 1097-1098.
- DUTSON, T.R., SAVELL, J.W. and SMITH, G.C. (1981). Electrical stimulation of ante mortem stressed beef. In: Hood, D.E. and Tarrant, P.V. (eds.), The Problem of Dark Cutting in Beef. Current Topics in Veterinary Medicine and Animal Science, Volume 10. The Hague/Boston/London: Martinus Nijhoff, Publishers, pp. 253-258.
- DUTSON, T.R., SAVELL, J.W. and SMITH, G.C. (1982). Electrical stimulation of ante-mortem stressed beef. Meat Science 6: 159-162.
- DUTSON, T.R. (1983). The measurement of pH in muscle and its importance to meat quality. Proceedings of the 36th Annual Reciprocal Meat Conference, pp. 92-97.
- DUTSON, T.R. and PEARSON, A.M. (1985). Postmortem conditioning of meat. In: Pearson, A.M. and Dutson, T.R. (eds.), Advances in Meat Research Vol. 1. Electrical Stimulation. Westport, Connecticut, U.S.A.: Avi Publishing Company Inc., pp. 45-73.
- EDWARDS, R.L., SMITH, G.C., CROSS, H.R. and CARPENTER, Z.L. (1980). Muscle to bone ratios in pork carcasses. Journal of Animal Science 51: 1321-1329.
- EIKELENBOOM, G. and SMULDERS, F.J.M. (1986). Effect of electrical stimulation on veal quality. Meat Science 16: 103-112.
- ELGASIM, E.A., KENNICK, W.H., MCGILL, L.A., ROCK, D.F. and SOELDNER, A. (1981). Effects of electrical stimulation and delayed chilling of beef carcasses on carcass and meat characteristics. Journal of Food Science 46: 340-343 and 349.
- ELLIOTT, G.F. (1968). Force-balance and stability in hexagonally-packed polyelectrolyte systems. Journal of Theoretical Biology 21: 71-87.
- ELLIOTT, R.J. (1967). Effect of optical systems and sample preparation on the visible reflection spectra of pork muscle. Journal of the Science of Food and Agriculture 18: 332-338.
- ELLIS, M., SMITH, W.C., HENDERSON, R., WHITEMORE, C.T. and LAIRD, R. (1983). Comparative performance and body composition of control and selection line large white pigs. II. Feeding to appetite for a fixed time. Animal Production 36: 407-413.

- ELSLEY, F.W.H., McDONALD, I. and FOWLER, V.R. (1964). The effect of plane of nutrition on the carcasses of pigs and lambs when variations in fat content are excluded. Animal Production 6: 141-154.
- ENFIELD, F.D. and WHATLEY Jr., J.A. (1961). Heritability of carcass length, carcass backfat thickness and loin, lean area in swine. Journal of Animal Science 20: 631-634.
- ENSER, M.B., WOOD, J.D., RESTALL, D.J. and MacFIE, H.J.H. (1976). The cellularity of adipose tissue from pigs of different weights. Journal of Agricultural Science, Cambridge 86: 633-638.
- ESSEN-GUSTAVSSON, B. and FJELKNER-MODIG, S. (1985). Skeletal muscle characteristics in different breeds of pigs in relation to sensory properties of meat. Meat Science 13: 33-47.
- ETHERINGTON, D.J. (1984). The contribution of proteolytic enzymes to postmortem changes in muscle. Journal of Animal Science 59: 1644-1650.
- ETHERTON, T.D. (1980). Subcutaneous adipose tissue cellularity of swine with different propensities for adipose tissue growth. Growth 44: 182-191.
- EZEKWE, M.O. and MARTIN, R.J. (1975). Cellular characteristics of skeletal muscle in selected strains of pigs and mice and the unselected controls. Growth 39: 95-106.
- FABIANSSON, S. and BUCHTER, L. (1984). The influence of low voltage electrical stimulation on some physical and sensoric properties of beef. Acta, Agriculturae Scandinavica 34: 368-376.
- FABIANSSON, S., JARENBACK, L. and RUDERUS, H. (1984). The influence of linear chilling rates on physical and chemical parameters of beef. Acta, Agriculturae Scandinavica 34: 357-367.
- FAHMY, M.H. and BERNARD, C.S. (1970). Genetic and phenotypic study of pre- and post-weaning weights and gain in swine. Canadian Journal of Animal Science 50: 593-599.
- FAHMY, M.H., BERNARD, C.S., LEMAY, J.P. and NADEAU, M. (1972). Influence of breed of sire on the production of light and heavy market lambs. Canadian Journal of Animal Science 52: 259-266.
- FAUST, I.M., JOHNSON, P.R., STERN, J.S. and HIRSCH, J. (1978). Diet-induced adipocyte number increase in adult rats: a new model of obesity. American Journal of Physiology 235: E279-286.

- FENNESSY, P.F., GREER, G.J. and BASS, J.J. (1982). Progeny test of selected lean and fat rams. Proceedings of the New Zealand Society of Animal Production **42**: 137-140.
- FENNESSY, P.F. (1985). Growth, size and composition. Proceedings of the 11th Workshop on Overfatness and Lean Meat Production from Sheep, Massey University, Palmerston North, New Zealand, p. 27.
- FENNESSY, P.F., GREER, G.J. and BAIN, W.E. (1987). Selection to change carcass fatness in sheep. Proceedings of the 4th AAAP Animal Science Congress, Hamilton, New Zealand, p. 382.
- FERRELL, C.L., CROUSE, J.D., FIELD, R.A. and CHANT, J.L. (1979). Effects of sex, diet and stage of growth upon energy utilization by lambs. Journal of Animal Science **49**: 790-801.
- FERRELL, C.L., NIENABER, J.A. and KOONG, L.J. (1983). Effects of previous nutrition on maintenance requirements and efficiency of feed utilization of growing lambs. Journal of Animal Science **57**: 431-432 (Supplement 1).
- FIELD, R.A., KEMP, J.D. and VARNEY, W.Y. (1963). Indices of lamb carcass composition. Journal of Animal Science **22**: 218-221.
- FIELD, R.A., PEARSON, A.M., MAGEE, W.T. and MERKEL, R.A. (1970). Chemical and histological characteristics of the longissimus in young bulls selected for tenderness or leanness. Journal of Animal Science **30**: 717-721.
- FIELD, R.A., WILLIAMS, J.C., FERRELL, C.L., CROUSE, J.D. and KUNSMAN, J.E. (1978). Dietary alteration of palatability and fatty acids in meat from light and heavy weight ram lambs. Journal of Animal Science **47**: 858-864.
- FILLIBEN, J.J. (1975). The probability plot correlation coefficient test for normality. Technometrics **17**: 111-116.
- FJELKNER-MODIG, S. and RUDERUS, H. (1983). The influence of exhaustion and electrical stimulation on the meat quality of young bulls. II. Physical and sensory properties. Meat Science **8**: 203-220.
- FOLLETT, M.J., NORMAN, G.A. and RATCLIFT, P.W. (1974). The ante-rigor excision and air cooking of beef semimembranosus muscles at temperatures between -5°C and $+15^{\circ}\text{C}$. Journal of Food Technology **9**: 509-523.
- FORD, A.L. and PARK, R.J. (1980). Odours and flavours in meat. In: Lawrie, R. (ed.), Developments in Meat Science, Vol. 1, Chapter 9. London, England: Applied Science Publishers.

- FORTIN, A. and ELLIOT, J.I. (1985). Relationships between backfat thickness and chemical composition of the body components of swine. Journal of Animal Science 61: 158-164.
- FOURIE, P.D. (1962). Growth and development of sheep. I. A carcass dissection technique. New Zealand Journal of Agricultural Research 5: 190-222.
- FOURIE, P.D. (1965). Growth and Development of Sheep, with Special Reference to New Zealand Breeds. Ph.D. Thesis, University of Pretoria, South Africa. Thesis copy lodged at Ruakura Agricultural Research Centre Library, Hamilton, New Zealand.
- FOURIE, P.D., KIRTON, A.H. and JURY, K.E. (1970). Growth and development of sheep. II. Effect of breed and sex on the growth and carcass composition of the Southdown and Romney and their cross. New Zealand Journal of Agricultural Research 13: 753-770.
- FOWLER, V.R. (1968). Body development and some problems of its evaluation. In: Lodge, G.A. and Lamming, G.E. (eds.), Growth and Development of Mammals. London, England: Butterworths, pp. 195-211.
- FRANCIS, F.J. and CLYDESDALE, F.M. (1975). Food Colorimetry: Theory and Application. Westport, Connecticut, U.S.A.: The Avi Publishing Company.
- FRANKE, W.C. and SOLBERG, M. (1971). Quantitative determination of metmyoglobin and total pigment in an intact meat sample using reflectance spectrophotometry. Journal of Food Science 36: 515-519.
- FRAZER, A.E. (1976). Tighter grading for lamb fatness in coming season. New Zealand Meat Producer 4(10): 1.
- FRAZER, A.E. (1982). Trends in meat market requirements: implications for producers. Proceedings of the New Zealand Society of Animal Production 42: 99-103.
- FREDEEN, H.T., MARTIN, A.H. and WEISS, G.M. (1974). Changes in tenderness of beef longissimus dorsi as related to muscle colour and pH. Journal of Food Science 39: 532-536.
- FREDEEN, H.T. and MIKAMI, H. (1986). Mass selection in a pig population: correlated changes in carcass merit. Journal of Animal Science 62: 1546-1554.
- FURNIVAL, E.P., CORBETT, J.L. and SHORTHOSE, W.R. (1977). Meat properties of lambs grown to 32 Kg at various rates on phalaris or lucerne pastures and an apparent effect of pre-slaughter ambient temperature. Journal of Agricultural Science, Cambridge 88: 207-216.

- GADDIS, A.M., HANKINS, O.G. and HINER, R.L. (1950). Relationships between the amount and composition of press fluid, palatability and other factors of meat. Food Technology 4: 498-503.
- GAILI, E.S.E. (1978). A note on the effect of breed-type and sex on the distribution of intramuscular fat in carcasses of sheep. Animal Production 26: 217-219.
- GANN, G.L. and MERKEL, R.A. (1978). Ultrastructural changes in bovine longissimus muscle during postmortem aging. Meat Science 2: 129-144.
- GARBUTT, G.J., ANTHONY, W.B., WALTER, D.F. and McGUIRE, J.A. (1979). Perirectal adipose tissue development of post weaned rapidly growing bull calves. Journal of Animal Science 48: 525-530.
- GARDENER, R.W., HOGUE, D.E. and BENSADOUN, A. (1964). Body composition and efficiency of growth of suckling lambs as affected by level of feed intake. Journal of Animal Science 23: 943-952.
- GAULT, N.F.S. (1985). The relationship between water-holding capacity and cooked meat tenderness in some beef muscles as influenced by acidic conditions below the ultimate pH. Meat Science 15: 15-30.
- GAUTHIER, G.F. (1970). The ultrastructure of three fibre types in mammalian skeletal muscle. In: Briskey, E.J., Cassens, R.G. and Marsh, B.B. (eds.), The Physiology and Biochemistry of Muscle as Food, 2nd ed. Wisconsin, U.S.A.: The University of Wisconsin Press, pp. 103-130.
- GEENTY, K.G., CLARKE, J.N. and JURY, K.E. (1979). Carcass growth and development of Romney, Corriedale, Dorset and crossbred sheep. New Zealand Journal of Agricultural Research 22: 23-32.
- GEORGE, J.C. and NAIK, R.M. (1958). Relative distribution and chemical nature of the fuel store of the two types of fibres in pectoralis major muscle of the pigeon. Nature 181: 709-711.
- GEORGE, A.R., BENDALL, J.R. and JONES, R.C.D. (1980). The tenderising effect of electrical stimulation of beef carcasses. Meat Science 4: 51-68.
- GILMOUR, A.R. (1985). REG - Generalized Models Programme. Misc. Bulletin 1 (2nd ed.), Division of Agricultural Services, New South Wales Department of Agriculture, Sydney, N.S.W., Australia.

- GOGUE, J. and GUEBLEZ, R. (1983). Phenotypic and genetic study of the Belgian Landrace and Pietrain breeds for characters measured at official progeny testing stations. Animal Breeding Abstract 51: 824.
- GOKALP, H.Y., OCKERMAN, H.W., PLIMPTON, R.F. and HARPER, W.J. (1983). Fatty acids of neutral and phospholipids, rancidity scores and TBA values as influenced by packaging and storage. Journal of Food Science 48: 829-834.
- GOLDMAN, Y.E., MATSUBARA, I. and SIMMONS, R.M. (1979). Lateral filamentary spacing in frog skinned muscle fibres in the relaxed and rigor states. Journal of Physiology 295: 80p.
- GOLDRICK, R.B. (1967). Morphological changes in the adipocyte during fat deposition and mobilization. American Journal of Physiology 212: 777-782.
- GOLDSPINK, G. (1964). The combined effects of exercise and reduced food intake on skeletal muscle fibres. Journal of Cellular and Comparative Physiology 63: 209-216.
- GOLL, D.E., BRAY, R.W. and HOEKSTRA, W.G. (1964). Age associated changes in bovine muscle connective tissue. III. Rate of solubilization at 100°C. Journal of Food Science 29: 622-628.
- GOLL, D.E., CARLIN, A.F., ANDERSON, L.P., KLINE, E.A. and WALTER, M.J. (1965). Effect of marbling and maturity on beef muscle characteristics. II. Physical, chemical and sensory evaluation of steaks. Food Technology 19: 845-849.
- GOLL, D.E., STROMER, M.H., OLSON, D.G., DAYTON, W.R., SUZUKI, A. and ROBSON, R.M. (1974). The role of myofibrillar proteins in meat tenderness. Meat Industry Research Conference, American Meat Institute Foundation. Arlington, Virginia, U.S.A., pp. 75-98.
- GOLL, D.E., OTSUKA, Y., NAGAINIS, P.A., SHANNON, J.D., SATHE, S.K. and MUGURUMA, M. (1983). Role of muscle proteinases in maintenance of muscle integrity and mass. Journal of Food Biochemistry 7: 137-177.
- GOLLNICK, P.D., ARMSTRONGE, R.B., SAUBERT, C.W., PIEHL, K. and SALTIN, B. (1972). Enzyme activity and fibre composition in skeletal muscle of untrained and trained men. Journal of Applied Physiology 33: 312-319.

- GOOD, D.L., DAHL, G.M., WEARDEN, S. and WESELI, D.J. (1961). Relationships among live and carcass characteristics of selected slaughter steers. Journal of Animal Science 20: 698-701.
- GOODEN, J.M., BEACH, A.D. and PURCHAS, R.W. (1980). Measurement of subcutaneous backfat depth in live lambs with an ultrasonic probe. New Zealand Journal of Agricultural Research 23: 161-165.
- GOVINDARAJA, S. (1973). Fresh meat color. Critical Reviews in Food Technology 4: 117-140.
- GRAY, J.I. and PEARSON, A.M. (1984). Cured meat flavor. Advance in Food Research 29: 1-86.
- GREATHOUSE, J.R., HUNT, M.C., DIKEMAN, M.E., CORAH, L.R., KASTNER, C.L. and KROPF, D.H. (1983). Ralgro-implanted bulls: performance, carcass characteristics, longissimus palatability and carcass electrical stimulation. Journal of Animal Science 57: 355-363.
- GREENWOOD, M.R.C. and HIRSCH, J. (1974). Postnatal development of adipocyte cellularity in the normal rat. Journal of Lipid Research 15: 474-483.
- GRIFFIN, C.L., STIFFLER, D.M., RAY, E.E. and BERRY, B.W. (1981). Effects of electrical stimulation, boning time and cooking method on beef roasts. Journal of Food Science 46: 987-990.
- GUENTHER, J.J., NOVOTNY, K.K. and HINTZ, R.L. (1981). The growth of three fiber types in beef longissimus muscle as influenced by breed and age. Animal Science Research Report, Oklahoma Agricultural Experiment Station, Oklahoma, U.S.A., pp. 51-53.
- GULLETT, E.A., ROWE, D.L. and HINES, R.J. (1984). Sensorial assessment of the eating quality of meat. Canadian Institute of Food Science and Technology Journal 17: 229-236.
- HAGYARD, C.J., HAND, R.J. and GILBERT, K.V. (1980). Lamb tenderness and electrical stimulation of dressed carcasses. New Zealand Journal of Agricultural Research 23: 27-31.
- HALL, J.B. and HUNT, M.C. (1982). Collagen solubility of A-maturity bovine longissimus muscle as affected by nutritional regimen. Journal of Animal Science 55: 321-328.
- HALLUND, O. and BENDALL, J.R. (1965). The long-term effect of electrical stimulation on the post-mortem fall of pH in the muscles of Landrace pigs. Journal of Food Science 30: 296-299.
- HAMM, R. (1960). Biochemistry of meat hydration. Advance in Food Research 10: 355-463.

- HAMM, R. and DEATHERAGE, F.E. (1960). Changes in hydration, solubility and changes of muscle proteins during heating of meat. Food Research 25: 587-610.
- HAMM, R. (1975). Water-holding capacity of meat. In: Cole, D.J.A. and Lawrie, R.A. (eds.), Meat. London, England: Butterworths, pp. 321-338.
- HAMM, R. (1981). Post-mortem changes in muscle affecting the quality of comminuted meat products. In: Lawrie, R.P. (ed.), Developments in Meat Science Vol. 2. London, England: Applied Science Publishers, pp. 93-124.
- HAMMOND, J. (1932). Growth and Development of Mutton Qualities in the Sheep. London, England: Oliver and Boyd.
- HANNING, F., BRAY, R.W., ALLEN, N.N. and NIEDERMEIER, R.P. (1957). Tenderness and juiciness of veal loin roasts and chops. A comparison of methods of measuring those qualities. Food Technology 11: 611-614.
- HANKINS, O.G. (1947). Estimation of the composition of lamb carcasses and cuts. U.S.D.A. Technical Bulletin No. 994.
- HANRAHAN, J.P., HOOPER, A.C. and McCARTHY, J.C. (1973). Effects of divergent selection for body weight on fibre number and diameter in two mouse muscles. Animal Production 16: 7-16.
- HANRAHAN, J.P., ALLEN, P. and L'ESTRANGE, J.L. (1978). Effect of Finnish Landrace and Galway breeds on carcass composition, fat distribution and fatty acid composition of different fat depots in lambs. In: De Boer, H. and Martin, J. (eds.), Patterns of Growth and Development in Cattle. Current Topics in Veterinary Medicine and Animal Science. The Hague, Netherlands: Martinus Nijhoff, pp. 277-286.
- HARDY, F. and NOBLE, I. (1945). A comparison of measurement of juiciness in roast pork loin by press-fluid and jury-rating methods. Food Research 10: 160-164.
- HARRIES, J.M., RHODES, D.N. and CHRYSTALL, B.B. (1972). Meat texture. I. Subjective assessment of the texture of cooked beef. Journal of Texture Studies 3: 101-114.
- HARRINGTON, G. (1963). The separation of technical errors and biological variation and other statistical problems arising in body composition studies. Annual of the New York Academy of Sciences 110: 642-653.
- HARRIS, P.V. (1976). Structural and other aspects of meat tenderness. Journal of Texture Studies 7: 49-63.

- HARRISON, D.L., BOWERS, J.A., ANDERSON, L.L., TUMA, H.J. and KROPF, D.H. (1970). Effect of aging on palatability and selected related characteristics of pork loin. Journal of Food Science 35: 292-294.
- HARRISON, A.R., KROPF, D.H., ALLEN, D.M., HUNT, M.C. and KASTNER, C.L. (1980). Relationships of spectrophotometric reflectance measurements to beef muscle visual color. Journal of Food Science 45: 1052-1053.
- HARTSHORNE, D.J., BARNS, E.M., PARKER, L. and FUCHS, F. (1972). The effect of temperature of actomyosin. Biochimica Biophysica Acta 267: 190-202.
- HAUGEBAK, C.D., HEDRICK, H.B. and ASPLUND, J.M. (1974). Adipose tissue accumulation and cellularity in growing and fattening lambs. Journal of Animal Science 39: 1016-1025.
- HAUSMAN, G.J. and MARTIN, R.J. (1981). Subcutaneous adipose tissue development in Yorkshire (lean) and Ossabaw (obese) pigs. Journal of Animal Science 52: 1442-1449.
- HAUSMAN, G.J., CAMPION, D.R. and THOMAS, G.B. (1983). Semitendinosus muscle development in several strains of fetal and perinatal pigs. Journal of Animal Science 57: 1608-1617.
- HAUSMAN, G.J., CAMPION, D.R. and THOMAS, G.B. (1985). Enzyme histochemical studies in an ontogeny study of muscle development in Ossabaw and decapitated fetuses: cellular reactions. Journal of Animal Science 60: 1562-1570.
- HAWKINS, R.R., KEMP, J.D., ELY, D.G., FOX, J.D., MOODY, W.G. and VIMINI, R.J. (1985a). Carcass and meat characteristics of crossbred lambs born to ewes of different genetic types and slaughtered at different weights. Livestock Production Science 12: 241-250.
- HAWKINS, R.R., MOODY, W.G. and KEMP, J.D. (1985b). Influence of genetic type, slaughter weight and sex on ovine muscle fibre and fat cell development. Journal of Animal Science 61: 1154-1163.
- HAWKINS, R.R. (1986). Factors Associated with the Variation in Beef Tenderness. Texas Tech University, Texas, U.S.A.: Dissertation Abstracts International, B (Science and Engineering). 1986. 47: 448-449B.
- HAWRYSH, Z.J., BERG, R.T. and HOWES, A.D. (1975). Eating quality of mature, marbled beef. Canadian Institute of Food Science and Technology Journal 8: 30-34.
- HAY, J.D., CURRIE, R.W. and WOLFE, F.H. (1972). The effect of aging on physiochemical properties of actomyosin from chicken breast and leg muscle. Journal of Food Science 37: 346-350.

- HAY, J.D., CURRIE, R.W. and WOLFE, F.D. (1973). Effect of postmortem aging on chicken muscle fibres. Journal of Food Science 38: 981-986.
- HAYWARD, L.H., HUNT, M.C., KASTNER, C.L. and KROPF, D.H. (1980). Blade tenderization effects on beef longissimus sensory and instron textural measurements. Journal of Food Science 45: 925-930 and 935.
- HEDRICK, H.B., THOMPSON, G.B. and KRAUSE, G.F. (1969). Comparison of feedlot performance and carcass characteristics of half-sib bulls, steers, and heifers. Journal of Animal Science 29: 687-694.
- HEGARTY, P.V.J. (1971). Muscle fibre growth and development. Proceedings of the 24th Annual Reciprocal Meat Conference, pp. 319-344.
- HEIDARI, M.B. and VOGT, D.W. (1983). Genetic and phenotypic correlations involving carcass traits in beef cattle. Journal of Animal Science 57: 151 (Abstract). Supplement 1.
- HEIDARI, M.B. (1985). Heritabilities and Genetic, Phenotypic and Environmental Correlations of Carcass Traits in Beef. University of Missouri, Columbia, Missouri, U.S.A.: Dissertation Abstracts International, B (Sciences and Engineering) 1985 45: 2434-2435.
- HENDERSON, D.W., GOLL, D.E. and STROMER, M.H. (1970). A comparison of shortening and Z-line degradation in postmortem bovine, porcine and rabbit muscle. American Journal of Anatomy 128: 117-136.
- HENDERSON, R., WHITTEMORE, C.T., ELLIS, M. and SMITH, W.C. (1980). Comparison of the Newcastle Large White control and selection line pigs on a fixed feed, fixed time trial. Animal Production 30: 464 (Abstract).
- HENDERSON, R., WHITTEMORE, C.T., ELLIS, M. and SMITH, W.C. (1981). Comparison of the Newcastle Large White control and selection line pigs on an appetite feeding trial. Animal Production 32: 360 (Abstract).
- HENDERSON, R., WHITTEMORE, C.T., ELLIS, M., SMITH, W.C., LAIRD, R. and PHILLIPS, P. (1983). Comparative performance and body composition of control and selection line Large White pigs. I. On a generous fixed feeding scale for a fixed time. Animal Production 36: 399-405.
- HENTGES, E.J., MARPLE, D.N., ROLAND Sr., D.A. and PRITCHETT, J.F. (1983). Growth and in vitro protein synthesis in two strains of chicks. Journal of Animal Science 57: 320-327.

- HERZ, K.O. and CHANG, S.S. (1970). Meat flavour. Advance in Food Research 18: 1-83.
- HETZER, H.O. and HARVEY, W.R. (1967). Selection for high and low fatness in swine. Journal of Animal Science 26: 1244-1251.
- HETZER, H.O. and MILLER, R.H. (1972). Rate of growth as influenced by selection for high and low fatness in swine. Journal of Animal Science 35: 730-742.
- HETZER, H.O. and MILLER, L.R. (1973). Selection for high and low fatness in swine, correlated responses of various carcass traits. Journal of Animal Science 37: 1289-1301.
- HIGHT, G.K. and BARTON, R.A. (1965). The effects of plane of nutrition on muscle fibre diameter and muscle composition of the M. longissimus dorsi in Romney ewes. New Zealand Journal of Agricultural Research 8: 602-606.
- HINER, R.L., HANKINS, O.G., SLOANE, H.S., FELLERS, C.R. and ANDERSON, E.E. (1953). Fibre diameter in relation to tenderness of beef muscle. Food Research 18: 364-376.
- HINER, R.L. (1954). Munsell disks and color paddles as methods of measuring color in meats. Proceedings of the 7th Annual Reciprocal Meat Conference, pp. 66-70.
- HINKS, C.E. and PRESCOTT, J.H.D. (1974). A note on the prediction of carcass composition in beef cattle. Animal Production 19: 115-117.
- HODGE, R.W. and STAR, M. (1984). Comparison of the fat status of lambs during continuous growth and following nutritional restriction and subsequent realimentation. Australian Journal of Experimental Agriculture and Animal Husbandry 24: 150-155.
- HOFMAN, K. (1982). Determining water binding in meat; quick, non-planemetric evaluation of the filter paper press method. Fleischwirtschaft 62: 346-348.
- HOFMAN, K., HAMM, R. and BLUCHEL, E. (1982). New information on the determination of water binding in meat by the filter paper press method. Fleischwirtschaft 62: 87-92.
- HONIKEL, K.O. and FISCHER, C. (1977). A rapid method for detection of PSE and DFD porcine muscles. Journal of Food Science 42: 1633-1636.
- HONIKEL, K.O., HAMID, A., FISCHER, C. and HAMM, R. (1981). Influence of postmortem changes in bovine muscle on the water-holding capacity of beef. Postmortem storage of muscle at various temperatures between 0° and 30°C. Journal of Food Science 46: 23-25 and 31.

- HONIKEL, K.O., RONCALES, P. and HAMM, R. (1983). The influence of temperature on shortening and rigor onset in beef muscle. Meat Science 8: 221-241.
- HONIKEL, K.O., KIM, C.J., HAMM, R. and RONCALES, P. (1986). Sarcomere shortening of prerigor muscles and its influence on drip loss. Meat Science 16: 267-282.
- HOOD, D.E. (1980). Factors affecting the rate of metmyoglobin accumulation in pre-packaged beef. Meat Science 4: 247-265.
- HOOD, R.L. and ALLEN, C.E. (1973). Cellularity of bovine adipose tissue. Journal of Lipid Research 14: 605-610.
- HOOD, R.L. (1977). Cellularity of adipose tissue during post-natal development. Proceedings of the Nutrition Society of Australia 2: 43-52.
- HOOD, R.L. and ALLEN, C.E. (1977). Cellularity of porcine adipose tissue: effects of growth and adiposity. Journal of Lipid Research 18: 275-284.
- HOOD, R.L. and THORNTON, R.F. (1979). The cellularity of ovine adipose tissue. Australian Journal of Agricultural Research 30: 153-161.
- HOOD, R.L. (1982). Relationships among growth, adipose cell size and lipid metabolism in ruminant adipose tissue. Federation Proceedings 41: 2555-2561.
- HOPKINSON, S.F., RINGKOB, T.P. and BAILEY, C.M. (1985). Cutability and the effect of electrical stimulation and aging on tenderness of beef from young intact males and castrates. Journal of Animal Science 60: 675-681.
- HORNSTEIN, I. and CROWE, P.F. (1960). Flavour studies on beef and pork. Journal of Agriculture and Food Chemistry 8: 494-498.
- HORNSTEIN, I., CROWE, P.F. and HEINBERG, M.J. (1961). Fatty acid composition of meat tissue lipids. Journal of Food Science 26: 581-586.
- HOSTETLER, R.L., LINK, B.A., LANDMANN, W.A. and FITZHUGH, H.A. Jr. (1972). Effect of carcass suspension on sarcomere length and shear force of some major bovine muscles. Journal of Food Science 37: 132-135.
- HOSTETLER, R.L., CARPENTER, Z.L., SMITH, G.C. and DUTSON, T.R. (1975). Comparison of postmortem treatments for improving tenderness of beef. Journal of Food Science 40: 223-226.

- HOSTETLER, R.L., DUTSON, T.R. and CARPENTER, Z.L. (1976). Effect of varying final internal temperature on shear values and sensory scores on muscle from carcasses suspended by two methods. Journal of Food Science **41**: 421-423.
- HOULIER, B., VALIN, C., MONIN, G. and SALE, P. (1984). Effect of muscle type on electrical stimulation efficiency. Science des Aliments **4**: 167-175.
- HUNT, M.C., SMITH, R.A., KROPF, D.H. and TUMA, H.J. (1975). Factors affecting show case color stability of frozen lamb in transparent film. Journal of Food Science **40**: 637-640.
- HUNT, M.C. and HEDRICK, H.B. (1977). Profile of fibre types and related properties of five bovine muscles. Journal of Food Science **42**: 513-517.
- HUNT, M.C. (1980). Meat color measurements. Proceedings of the 33rd Annual Reciprocal Meat Conference, pp. 41-46.
- HUSAINI, S.A., DEATHERAGE, F.E., KUNKLE, L.E. and DRAUDT, H.N. (1950). Studies on meat. I. The biochemistry of meat as related to tenderness. Food Technology **4**: 313-316.
- HUXLEY, J.S. (1932). Problems of Relative Growth. London, England: Methuen.
- ISLER, G.A. and SWIGER, L.A. (1969). Genetic correlations between feed, growth and carcass traits in swine. Journal of Animal Science **29**: 108 (Abstract).
- IZUMI, K., ITO, T. and FUKAZAWA, T. (1977). Isometric tension development of glycerinated fibres prepared from normal and PSE porcine muscles and the effect of myosine irrigation on the tension development of "ghost" fibres. Journal of Food Science **42**: 113-116.
- JACKSONS, T.H. and MANSOUR, Y.A. (1974). Differences between groups of lamb carcasses chosen for good and poor conformation. Animal Production **19**: 93-105.
- JAGUSCH, K.T., NORTON, B.W. and WALKER, D.M. (1970). Body composition studies with the milk-fed lamb. II. The effect on the age of the lamb and the protein content of the diet on the chemical composition of the body and its organs. Journal of Agricultural Science, Cambridge **75**: 279-285.
- JAUREGUI, C.A., REGENSTEIN, J.M. and BAKER, R.C. (1981). A simple centrifugal method for measuring expressible moisture, a water-binding property of muscle foods. Journal of Food Science **46**: 1271-1273.

- JEFFREY, A.B. (1983). Principles of water holding applied to meat technology. Journal of the Science of Food and Agriculture 34: 1020-1021 (Abstract).
- JENNINGS, T.G., BERRY, B.W. and BUCHANAN, A. (1976). Fat thickness, marbling and aging. I. Effects on beef palatability. Journal of Animal Science 43: 240 (Abstract).
- JENNINGS, T.G., BERRY, B.W. and JOSEPH, A.L. (1978). Influence of fat thickness, marbling and length of aging on beef palatability and shelf-life characteristics. Journal of Animal Science 46: 658-665.
- JENSEN, P., CRAIG, H.B. and ROBISON, O.W. (1967). Phenotypic and genetic associations among carcass traits of swine. Journal of Animal Science 26: 1252-1260.
- JEREMIAH, L.E., CARPENTER, Z.L., SMITH, G.C. and BUTLER, O.D. (1970). Beef quality. I. Marbling as an indicator of palatability. Departmental Technical Report No. 22, Texas Agricultural Station. Texas A & M University, Texas, U.S.A.
- JEREMIAH, L.E., SMITH, G.C. and CARPENTER, Z.L. (1971). Palatability of individual muscles from ovine leg steaks as related to chronological age and marbling. Journal of Food Science 35: 45-47.
- JEREMIAH, L.E., CARPENTER, Z.L. and SMITH, G.C. (1972). Beef color as related to consumer acceptance and palatability. Journal of Food Science 37: 476-479.
- JEREMIAH, L.E. and MARTIN, A.H. (1978). Histological and shear properties of bovine muscle and their alteration during post-mortem aging. Meat Science 2: 169-180.
- JEREMIAH, L.E. and MARTIN, A.H. (1980). The effects of electrical stimulation on retail acceptability and case-life of beef. Proceedings of the 26th European Meeting of Meat Research Workers, Vol. 2, Colorado Springs, Colorado, U.S.A., p. 30.
- JEREMIAH, L.E. and MARTIN, A.H. (1982). The influence of breed of sire and sex on bovine intramuscular collagen content and solubility after various intervals of postmortem aging. Canadian Journal of Animal Science 62: 77-84.
- JEREMIAH, L.E., MARTIN, A.H. and ACHTYMICHUK, G. (1984). The effects of delayed chilling and altered carcass suspension upon beef muscle. II. Histological and chemical properties. Journal of Food Quality 6: 273-284.
- JEREMIAH, L.E. and MARTIN, A.H. (1985). The effects of breed of sire and postmortem ageing upon certain histological properties of two bovine muscles. Journal of Food Quality 8: 91-99.

- JEREMIAH, L.E., MARTIN, A.H. and MURRAY, A.C. (1985). The effects of various post-mortem treatments on certain physical and sensory properties of three different bovine muscles. Meat Science 12: 155-176.
- JERGENSON, D.J., ROBSON, R.M., STROMER, M.H. and GOLL, D.E. (1974). Post-mortem muscle changes in porcine muscle myofibrils. Journal of Animal Science 39: 972 (Abstract).
- JOHNSON, P.G. and BOWERS, J.A. (1976). Influence of aging on the electrophoretic and structural characteristics of turkey breast muscle. Journal of Food Science 41: 255-261.
- JOHNSON, P.R. and HIRSCH, J. (1972). Cellularity of adipose depots in six strains of genetically obese mice. Journal of Lipid Research 13: 2-11.
- JOHNSON, R.G. and HENRICKSON, R.L. (1970). Effect of treatment of pre- and post-rigor porcine muscles with low sodium chloride concentrations on the subsequent extractability of proteins. Journal of Food Science 35: 268-271.
- JOHNSTON, D.M., STEWART, D.F., MOODY, W.G., BOLING, J.A. and KEMP, J.D. (1975). Effects of breed and time of feed on the size and distribution of beef muscle fibre types. Journal of Animal Science 40: 613-620.
- JOHNSTON, D.M., MOODY, W.G., BOLING, J.A. and BRADLEY, N.W. (1981). Influence of breed type, sex, feeding system and muscle bundle size on bovine fibre type characteristics. Journal of Food Science 46: 1760-1765.
- JOLLEY, P.H., HONIKEL, K.O. and HAMM, R. (1980/1981). Influence of temperature on the rate of postmortem metabolism and water-holding capacity of bovine neck muscles. Meat Science 5: 99-107.
- JONES, D.W., CROSTON, D. and KEMPSTER, A.J. (1985). Tissue growth and distribution in crossbred lambs by 10 sire breeds. Animal Production 40: 564 (Abstract).
- JONES, S.D.M., PRICE, M.A. and BERG, R.T. (1978). Effect of breed and sex on the relative growth and distribution of bone in cattle. Canadian Journal of Animal Science 58: 157-165.
- JONES, S.D.M. (1982). The accumulation and distribution of fat in ewe and ram lambs. Canadian Journal of Animal Science 62: 381-386.
- JONES, S.D.M., BURGESS, T.D. and DUPCHAK, K. (1983). Effects of dietary energy intake and sex on carcass tissue and offals growth in sheep. Canadian Journal of Animal Science 63: 303-314.

- JONES, S.D.M., TONG, A.K.W. and MURRAY, A.C. (1987). Effects of blast-chilling carcasses of different weight and fatness on the appearance of fresh pork. Canadian Journal of Animal Science 67: 13-19.
- JOST, L., DINKEL, C.A. and COSTELLO, W.J. (1983). Beef tenderness and palatability as influenced by chemical measures and quality and yield grade factors. Journal of Animal Science 56: 1077-1087.
- JOUBERT, D.M. (1956). An analysis of factors influencing post-natal growth and development of the muscle fibre. Journal of Agricultural Science, Cambridge 47: 59-102.
- JURY, K.E., FOURIE, P.D. and KIRTON, A.H. (1977). Growth and development of sheep. IV. Growth and the musculature. New Zealand Journal of Agricultural Research 20: 115-121.
- KANDA, T., PEARSON, A.M. and MERKEL, R.A. (1977). Influence of pH and temperature upon calcium accumulation and release by bovine sarcoplasmic reticulum. Food Chemistry 2: 253-266.
- KASTHER, C.L., SULLIVAN, D.P., AYAZ, M. and RUSSELL, T.S. (1976). Further evaluation of conventional and hot-boned bovine longissimus dorsi muscle excised at various conditioning periods. Journal of Food Science 41: 97-99.
- KAUFFMAN, R.G., CARPENTER, Z.L., BRAY, R.W. and HOEKSTRA, W.G. (1964). Biochemical properties of pork and their relationship to quality. I. pH of chilled, aged and cooked muscle tissue. Journal of Food Science 29: 65-69.
- KEETON, J.T. (1983). Effects of fat and NaCl/phosphate level on the chemical and sensory properties of pork patties. Journal of Food Science 48: 878-881 and 885.
- KELLAWAY, R.C. (1973). The effects of plane of nutrition, genotype, and sex on growth, body composition and wool production in grazing sheep. Journal of Agricultural Science, Cambridge 80: 17-27.
- KEMP, J.D. and BARTON, R.A. (1966). Composition of lamb carcasses and cuts of the New Zealand export grades. New Zealand Journal of Agricultural Research 9: 590-627.
- KEMP, J.D., CROUSE, J.D., DEWEESE, W. and MOODY, W.G. (1970a). Effect of slaughter weight and castration on carcass characteristics of lambs. Journal of Animal Science 30: 348-354.
- KEMP, J.D., LAMBUTH, T.R. and BARTON, R.A. (1970b). Relationships of lamb carcass measurements and sample cut composition to carcass side composition. Journal of Animal Science 31: 686-689.

- KEMP, J.D., SHELLY, J.M., ELY, D.G. and MOODY, W.G. (1972). Effects of castration and slaughter weight on fatness, cooking losses and palatability of lamb. Journal of Animal Science 34: 560-562.
- KEMP, J.D., ELY, D.G., FOX, J.D. and MOODY, W.G. (1981). Carcass and meat characteristics of crossbred lambs with and without Finnish Landrace breeding. Journal of Animal Science 52: 1026-1033.
- KEMP, J.D., ELY, D.G. and VIMINI, R.J. (1982). Effect of ewe genetic type, slaughter weight and sex on lamb carcass characteristics. Journal of Animal Science 55: 244 (Abstract). Supplement 1.
- KEMPSTER, A.J., AVIS, P.R.D., CUTHBERTSON, A. and HARRINGTON, G. (1976). Prediction of the lean content of lamb carcass of different breed types. Journal of Agricultural Science, Cambridge 86: 23-34.
- KEMPSTER, A.J. and CUTHBERTSON, A. (1977). A survey of the carcass characteristics of the main types of British lambs. Animal Production 25: 165-179.
- KEMPSTER, A.J., CUTHBERTSON, A., JONES, D.W. and OWEN, M.G. (1977). A preliminary evaluation of the 'scanogram' for predicting the carcass composition of live lambs. Animal Production 24: 145-146 (Abstract).
- KEMPSTER, A.J. (1978). Bone growth and development with particular reference to breed differences in carcass shape and lean to bone ratio. In: De Boer, H. and Martin, J. (eds.), Patterns of Growth and Development in Cattle. Current Topics in Veterinary Medicine, Vol. 2. The Hague/Boston/London: Martinus Nijhoff, pp. 149-166.
- KEMPSTER, A.J. and EVANS, D.G. (1979). A comparison of different predictors of the lean content of pig carcasses. I. Predictors for use in commercial classification and grading. Animal Production 28: 87-96.
- KEMPSTER, A.J. (1980). Fat partitioning and distribution in the carcasses of cattle, sheep and pigs: a review. Meat Science 5: 83-98.
- KEMPSTER, A.J., CROSTON, D. and JONES, D.W. (1981). Value of conformation as an indicator of sheep carcass composition within and between breeds. Animal Production 33: 39-49.
- KEMPSTER, A.J., CUTHBERTSON, A. and HARRINGTON, G. (1982a). Carcass Evaluation in Livestock Breeding, Production and Marketing. London, England: Granada Publishing Ltd.

- KEMPSTER, A.J., CUTHBERTSON, A. and HARRINGTON, G. (1982b). The relationship between conformation and the yield and distribution of lean meat in the carcasses of British pigs, cattle and sheep: a review. Meat Science 6: 37-53.
- KEMPSTER, A.J. (1983). Carcass quality and its measurement in sheep. In: Haresign, W. (ed.), Sheep Production. University of Nottingham. London, England: Butterworths, pp. 59-74.
- KEMPSTER, A.J., CROSTON, D., GUY, D.R. and JONES, D.W. (1983). A comparison of ten sire breeds for sheep meat production. II. Tissue growth and distribution. British Society of Animal Production, Winter Meeting, 1983.
- KEMPSTER, A.J., COOK, G.L. and GRANTLEY-SMITH, H. (1986). National estimates of the body composition of British cattle, sheep and pigs with special reference to trends in fatness. A review. Meat Science 17: 107-138.
- KERSEY, Denise R.S., IRVIN, K.M., SWIGER, L.A. and PLIMPTON, R.F. (1983). Selection for increased leanness of Yorkshire swine. IV. Indirect responses of the carcass, breeding efficiency and preweaning litter traits. Journal of Animal Science 56: 551-559.
- KHAN, A.W. and NAKAMURA, R. (1970). Effects of pre- and post-mortem glycolysis on poultry tenderness. Journal of Food Science 35: 266-267.
- KHAN, A.W. and LENTZ, C.P. (1973). Influence of ante-mortem glycolysis and dephosphorylation of high energy phosphate on beef aging and tenderness. Journal of Food Science 38: 56-58.
- KHAN, A.W. and VOISEY, P.W. (1973). Determination of shear force value of major beef muscles. Canadian Institute of Food and Technology Journal 6: 47-49.
- KIESSLING, K.H., LUNDSTROM, K., PETERSSON, H. and STALHAMMAR, H. (1982). Age and feed related changes of fibre composition in pig muscle. Swedish Journal of Agricultural Research 12: 69-75.
- KIESSLING, K.H. and HANSSON, I. (1983). Fibre composition and enzyme activities in pig muscles. Swedish Journal of Agricultural Research 13: 257-261.
- KING, J.W.B. (1957). The heritability of carcass traits in British bacon pigs. Proceedings of the British Society of Animal Production, pp. 49-69.

- KING, N.L., KURTH, L. and SHORTHOSE, W.R. (1981). Proteolytic degradation of connectin, a high molecular weight myofibrillar protein, during heating of meat. Meat Science 5: 389-396.
- KIRTON, A.H. and BARTON, R.A. (1962). Study of indices of the chemical composition of lamb carcasses. Journal of Animal Science 21: 553-557.
- KIRTON, A.H., HIGHT, G.K. and DUGANZICH, D.M. (1967a). A comparison of the carcass quality of Romney with Border Leicester X Romney lambs and Southdown X Romney with Southdown X (Border Leicester X Romney) lambs. New Zealand Journal of Agricultural Research 10: 33-42.
- KIRTON, A.H., CLARKE, J.N. and CARTER, A.H. (1967b). Effect of pre-slaughter fasting on liveweight, carcass weight, and carcass composition of Southdown ram lambs. New Zealand Journal of Agricultural Research 10: 43-55.
- KIRTON, A.H. and PICKERING, F.S. (1967). Factors associated with differences in carcass conformation in lamb. New Zealand Journal of Agricultural Research 10: 183-200.
- KIRTON, A.H., DALTON, D.C. and ACKERLEY, L.R. (1974). Performance of sheep on New Zealand hill country. New Zealand Journal of Agricultural Research 17: 283-293.
- KIRTON, A.H. (1976). Growth, carcass composition and palatability of sheep. Proceedings of the Carcass Classification Symposium, Adelaide, Sydney, Australia: Australian Meat Board, Paper S1, 22 pp.
- KIRTON, A.H., CLARK, J.N. and CARTER, A.H. (1978). Comparison of lamb carcasses sired by Southdown with those sired by Dorset Down or Suffolk rams mated to Romney ewes. New Zealand Journal of Experimental Agriculture 6: 55-57.
- KIRTON, A.H. and JOHNSON, D.L. (1979). Interrelationships between GR and other lamb carcass fatness measurements. Proceedings of the New Zealand Society of Animal Production 39: 194-201.
- KIRTON, A.H., SINCLAIR, D.P., CHRYSTALL, B.B., DEVINE, C.E. and WOODS, E.G. (1981). Effect of plane of nutrition on carcass composition and the palatability of pasture fed lamb. Journal of Animal Science 52: 285-291.
- KIRTON, A.H. (1982). Differences between P and Y export lamb carcass grades in M. longissimus dorsi area and shape. Proceedings of the New Zealand Society of Animal Production 42: 121-123.

- KIRTON, A.H., WOOD, E.G. and DUGANZICH, D.M. (1983). Comparison of well and poorly muscled lamb carcasses as selected by experienced meat industry personnel. Proceedings of the New Zealand Society of Animal Production **43**: 111-113.
- KIRTON, A.H., CARTER, A.H., CLARKE, J.N. and DUGANZICH, D.M. (1984). Dressing percentage of lambs. Proceedings of the New Zealand Society of Animal Production **44**: 231-233.
- KIRTON, A.H., DALTON, D.C., WINN, G. and DUGANZICH, D.M. (1985). Body composition of cull Romney, Dorset X Romney and Cheviot ewes from New Zealand hill country. New Zealand Journal of Agricultural Research **28**: 241-247.
- KLYDE, B.J. and HIRSCH, J. (1979). Increased cellular proliferation in adipose tissue of adult rats fed a high fat diet. Journal of Lipid Research **20**: 705-715.
- KOCH, R.M., CUNDIFF, L.V. and GREGORY, K.E. (1982). Heritabilities and genetic, environmental and phenotypic correlations of carcass traits in a population of diverse biological types and their implications in selection programs. Journal of Animal Science **55**: 1319-1329.
- KONDOS, A.C. and TAYLOR, D.G. (1987). Effect of electrical stimulation and temperature on biochemical changes in beef muscle. Meat Science **19**: 207-216.
- KOOHMARAIE, M., KENNICK, W.H., ELGASIM, E.A. and ANGLEMIER, A.F. (1984). Effect of prerigor pressurization on the activity of calcium-activated-factor. Journal of Food Science **49**: 680-684.
- KOOHMARAIE, M., SCHOLLMEYER, J.E. and DUSTON, T.R. (1986). Effect of low-calcium-requiring calcium-activated-factor on myofibrils under varying pH and temperature conditions. Journal of Food Science **51**: 28-32.
- KOOHMARAIE, M., SEIDEMAN, S.C., SCHOLLMEYER, J.E., DUSTON, T.R. and CROUSE, J.D. (1987). Effect of post-mortem storage on Ca-dependent proteases, their inhibitor and myofibril fragmentation. Meat Science **19**: 187-196.
- KOONG, L.J., NIENABER, J.A. and MERSMANN, H.J. (1983). Effects of plane of nutrition on organ size and fasting heat production in genetically obese and lean pigs. Journal of Nutrition **113**: 1626-1631.
- KRAMLICH, W.E. and PEARSON, A.M. (1958). Some preliminary studies on meat flavor. Food Research **23**: 567-574.
- KRUGGEL, W.G. and FIELD, R.A. (1971). Soluble intramuscular collagen characteristics from stretched and aged muscle. Journal of Food Science **36**: 1116-1117.

- KRUGGEL, W.G., FIELD, R.A., MILLER, G.J., HORTON, K.M. and BUSBOOM, J.M. (1982). Influence of sex and diet on lutein in lamb fat. Journal of Animal Science 54: 970-975.
- KUHLERS, D.L., JUNGST, S.B., HUFFMAN, D.L., CORDRAY, J.C. and BROWN, P.M. (1984). Growth and carcass traits at 135 kg for progeny of swine selected for growth and backfat. Journal of Animal Science 58: 275-280.
- LAAKKONEN, E., SHERBON, J.W. and WELLINGTON, G.H. (1970). Low-temperature, long-time heating of bovine muscle. II. Changes in electrophoretic patterns. Journal of Food Science 35: 178-180.
- LABORDE, D., MONIN, G., DAUZAT, R. and GARDETTE, J.P. (1985). Water-holding capacity of pork. Influence of muscle metabolic type and importance of sarcoplasmic components. Sciences des Aliments 5: 353-364.
- LAWRIE, R.A. (1950). Some observations on factors affecting myoglobin concentrations in muscle. Journal of Agricultural Science, Cambridge 40: 356-366.
- LAWRIE, R.A. (1978). The status of flesh foods with particular reference to meat. Food Technology in Australia 30: 190-195.
- LAWRIE, R.A. (1985). The eating quality of meat. In: Lawrie, R.A. (ed.), Meat Science, 4th ed. London, England: Pergamon Press, pp. 300-362.
- LAX, J. and PISANSARAKIT, P. (1982). Effect of selection for body weight on fibre types and fibre number in some mouse muscles. In: Barton, R.A. and Smith, W.C. (eds.), Proceedings of the World Congress on Sheep and Beef Cattle Breeding, Vol. 1, Palmerston North and Christchurch, New Zealand, pp. 421-425.
- LeCLERCQ, B., BLUM, J.C. and BOYER, J.P. (1980). Selecting broilers for low or high abdominal fat: initial observations. British Poultry Science 21: 107-113.
- LEDWARD, D.A. (1985). Post-slaughter influences on the formation of metmyoglobin in beef muscles. Meat Science 15: 149-171.
- LEDWARD, D.A., DICKINSON, R.F., POWELL, V.H. and SHORTHORSE, W.R. (1986). The colour and colour stability of beef longissimus dorsi and semimembranosus muscles after effective electrical stimulation. Meat Science 16: 245-265.
- LEDGER, H.P. and HUTCHINSON, H.G. (1962). The value of the tenth rib as a sample joint for the estimation of lean, fat and bone in the carcasses of East African Zebu cattle. Journal of Agricultural Science, Cambridge 58: 81-90.

- LEE, G.J. (1984). A comparison of carcass traits in Scottish Blackface and Welsh mountain lambs and their crosses. Animal Production **39**: 433-440.
- LEE, G.J. (1986a). Growth and carcass characteristics of ram cryptorchid and wether Border Leicester X Merino lamb: effect of increasing carcass weight. Australian Journal of Experimental Agriculture **26**: 153-157.
- LEE, G.J. (1986b). Growth and carcass composition of ram and wether lambs fed at two levels of nutrition. Australian Journal of Experimental Agriculture **26**: 275-278.
- LEE, Y.B. and ASHMORE, C.R. (1985). Effect of early postmortem temperature on beef tenderness. Journal of Animal Science **60**: 1588-1596.
- LEFAUCHEUR, L. and VIGNERON, P. (1986). Post-natal changes in some histochemical and enzymatic characteristics of three pig muscles. Meat Science **16**: 199-216.
- LEWIS, P.K. Jr., CAMPBELL, K.P., YOUNGER, L., HECK, M.C. and BROWN, C.J. (1973). Feeding a diuretic, antemortem stress and postmortem stretching on fibre diameter and sarcomere length. Journal of Animal Science **37**: 265 (Abstract).
- LEWIS, P.K. and BABIKER, S.A. (1983). Effect of electrical stimulation and cooking temperature on the within-sample variation of cooking loss and shear force of lamb. Meat Science **8**: 317-321.
- LEYMASTER, K.A. and JENKINS, T.G. (1985). Characterization of accretive rates for growth constituents in Suffolk sheep. Journal of Animal Science **61**: 430-435.
- LIGHT, N., CHAMPION, A.E., VOYLE, C. and BAILEY, A.J. (1985). The role of epimysial perimysial and endomysial collagen in determining texture in six bovine muscles. Meat Science **13**: 137-149.
- LILLIE, R.D. (1965). Histopathologic Technic and Practical Histochemistry. New York, U.S.A.: McGraw-Hill Book Company.
- LIN, R.R., CARPENTER, J.A. and REAGAN, J.O. (1985). Chemical, cooking and textural properties of semimembranosus, semitendinosus and biceps femoris muscles of pork. Journal of Food Quality **7**: 277-281.
- LINDHOLM, A. and PIEHL, K. (1974). Fibre composition, enzyme activity and concentrations of metabolites and electrolytes in muscles of standardized horses. Acta Veterinaria Scandinavica **15**: 287-309.

- LIRETTE, A., SEOANE, J.R., MINVIELLE, F. and FROEHLICH, D. (1984). Effects of breed and castration on conformation, classification tissue, distribution, composition and quality of lamb carcasses. Journal of Animal Science 58: 1343-1357.
- LISTER, D. (1976). Effects of nutrition and genetics on the composition of the body. Proceedings of the Nutrition Society 58: 351-356.
- LITTLE, D.A. and SANDLAND, R.L. (1975). Studies on the distribution of body fat in sheep during continuous growth and following nutritional restriction and rehabilitation. Australian Journal of Agricultural Research 26: 363-374.
- LIVINGSTON, D.M.S., BLAIR, S.R. and ENGLISH, P.R. (1966). The usefulness of muscle fibre diameter in studies of the lean meat content of pigs. Animal Production 8: 267-274.
- LLOYD, W.R., SLYTER, A.L. and COSTELLO, W.J. (1981). Effect of breed sex and final weight on feedlot performance, carcass characteristics and meat palatability of lambs. Journal of Animal Science 51: 316-320.
- LOBLEY, G.E., WABSTER, A.J.F. and REEDS, P.J. (1978). Protein synthesis in lean and obese Zucker rats. Proceedings of the Nutrition Society 37: 20A.
- LOCHNER, J.V., KAUFFMAN, R.G. and MARSH, B.B. (1980). Early postmortem cooling rate and beef tenderness. Meat Science 4: 227-241.
- LOCKER, R.H. (1959). Striation patterns of ox muscle in rigor mortis. Journal Biophysical Biochemical Cytology 6: 419-422.
- LOCKER, R.H. (1960). Degree of muscular contraction as a factor in tenderness of beef. Food Research 25: 304-307.
- LOCKER, R.H. and HAGYARD, C.J. (1963). A cold shortening effect in beef muscles. Journal of the Science of Food and Agriculture 14: 787-793.
- LOCKER, R.H. and DAINES, G.J. (1974). Cooking loss in beef. The effect of cold shortening, searing and rate of heating; time course and histology of changes during cooking. Journal of the Science of Food and Agriculture 25: 1411-1418.
- LOCKER, R.H. and DAINES, G.J. (1975). Rigor mortis in beef sternomandibularis muscle at 37°C. Journal of the Science of Food Agriculture 26: 1721-1733.
- LOCKER, R.H., DAVEY, C.L., NOTTINGHAM, P.M., HAUGHEY, D.P. and LAW, N.H. (1975). New concepts in meat processing. Advance in Food Research 21: 157-222.

- LOCKER, R.H. and DAINES, G.J. (1976). Tenderness in relation to the temperature of rigor onset in cold shortened beef. Journal of the Science of Food and Agriculture 27: 193-196.
- LOCKER, R.H., DAINES, G.J., CARSE, W.A. and LEET, N.G. (1977). Meat tenderness and the gap filaments. Meat Science 1: 87-104.
- LOCKER, R.H. (1982). A new theory of tenderness in meat, based on gap filaments. Proceedings of the 35th Annual Reciprocal Meat Conference, pp. 92-100.
- LOCKER, R.H. and WILD, P.J.C. (1982). Yield point in raw beef muscle. The effects of ageing, rigor temperature and stretch. Meat Science 7: 93-107.
- LOCKER, R.H. (1985). Cold-induced toughness of meat. In: Pearson, A.M. and Dutson, T.R. (eds.), Advance in Meat Research. Vol 1. Electrical Stimulation. Westport, Connecticut, U.S.A.: Avi Publishing Company, pp. 1-44.
- LOHMAN, T.G. (1971). Biological variation in body composition. Journal of Animal Science 32: 647-653.
- LOHSE, C.L., MOSS, F.P. and BUTTERFIELD, R.M. (1971). Growth patterns of muscles of Merino sheep from birth to 517 days. animal Production 13: 117-126.
- LOHSE, C.L. (1973). The influence of sex on muscle growth in Merino sheep. Growth 37: 177-187.
- LOVE, J.D. and PEARSON, A.M. (1971). Lipid oxidation in meat and meat products - a review. American Oil Chemists Society Journal 48: 547-549.
- LUCKETT, R.L., ICAZA, E.A., BUDNER, T.D. and BOSTON, A.C. (1975a). Beef tenderness and its relation to carcass traits and pH. Journal of Animal Science 40: 176 (Abstract).
- LUCKETT, R.L., BIDNER, T.D., ICAZA, E.A. and TURNER, J.W. (1975b). Tenderness studies in straightbred and crossbred steers. Journal of Animal Science 40: 468-475.
- LUFF, A.R. and GOLDSPINK, G. (1967). Large and small muscles. Life Science 6: 1821-1826.
- LUITINGH, H.C. (1962). Developmental changes in beef steers as influenced by fattening, age, type of ration. Journal of Agricultural Science, Cambridge 58: 1-47.
- LUNDSTROM, K., NILSSON, H. and MALMFORS, B. (1979). Interrelations between meat quality characteristics in pigs. Muscle function and porcine meat quality. Acta Agriculturae Scandinavica Supplement 21: 71-79.

- LYON, M., KASTNER, C.L., DIKEMAN, M.F., HUNT, M.C., KROPF, D.H. and SCHWENKE, J.R. (1983). Effects of electrical stimulation, aging and blade tenderization on hot-boned beef psaos major and triceps brachii muscles. Journal of Food Science 48: 131-135.
- MacBRIDE, M.A. and PARRISH Jr., F.C. (1977). The 30,000-Dalton component of tender bovine longissimus muscle. Journal of Food Science 42: 1627-1629.
- MacIVER, R.M. (1971). Response to within-family selection in a small closed pig herd. Animal Production 13: 245-255.
- MacLEOD, G. and COOPOCK, B.M. (1976). Volatile flavor components of beef boiled conventionally and by microwave radiation. Journal of Agriculture and Food Chemistry 24: 835-843.
- MacLEOD, G. and SEYYEDAIN-ARDEBILI, M. (1981). Natural and simulated meat flavors (with particular reference to beef). Critical Reviews Food Science and Nutrition 14: 309-437.
- MARINOVA, P., VOINOVA, R., NEDELICHEV, D. and PINKAS, A. (1984). Meat quality of lambs of different breeding types. I. The metabolic type of muscle fibres. Animal Breeding Abstract 52: 79.
- MARSH, B.B. and LEET, N.G. (1966). Studies in meat tenderness. III. The effects of cold shortening on tenderness. Journal of Food Science 31: 450-459.
- MARSH, B.B., WOODHAMS, P.R. and LEET, N.G. (1968). Studies in meat tenderness. V. The effect on tenderness of carcass cooling and freezing before the completion of rigor mortis. Journal of Food Science 33: 12-18.
- MARSH, B.B. and CARSE, W.A. (1974). Meat tenderness and the sliding-filament hypothesis. Journal of Food Technology 9: 129-139.
- MARSH, B.B., LEET, N.C. and DICKSON, M.R. (1974). The ultrastructure and tenderness of highly cold shortened muscle. Journal of Food Technology 9: 141-147.
- MARSH, B.B., LOCHNER, J.V., TAKAHASHI, G. and KRAGNESS, D.D. (1980/1981). Effects of early post-mortem pH and temperature on beef tenderness. Meat Science 5: 479-483.
- MARSH, B.B. (1983). Effects of early-postmortem muscle pH and temperature on meat tenderness. Proceedings of the 36th Annual Reciprocal Meat Conference, pp. 131-135.
- MARTIN, A.H., FREDEEN, H.T. and WEISS, G.M. (1971). Tenderness of beef longissimus dorsi muscle from steers, heifers and bulls as influenced by source, postmortem aging and carcass characteristics. Journal of Food Science 36: 619-623.

- MARTIN, A.H. and FREDEEN, H.T. (1974a). Postmortem pH change as related to tenderness and water-holding capacity of muscle from steer, bull and heifer carcasses. Canadian Journal of Animal Science 54: 127-135.
- MARTIN, A.H. and FREDEEN, H.T. (1974b). Pork quality in relation to carcass fatness and muscling. Canadian Journal of Animal Science 54: 137-143.
- MARTIN, A.H., FREDEEN, H.T. and L'HIRONDELLE, P.J. (1975). Muscle temperature, pH and rate of rigor development in relation to quality and quantity characteristics in pig carcasses. Canadian Journal of Animal Science 55: 527-532.
- MARTIN, A.H., FREDEEN, H.T., L'HIRONDELLE, P.J., MURRAY, A.C. and WEISS, G.M. (1981). Pork quality attributes. Their estimation and relationship with carcass composition in commercial pigs. Canadian Journal of Animal Science 61: 289-298.
- MARTIN, A.H., MURRAY, A.C., JEREMIAH, L.E. and DUTSON, P.J. (1983). Electrical stimulation and carcass aging effects on beef carcasses in relation to postmortem glycolytic rates. Journal of Animal Science 57: 1456-1462.
- MATYNIAK, J. and ZIOLECKI, J. (1983). Changes in some biochemical and physical characteristics of duck meat kept under deep-chilled storage. Fleischwirtsch 63: 597-598.
- MAY, M.L., DIKEMAN, M.E. and SCHALLES, R. (1977). Longissimus muscle histological characteristics of Simmental X Angus, Hereford X Angus and Limousin X Angus crossbred steers as related to carcass composition and meat palatability traits. Journal of Animal Science 44: 571-580.
- McCLELLAND, T.H. and RUSSELL, A.J.F. (1972). The distribution of body fat in Scottish Blackface and Finnish Landrace. Animal Production 15: 301-306.
- McCLELLAND, T.H., BONAITI, B. and TAYLOR, St.C.S. (1976). Breed differences in body composition of equally mature sheep. Animal Production 23: 281-293.
- McCOLLUM, P.D. and HENRICKSON, R.L. (1977). The effect of electrical stimulation on the rate of post-mortem glycolysis in some bovine muscles. Journal of Food Quality 1: 15-22.
- McCRAE, S.E., SECCOMBE, C.G., MARSH, B.B. and CARSE, W.A. (1971). Studies on meat tenderness. IX. The tenderness of various lamb muscles in relation to their skeletal restraint and delay before freezing. Journal of Food Science 36: 566-570.

- McDOUGALL, D.B., SHAW, B.G., NUKE, G.R. and RHODES, D.N. (1979). Effect of pre-slaughter handling on the quality and microbiology of venison from farmed young red deer. Journal of the Science of Food and Agriculture 30: 1160-1167.
- McINTYRE, B.L. and RYAN, W.J. (1984). The influence of type of diet and electrical stimulation on the eating quality of beef. Proceedings of the Australian Society of Animal Production 15: 468-471.
- McKEITH, F.K., SMITH, G.C., SAVELL, J.W., DUTSON, T.R., CARPENTER, Z.L. and HAMMOND, D.R. (1981). Effects of certain electrical stimulation parameters on quality and palatability of beef. Journal of Food Science 46: 13-18.
- McMEEKAN, C.P. (1940a). Growth and development of the pig, with special reference to carcass quality characters. I. Age changes in growth and development. Journal of Agricultural Science, Cambridge 30: 276-344.
- McMEEKAN, C.P. (1940b). Growth and development of the pig, with special reference to carcass quality characters. II. The influence of the plane of nutrition on growth and development. Journal of Agricultural Science, Cambridge 30: 387-436.
- MELTON, C.C., DIKEMAN, M., TUMA, H.J. and SCHALLES, R.R. (1974). Histological relationships of muscle biopsies to bovine meat quality and carcass composition. Journal of Animal Science 38: 24-31.
- MELTON, C.C., DIKEMAN, M.E., TUMA, H.J. and KROPF, D.H. (1975). Histochemical relationships of muscle biopsies with bovine muscle quality and composition. Journal of Animal Science 40: 451-456.
- MERKEL, R.A., SPOONER, M.E., EMERY, R.S., ROMSOS, D.R. and PARR, A.F. (1973). Cellularity of ovine subcutaneous adipose tissue. Journal of Animal Science 37: 268 (Abstract).
- MERSMANN, H.J., GOODMAN, J.R. and BROWN, L.J. (1975). Development of swine adipose tissue: morphology and chemical composition. Journal of Lipid Research 16: 269-279.
- MERSMANN, H.J., POND, W.G. and YEN, J.T. (1984). Use of carbohydrate and fat as energy source by obese and lean swine. Journal of Animal Science 58: 894-902.
- MERSMANN, H.J. (1985). Adipose tissue lipolytic rate in genetically obese and lean swine. Journal of Animal Science 60: 131-135.

- HERSMANN, H.J. (1986). Postnatal expression of adipose tissue metabolic activity associated with a porcine genetic obesity. Journal of Animal Science **63**: 741-746.
- MEYER, J.H. and CLAWSON, W.J. (1964). Undernutrition and subsequent realimentation in rats and sheep. Journal of Animal Science **23**: 214-224.
- MEYER, R.M., YOUNG, A.W., MARSH, B.B. and KAUFFMAN, R.G. (1977). Effect of backfat in preventing cold shortening and maintaining tenderness in beef. Journal of Animal Science **45**: 70 (Abstract). Supplement 1.
- MEYER, H.H., KIRTON, A.H., DOBBIE, J.L. and HARVEY, T.G. (1978). Oxfords, Suffolks, and Southdowns - growth and carcass composition compared. AgLink Services FPP 137.
- MEYER, H.H., KIRTON, A.H., SMITH, J.F. and JAGUSCH, K.T. (1981/1982). Breeding for leaner lamb carcasses. New Zealand Ministry of Agriculture and Fisheries, Agricultural Research Division Annual Report, p. 32.
- MILES, C.L. and LAWRIE, R.A. (1970). Relation between pH and tenderness in cooked muscle. Journal of Food Technology **5**: 325-330.
- MILLER, A.J., ACKERMAN, S.A. and PALUMBO, S.A. (1980b). Effects of frozen storage on functionality of meat for processing. Journal of Food Science **45**: 1466-1471.
- MILLER, A.T., KARMAS, E. and FULU, M. (1983). Age-related changes in the collagen of bovine corium: studies on extractability, solubility and molecular size distribution. Journal of Food Science **48**: 681-707.
- MILLER, G.J., KUNSMAN, J.E. and FIELD, R.A. (1980a). Characteristics of soft subcutaneous fat in ram lambs fed corn and corn-silage diets. Journal of Food Science **45**: 279-282 and 287.
- MILLMAN, B.M. and NICKEL, B.G. (1980). Electrostatic forces in muscle and cylindrical gel systems. Biophysical Journal **32**: 49-63.
- MILLMAN, B.M., RACEY, T.J. and MATSUBARA, I. (1981). Effects of hyperosmotic solutions on the filament lattice of intact frog skeletal muscle. Biophysical Journal **33**: 189-202.
- MINITAB (1982). Minitab 82. 1, Reference Manual, Statistics Department 215 Pond Laboratory. Pennsylvania, U.S.A.: The Pennsylvania State University, p. 49. Copy held by Massey University, Computer Centre.

- MISOCK, J.D., CAMPION, D.R., FIELD, R.A. and RILEY, M.L. (1976). Palatability of heavy ram lambs. Journal of Animal Science 42: 1440-1444.
- MITCHELL, R.M. and JAGUSCH, K.J. (1972). Energy balance studies with weaned lambs. I. Utilisation of metabolisable energy of lucerne by lambs weaned at five weeks of age. New Zealand Journal of Agricultural Research 15: 788-794.
- MOELLER, P.W., FIELDS, P.A., DUTSON, T.R., LANDMANN, W.A. and CARPENTER, Z.L. (1976). Effect of high temperature conditioning on subcellular distribution and levels of lysosomal enzymes. Journal of Food Science 41: 216-217.
- MOELLER, P.W., FIELDS, P.A., DUTSON, T.R., LANDMANN, W.A. and CARPENTER, Z.L. (1977). High temperature effects of lysosomal enzyme distribution and fragmentation of bovine muscle. Journal of Food Science 42: 510-513.
- MOHAMED, A.M. (1976). Genetic Parameters of Carcass Traits in the New Zealand Romney. M.Sc. Thesis, Massey University, Palmerston North, New Zealand.
- MOLLER, A.J., VESTERGAARD, T. and WISMER-PEDERSEN, J. (1973). Myofibril fragmentation in bovine longissimus dorsi as an index of tenderness. Journal of Food Science 38: 824-825.
- MOLLER, A.J., BOUTON, P.E., HARRIS, P.V. and JONES, P.N. (1983). Effect of electrical stimulation on the tenderization of mutton by aging. Journal of Food Science 48: 874-877 and 896.
- MOODY, W.G. and CASSENS, R.G. (1968). Histochemical differentiation of red and white muscle fibres. Journal of Animal Science 27: 961-968.
- MOODY, W.G., TICHENOR, D.A., KEMP, J.D. and FOX, J.D. (1970). Effects of weight, castration and rate of gain on muscle fibre and fat cell diameter in two ovine muscles. Journal of Animal Science 31: 676-680.
- MOODY, W.G., KEMP, J.D., MAHYUDDIN, M., JOHNSTON, D.M. and ELY, D.G. (1980). Effect of feeding systems, slaughter weight and sex on histological properties of lamb carcasses. Journal of Animal Science 50: 249-256.
- MOODY, W.G. (1983). Beef flavour - a review. Food Technology 37: 227-232 and 238.
- MOODY, W.G., FOX, J.D. and NELSON, G. (1984). Effect of electrical stimulation and conditioning temperature on beef quality. Journal of Animal Science 59: 236-237 (Abstract). Supplement 1.

- MORAN, J.B. (1983). The value of the rib joint in predicting carcass chemical composition in various breeds of cattle and buffalo. Journal of Agricultural Science, Cambridge 100: 701-707.
- MORGAN, J.A. and OWEN, J.B. (1972a). The nutrition of artificially reared lambs. I. The effect of different feeding methods applied at three stages of growth. Animal Production 15: 285-292.
- MORGAN, J.A. and OWEN, J.B. (1972b). The nutrition of artificially reared lambs. II. The effect of feed restriction at three stages of growth on growth and carcass composition. Animal Production 15: 293-300.
- MORGAN, J.A. and OWEN, J.B. (1973). The nutrition of artificially reared lambs. III. The effect of sex on the performance and carcass composition of lambs subjected to different nutritional treatments. Animal Production 16: 49-57.
- MORGAN, W. (1979). The effects of electrical stimulation and conventional handling of beef on beef quality. Journal of the Science of Food and Agriculture 30: 1108 (Abstract).
- MORRISON, E.J. and DAHMEN, J.J. (1983). Carcass composition of larger market lambs of different breed crosses. Animal Breeding Abstract 51: 453.
- MOSKOWITZ, H.R. (1981). Relating subjective and instrumental measures. A psychophysical review. Journal of Food Quality 4: 15-33.
- MOXHAM, R.W. and BROWNLIE, L.E. (1976). Sheep carcass grading and classification in Australia. Proceedings of the Carcass Classification Symposium, Adelaide, Australia, May 1976. Sydney, Australia: Australian Meat Board, Paper S4, pp.1-15.
- MURRAY, D.M. and SLEZACEK, O. (1975). The effect of growth rate on muscle distribution in sheep. Journal of Agricultural Science, Cambridge 85: 189-191.
- MURRAY, D.M. and SLEZACEK, O. (1976). Growth rate and its effect on empty body weight, carcass weight and dissected carcass composition of sheep. Journal of Agricultural Science, Cambridge 87: 171-179.
- NACHLAS, M.M., TSOU, K.C., SESOUZA, E.D., CHENG, S.S. and SELIGMAN, A.M. (1957). Cytochemical demonstration of succinic dehydrogenase by the use of a new P-nitrophenyl substituted diterazole. Journal Histochemistry and Cytochemistry 5: 420-436.
- NAGAINIS, P. and WOLFE, F.H. (1982). Calcium activated neutral protease hydrolyses Z-disc actin. Journal of Food Science 47: 1358-1364.

- NAUMANN, H.D., RHODES, V.J. and VOLK, J.D. (1960). Sensory attributes of pork differing in marbling and firmness. Journal of Animal Science 19: 1241 (Abstract).
- NEWBOLD, R.P. and HARRIS, P.V. (1972). The effect of pre-rigor changes on meat tenderness. A review. Journal of Food Science 37: 337-340.
- NEWBOLD, R.P. and SMALL, L.M. (1985). Electrical stimulation of post-mortem glycolysis in the semitendinosus muscle of sheep. Meat Science 12: 1-16.
- NICASTRO, F., MOODY, W.G., KEMP, J.D., ELY, D.G. and AARON, D.K. (1985). Effect of sources and levels of protein on histological properties of muscle fibres and subcutaneous fat lamb carcasses. Journal of Animal Science 61: 281-282, Supplement 1.
- NICHOLAS, G.A., LOBLEY, G.E. and HARRIS, C.I. (1977). Use of the constant infusion technique for measuring rates of protein synthesis in the New Zealand White rabbit. British Journal of Nutrition 38: 1-17.
- NICHOLS, J.E. and CROSS, H.R. (1980). Effect of electrical stimulation and early postmortem excision on pH decline, sarcomere length and color in beef muscles. Journal of Food Protection 43: 514-519.
- NORTON, H.W. (1968). Opportunities and pitfalls in mathematics of body-composition studies. In: Reid, J.T. (ed.), Body Composition in Animals and Man. Washington, D.C., U.S.A.: National Academy of Sciences Publication, pp. 137-147.
- NOSTVOLD, O., SCHIE, K.A. and FROYSTEIN, T. (1979). Muscle fibre characteristics in lines of pigs selected for rate of gain and backfat thickness. In: Muscle Function and Porcine Meat Quality. A Symposium of N.J.F. Acta Agriculturae Scandinavica, Supplement 21, pp. 136-142.
- OCKERMAN, H.W., TAWOREK, D., VanSTAVERN, B., PARRETT, N. and PIERSON, C.J. (1984). Castration and sire effects on carcass traits, in meat palatability and muscle fibre characteristics in Angus cattle. Journal of Animal Science 59: 981-990.
- OFFER, G. and TRINICK, J. (1983). On the mechanism of water holding in meat: the swelling and shrinking of myofibrils. Meat Science 8: 245-281.
- OGATA, T. and MORI, M. (1964). Histochemical study of oxidative enzymes in vertebrate muscles. Journal of Histochemistry and Cytochemistry 12: 171-182.

- OLDFIELD, J.E., FOX, C.W., BAHN, A.V., BICKOFF, E.M. and KOHLER, G.O. (1966). Coumestrol in alfalfa as a factor in growth and carcass quality in lambs. Journal of Animal Science 25: 167-174.
- OLIVER, W.M., CARPENTER, Z.L., KING, G.T. and SHELTON, M. (1968). Predicting cutability of lamb carcass from carcass weights and measures. Journal of Animal Science 27: 1254-1260.
- OLLIVIER, L. (1977). A ten-year experiment on individual selection of boars used in artificial insemination. I. Observed responses on growth carcass and meat quality traits. Ann. de Genetiaue et de Selection Animale 9: 353-377.
- OLSON, D.G., PARRISH, F.C. Jr. and STROMER, M.H. (1976a). Myofibril fragmentation and shear resistance of three bovine muscles during postmortem storage. Journal of Food Science 41: 1036-1041.
- OLSON, D.G., PARRISH, F.C., DAYTON, W.R. and GOLL, D.E. (1977). Effect on postmortem storage and calcium activated factor on the myofibrillar proteins of bovine skeletal muscle. Journal of Food Science 42: 117-124.
- OLSON, L.W., DICKERSON, G.E., CROUSE, J.D. and GLIMP, H.A. (1976b). Selection criteria for intensive market lamb production: carcass and growth traits. Journal of Animal Science 43: 90-101.
- OITHOFF, J.C., DICKERSON, G.E. and NIENABER, J.A. (1985). Effects of body composition and tissue distribution on fasting heat production in mature ewes. Journal of Animal Science 61: 226-227 (Abstract). Supplement 1.
- ORCUTT, M.W., DUTSON, T.R., CORNFORTH, D.P. and SMITH, G.C. (1984). Factors affecting the formation of a dark, coarse band ("heat-ring") in bovine longissimus muscle. Journal of Animal Science 58: 1366-1373.
- ORCUTT, M.W. and DUTSON, T.R. (1985). Post-mortem degradation of gap filaments at different post-mortem pHs and temperatures. Meat Science 14: 221-241.
- ORESHKIN, E.F., BORISOVA, G.S., TCHUBAROVA, G.S. and GORATOVE, V.M. (1986). Conformational changes in the muscle proteins of cured beef during heating. Meat Science 16: 297-305.
- OSIKOWSKI, M. and BORYS, B. (1976). Effect on production and carcass quality characteristics of wether lambs of crossing black headed mutton, Ile de France and Texel rams with Polish ewes. Livestock Production Science 3: 343-349.

- PADYKULA, H.A. and HERMAN, E. (1955). The specificity of the histochemical method for adenosine triphosphate. Journal of Histochemistry and Cytochemistry 3: 170-195.
- PADYKULA, H.A. and AGUTHIER, G.F. (1963). Cytochemical studies of adenosine triphosphatases in skeletal muscle. Journal of Cell Biology 18: 87-107.
- PADYKULA, H.A. and GAUTHIER, C.F. (1970). The ultrastructure of the neuromuscular junctions of mammalian red, white and intermediate skeletal muscle fibres. Journal of Cell Biology 46: 27-41.
- PALSSON, H. (1939). Meat qualities in the sheep with special reference to Scottish breeds and crosses. Journal of Agricultural Science, Cambridge 29: 544-626.
- PALSSON, H. (1940). Meat quality in the sheep with special reference to Scottish breeds and crosses. III. Comparative development of skelated individuals of different breeds and crosses as lambs and hoggets. Journal of Agricultural Science, Cambridge 30: 1-64.
- PALSSON, H. and VERGES, J.B. (1952a). Effect of plane of nutrition on growth and development of carcass quality in lambs. I. The effects of high and low planes of nutrition at different ages. Journal of Agricultural Science, Cambridge 42: 1-92.
- PALSSON, H. and VERGES, J.B. (1952b). Effect of plane of nutrition on growth and development of carcass quality in lambs. II. Effects of lambs of 30 lb carcass weight. Journal of Agricultural Science, Cambridge 42: 93-149.
- PARRATT, A.C., BURT, C.M., BENNETT, G.L., CLARKE, J.N., KIRTON, A.H. and RAE, A.L. (1987). Heritabilities, genetic and phenotypic correlations for carcass traits and ultrasonic fat depth of sheep. Proceedings of the 6th Conference, Australian Association of Animal Breeding and Genetics, pp. 76-78.
- PARRETT, D.F., ROMANS, J.R., BECHTEL, P.J., WEICHEUTHAL, B.A. and BERGER, L.L. (1985). Beef steers slaughtered at three fat constant end points. I. Growth, efficiency and carcass characteristics. Journal of Animal Science 61: 436-441.
- PARRISH Jr., F.C., YOUNG, R.B., MINER, B.E. and ANDERSEN, L.D. (1973). Effect of postmortem conditions on certain chemical, morphological and organoleptic properties of bovine muscle. Journal of Food Science 38: 690-695.
- PARRISH Jr., F.C. (1974). Relationship of marbling to meat tenderness. Proceedings of the Meat Industry Research Conference, American Meat Science Association, pp. 117-131.

- PAUL, P.C., TORTEN, J. and SPURLOCK, G.M. (1964a). Eating quality of lamb. I. Effect of age. Food Technology 18: 1779-1782.
- PAUL, P.C., TORTEN, J. and SPURLOCK, G.M. (1964b). Eating quality of lamb. II. Effect of preslaughter nutrition. Food Technology 18: 1783-1785.
- PAUL, P.C., McCRAE, S.E. and HOFFERBER, L.M. (1973). Heat-induced changes in extractability of beef muscle collagen. Journal of Food Science 38: 66-68.
- PEARSON, A.M. (1963). Objective and subjective measurements for meat tenderness. Proceedings of Meat Tenderness Symposium. Camden, New Jersey, U.S.A.: Campbell Soup Co., pp. 135-160.
- PEARSON, A.M. (1968). Estimating meat yield and quality in live animals. Proceedings of the Second World Conference on Animal Production, pp. 139-149.
- PEARSON, A.M., WENHAM, L.M., CARSE, W.A., McLEOD, K., DAVEY, C.L. and KIRTON, A.H. (1973). Observations on the contributions of fat and lean to the aroma of cooked beef and lamb. Journal of Animal Science 36: 511-515.
- PEKAS, J.C., YEN, J.T. and POND, W.G. (1983). Gastrointestinal, carcass and performance traits of obese versus lean genotype swine: effect of dietary fiber. Nutrition Reports International 27: 259-270.
- PENFIELD, M.P. and MEYER, B.H. (1975). Changes in tenderness and collagen of beef semitendinosus muscle heated at two rates. Journal of Food Science 40: 150-154.
- PENNY, I.F., VOYLE, C.A. and LAWRIE, R.A. (1963). A comparison of freeze-dried beef muscles of high or low ultimate pH. Journal of the Science of Food and Agriculture 14: 535-543.
- PENNY, I.F. (1974). The action of a muscle proteinase on the myofibrillar proteins of bovine muscle. Journal of the Science of Food and Agriculture 25: 1273-1274.
- PENNY, I.F., VOYLE, C.A. and DRANSFIELD, E. (1974). The tenderizing effect of a muscle proteinase on beef. Journal of the Science of Food and Agriculture 25: 703-708.
- PENNY, I.F. (1976). The effect of conditioning on the myofibrillar proteins of pork muscle. Journal of the Science of Food and Agriculture 27: 1147-1155.
- PENNY, I.F. and DRANSFIELD, E. (1979). Relationship between toughness and troponin T in conditioned beef. Meat Science 3: 135-141.

- PENNY, I.F. and FERGUSON-PRYCE, R. (1979). Measurement of autolysis in beef muscle homogenates. Meat Science 3: 121-134.
- PENNY, I.F. (1980). The enzymology of meat conditioning. In: Lawrie, R.P. (ed.), Development in Meat Science. London, England: Applied Science Publishers, pp. 115-143.
- PERRY, D., THOMPSON, J.M. and BUTTERFIELD, R.M. (1986). Total body fat and fat partitioning in mature rams from four breeds. Proceedings of the Australian Society of Animal Production 16: 426 (Abstract).
- PETAJA, E., KUKKONEN, E. and PUOLANNE, E. (1985). Effect of post-mortem temperature on beef tenderness. Meat Science 12: 145-154.
- PETERSEN, G.V. (1984). Cross-sectional studies of ultimate pH in lambs. New Zealand Veterinary Journal 32: 51-57.
- PFEIFFER, N.E., FIELD, R.A., VARNELL, T.R., KRUGGEL, W.G. and KAISER, I.I. (1972). Effects of postmortem aging and stretching on the macromolecular properties of collagen. Journal of Food Science 37: 897-900.
- PIERSON, C.J. and FOX, J.D. (1976). Effect of postmortem aging time and temperature on pH, tenderness and soluble collagen fractions in bovine longissimus muscle. Journal of Animal Science 43: 1206-1210.
- PILGRIM, J.F. (1957). The components of food acceptance and their measurement. American Journal of Clinical Nutrition 5: 171-175.
- PINKAS, A., VALIN, C., MARINOVA, P., NEDELICHEV, D. and STOYANOV, A. (1981). Study on the type and diameter of muscle fibres in lambs of some breeds and crosses. Proceedings of the 27th European Meeting of Meat Research Workers, Vol. 1, pp. 76-79.
- PINKAS, A., MARINOVA, P., TOMOV, I. and MONIN, G. (1982). Influence of age at slaughter, rearing technique and pre-slaughter treatment on some quality traits of lamb meat. Meat Science 6: 245-255.
- PIRKO, P.C. and AYRESS, J.C. (1957). Pigment changes in packaged beef during storage. Food Technology 11: 461-468.
- POND, W.G., YEN, J.T., LINDVALL, R.N. and HILL, D. (1981). Dietary alfalfa meal for genetically obese and lean growing pigs: effect on body weight gain and on carcass and gastrointestinal tract measurements and blood metabolites. Journal of Animal Science 51: 367-373.

- PRENTIS, P.P., PENNY, R.K. and GOLDSPINK, G. (1984). Possible use of an indicator muscle in future breeding experiments in domestic fowl. British Poultry Science 25: 1-9.
- PRESCOTT, J.H.D. and LAMMING, G.E. (1964). The effects of castration on meat production in cattle, sheep and pigs. Journal of Agricultural Science, Cambridge 63: 341-357.
- PRICE, M.A. (1975). The effects of added dietary lipid on the body composition of rams and wethers. Journal of Agricultural Science, Cambridge 84: 201-208.
- PURCHAS, R.W. (1972). The relative importance of some determinants of beef tenderness. Journal of Food Science 37: 341-345.
- PURCHAS, R.W. and DAVIES, H.L. (1974a). Carcass and meat quality of Friesian steers fed on either pasture or barley. Australian Journal of Agricultural Research 25: 183-192.
- PURCHAS, R.W. and DAVIES, H.L. (1974b). Meat production of Friesian steers. The effect of intramuscular fat on palatability and the effect of growth rates on composition changes. Australian Journal of Agricultural Research 25: 667-677.
- PURCHAS, R.W. and BARTON, R.A. (1976). The tenderness of meat breeds of cattle raised under New Zealand pastoral conditions. New Zealand Journal of Agricultural Research 19: 421-428.
- PURCHAS, R.W. (1977). Measurement of body adipose tissue in animals. In: Fatness in Animals and Man. Proceedings of the Nutrition Society of New Zealand, pp. 38-55.
- PURCHAS, R.W. (1978). Some effects of nutrition and castration on meat production from male Suffolk cross (Border Leicester-Romney cross) lambs. I. Growth and carcass quality. New Zealand Journal of Agricultural Research 21: 367-376.
- PURCHAS, R.W. (1979). A comparison of the fatness of weaned and unweaned lambs. Proceedings of the New Zealand Society of Animal Production 39: 211-216.
- PURCHAS, R.W., O'BRIEN, L.E. and DEN, D. (1979). Some effects of nutrition and castration on meat production from male Suffolk cross (Border Leicester-Romney cross) lambs. New Zealand Journal of Agricultural Research 22: 375-383.
- PURCHAS, R.W. (1981). Genetic of fat. 4 Quarter 2: 7-9.
- PURCHAS, R.W. and BEACH, A.D. (1981). Between operator repeatability of fat depth measurements made on live sheep and lambs with an ultrasonic probe. New Zealand Journal of Experimental Agriculture 9: 213-220.

- PURCHAS, R.W., RAE, A.L., BARTON, R.A. and BEACH, A.D. (1981). The repeatability of ultrasonic fat depth measurements made on sheep up to 18 months of age. Proceedings of the New Zealand Society of Animal Production 41: 133-139.
- PURCHAS, R.W., RAE, A.L. and BARTON, R.A. (1982). Repeatability of weight-corrected ultrasonic fat-depth measurements made on ewes at intervals of one year. New Zealand Journal of Agricultural Research 25: 185-190.
- PURCHAS, R.W. and KEOGH, R.G. (1984). Fatness of lambs grazed on "grasslands maku lotus and grasslands liuia white clover". Proceedings of the New Zealand Society of Animal Production 44: 219-221.
- PURCHAS, R.W. and KADIM, I.T. (1985). The quality of meat from Southdown sheep selected for or against fatness. Proceedings of the 11th Workshop on Overfatness and Lean-Meat Production from Sheep, pp. 36-37.
- PURCHAS, R.W., ROMSOS, D.R., ALLEN, R.E. and MERKEL, R.A. (1985). Muscle growth and satellite cell proliferative activity in obese (OB/OB) mice. Journal of Animal Science 60: 644-651.
- PURCHAS, R.W. (1986). Principles of body growth. In: McCutcheon, S.N., McDonald, M.F. and Wickham, G.A. (eds.), Sheep Production. Vol. 2. Feeding, Growth and Health. pp. 27-56.
- PURCHAS, R.W., JOHNSON, C.B., BIRCH, E.J., WINGER, R.J., HAGYARD, C.J. and KEOGH, R.G. (1986). Flavour Studies with Beef and Lamb. Research Report, Animal Science Department, Massey University, Palmerston North, New Zealand.
- PURSER, A.F. (1980). Cannon bone size and meat production in sheep. Agricultural Research Council, Animal Breeding Research Organization Report, pp. 15-19.
- QUARRIER, E., CARPENTER, Z.L. and SMITH, G.C. (1972). A physical method to increase tenderness in lamb carcasses. Journal of Food Science 37: 130-131.
- RAE, B.R., KROPF, D.H. and TUMA, H.J. (1968). Effect of bovine maturity and marbling on proportion of red and white skeletal muscle fibres. Journal of Animal Science 26: 1146 (Abstract).
- RAHELI'C AND PUA'C, S. (1980). Relation of fibre types in six large muscles of pig. Proceedings of the 26th European Meeting of Meat Research Workers, Vol. 1. Colorado Springs, Colorado, U.S.A., 1980, pp. 14-17.

- RANSOM, K.P. (1981). Heritability of pre-slaughter body weight and some carcass characters in Dorset sheep. Proceedings of Second Conference of Australian Association of Animal Breeding and Genetics, pp. 204-205.
- RASHID, N.H., HENRICKSON, R.L., ASGHAR, A. and CLAYPOOL, P.L. (1983a). Evaluation of certain electrical parameters for stimulating lamb carcasses. Journal of Food Science 48: 10-14.
- RASHID, N.H., HENRICKSON, R.L., ASGHAR, A. and CLAYPOOL, P.L. (1983b). Biochemical and characteristics of ovine muscles as affected by electrical stimulation, hot boning and mode of chilling. Journal of Food Science 48: 136-140.
- RATTRAY, P.V. and DREW, K.R. (1976). Production of heavy weight lambs. Ruakura Farmers Conference, pp. 27-33.
- RAY, E.E., BERRY, B.W. and REYNOLDS, D.A. (1966). Factors affecting the muscle fibre diameter in the ovine. Journal of Animal Science 25: 588-589 (Abstract).
- REAGON, J.O., CARPENTER, Z.L., SMITH, G.C. and DUTSON, T.R. (1975). Age-related traits affecting beef tenderness. Journal of Animal Science 41: 300 (Abstract).
- REDDY, B.G. (1971). Influence of Age and Nutrition on Longissimus Histological and Histochemical Characteristics of Bulls and Steers as Related to Quality. Kansas State University, Kansas, U.S.A. Dissertation Abstracts International. B. (Sciences and Engineering), 1971. 32: 1011B.
- REID, J.T., BENSADOUN, A., BULL, L.S., BURTON, J.H., GLEESON, P.A., HAN, I.K., JOO, Y.D., JOHNSON, D.E., McMANUS, W.R., PALADINES, O.L., STROUD, J.Q., TYRRELL, H.F., Van NIEKERK, B.D.H. and WELLINGTON, G.W. (1968). Some peculiarities in the body composition of animals. In: Reid, J.T. (ed.), Body Composition in Animals and Man. Washington, D.C., U.S.A.: National Academy of Science, pp. 19-44.
- RENERRE, M. and MAZUEL, J.P. (1985). Relationships between instrumental and sensorial measurement methods of meat color. Sciences des Aliments 5: 541-557.
- RENK, B.Z., KAUFFMAN, R.G. and SCHUEFER, D.M. (1985). Effect of temperature and method of cookery on the retention of intramuscular lipid in beef and pork. Journal of Animal Science 61: 876-881.
- RICARD, F.H., LeCLERCQ, B. and TOURAILLE, C. (1983). Selecting broilers for low or high abdominal fat: distribution of carcass fat and quality of meat. British Poultry Science 24: 511-516.

- RICHMOND, R.J., JONES, S.D.M., PRICE, M.A. and BERG, R.T. (1979). Effects of breed and sex on the relative growth and distribution of bone in pigs. Canadian Journal of Animal Science 59: 471-479.
- RILEY, R.R., SAVELL, J.W. and SMITH, G.C. (1980a). Storage characteristics of wholesale and retail cuts from electrically stimulated lamb carcasses. Journal of Food Science 45: 1101-1103.
- RILEY, R.R., SAVELL, J.W., SMITH, G.C. and SHELTON, M. (1980b). Quality, appearance and tenderness of electrically stimulated lamb. Journal of Food Science 45: 119-121.
- RILEY, R.R., SAVELL, J.W., MURPHEY, C.E., SMITH, G.C., STIFFLER, D.M. and CROSS, H.R. (1983a). Effects of electrical stimulation, subcutaneous fat thickness and muscularity traits on palatability of beef from young bull carcasses. Journal of Animal Science 56: 584-591.
- RILEY, R.R., SAVELL, J.W., MURPHEY, G.E., SMITH, G.C., STIFFLER, D.M. and CROSS, H.E. (1983b). Palatability of beef from steer and young bull carcasses as influenced by electrical stimulation, subcutaneous fat thickness and marbling. Journal of Animal Science 56: 592-597.
- ROBELIN, J. (1981). Cellularity of bovine adipose tissue: developmental changes from 15 to 65 percent mature weight. Journal of Lipid Research 22: 452-457.
- ROBELIN, J. (1986). Growth of adipose tissues in cattle; partitioning between depots, chemical composition and cellularity. A review. Livestock Production Science 14: 349-364.
- ROBSON, R.M., O'SHEA, J.M., HARTZER, M.K., RATHUN, W.E., LaSALLE, F., SCHREINER, P.J., KASANG, L.E., STROMER, M.H., LUSBY, M.L., RIDPATH, J.F., PANG, Y.Y., EVANS, R.R., ZEECE, M.G., PARRISH, F.C. Jr. and HUIATT, T.W. (1984). Role of new cytoskeletal elements in maintenance of muscle integrity. Journal of Food Biochemistry 8: 1-24.
- ROGERS, K.L., ETHERTON, T.D. and KRIS-ETHERTON, P.M. (1984). Biophasic diameter distribution of adipocytes from lean and obese rats. Growth 48: 331-338.
- ROMANS, J.R., TUMA, H.J. and TUCKER, W.L. (1965). Influence of carcass maturity and marbling on the physical and chemical characteristics of beef. I. Palatability, fibre diameter and proximate analysis. Journal of Animal Science 24: 681-685.

- ROOK, A.J., ELLIS, M., WHITTEMORE, C.T. and PHILLIPS, P. (1987). Relationships between whole body chemical composition, physical dissected carcass parts and backfat measurement in pigs. Animal Production 44: 263-273.
- ROUSE, G.H., TOPEL, D.G., VETTER, R.L., RUST, R.E. and WICKERSHAM, T.W. (1970). Carcass composition of lamb at different stages of development. Journal of Animal Science 31: 846-855.
- ROWE, R.W.D. (1974). Collagen fiber arrangement in intramuscular connective tissue, changes associated with muscle shortening and their possible relevance to raw meat toughness measurement. Journal of Food Technology 9: 501-509.
- RUDDICK, J.E. and RICHARDS, J.F. (1975). Comparison of sarcomere length measurement of cooked chicken pectoralis muscle by laser diffraction and oil immersion microscopy. Journal of Food Science 40: 500-501.
- RUSSEL, A.J.F. and BARTON, R.A. (1967). Bone-muscle relationships in lamb and mutton carcasses. Journal of Agricultural Science, Cambridge 68: 187-190.
- RUSSEL, A.J.F., GUNN, R.G. and DONEY, J.M. (1968). Components of weight loss in pregnant hill ewes during winter. Animal Production 10: 43-51.
- RUSSEL, A.J.F., DONEY, J.M. and GUNN, R.G. (1971). The distribution of chemical fat in the bodies of Scottish Blackface ewes. Animal Production 13: 503-509.
- SAFFLE, R.L. and BRATZLER, L.J. (1959). The effect of fatness on some processing and palatability characteristics of pork carcasses. Food Technology 13: 236-239.
- SALM, C.P., MILLS, E.W., REEVES, E.S., JUDGE, M.D. and ABERLE, E.D. (1981). Effect of electrical stimulation on muscle characteristics of beef cattle fed a high energy diet for varying lengths of time. Journal of Food Science 46: 1284-1285.
- SAMAHA, F.J., GUTH, L. and ALBERS, R.W. (1970). Phenotypic differences between the actomyosin ATPase of the three fibre types of mammalian skeletal muscle. Experimental Neurology 26: 120-125.
- SANDERSON, M. and VAIL, G.E. (1963). A method for determining press fluid in cooked beef. Journal of Food Science 28: 596-599.
- SANDU, G., DRAGANESCU, C. and GIT, V. (1985). Biological efficiency of traits and selection indices in sire lines of pigs. Animal Breeding Abstract 53: 955.

- SANG, B.C., ANN, B.S., PARK, M.K., PARK, T.J., KANG, M.S., LEE, H.G. and CHEE, S.H. (1986). Estimate of heritabilities and genetic correlation of post-mortem traits in pigs. Animal Breeding Abstract 59: 235.
- SATORIUS, M.J. and CHILD, A.M. (1938). Effect of coagulation on press fluid, shear force, muscle-cell diameter and composition of beef muscle. Food Research 3: 619-626.
- SAVELL, J.W., DUTSON, T.R., SMITH, G.C. and CARPENTER, Z.L. (1978a). Structural changes in electrically stimulated beef muscle. Journal of Food Science 43: 1606-1607 and 1609.
- SAVELL, J.W., SMITH, G.C. and CARPENTER, Z.L. (1978b). Effect of electrical stimulation on quality and palatability of light-weight beef carcasses. Journal of Animal Science 46: 1221-1228.
- SAVELL, J.W., SMITH, G.C. and CARPENTER, Z.L. (1978c). Beef quality and palatability as affected by electrical stimulation and cooler aging. Journal of Food Science 43: 1666-1668 and 1677.
- SAVELL, J.W., McKEITH, F.K. and SMITH, G.C. (1981). Reducing postmortem aging time of beef with electrical stimulation. Journal of Food Science 46: 1777-1781.
- SAVELL, J.W., McKEITH, F.K., MURPHEY, C.E., SMITH, G.C. and CARPENTER, Z.L. (1982). Singular and combined effects of electrical stimulation, postmortem aging and blade tenderisation on the palatability attributes of beef from young bulls. Meat Science 6: 97-109.
- SCHWARTZ, W.N. and BIRD, J.W. (1977). Degradation of myofibrillar proteins by cathepsins B and D. Biochemistry Journal 167: 811-820.
- SCOTT, R.A., CORNELIUS, S.G. and MERSMANN, H.J. (1981). Effects of age on lipogenesis and lipolysis in lean and obese swine. Journal of Animal Science 52: 505-511.
- SEARLE, T.W., GRAHAM, N.McC. and O'CALLAGHAN, M. (1972). Growth in sheep. I. The chemical composition of the body. Journal of Agricultural Science, Cambridge 79: 371-382.
- SEARLE, T.W. and GRAHAM, N. McC. (1975). Studies of weaner sheep during and after a period of weight stasis. II. Body composition. Australian Journal of Agricultural Research 26: 355-361.
- SEARLE, T.W. and GRIFFITHS, D.A. (1976). The body composition of growing sheep during milk feeding, and the effect on composition of weaning at various body weights. Journal of Agricultural Science, Cambridge 86: 483-493.

- SEEBECK, R.M. and TULLOH, N.M. (1966). The representation of yield of dressed carcass. Animal Production 8: 281-288.
- SEEBECK, R.M. (1968). A dissection study of the distribution of tissues in lamb carcasses. Proceedings of the Australian Society of Animal Production 7: 297-302.
- SEIDEMAN, S.C., CROSS, H.R., OLTJEN, R.R. and SCHANBACHER, B.D. (1982). Utilization of the intact male for red meat production. A review. Journal of Animal Science 55: 826-840.
- SEIDEMAN, S.C. and DURLAND, P.R. (1984). The effect of cookery on muscle proteins and palatability. A review. Journal of Food Quality 6: 291-314.
- SEIDEMAN, S.C., CROSS, H.R., SMITH, G.C. and DURLAND, P.R. (1984). Factors associated with fresh meat color. A review. Journal of Food Quality 6: 211-237.
- SEIDEMAN, S.C. (1986). Methods of expressing collagen characteristics and their relationship to meat tenderness and muscle fiber types. Journal of Food Science 51: 273-276.
- SEIDEMAN, S.C. and CROUSE, J.D. (1986). The effects of sex condition, genotype and diet on bovine muscle fiber characteristics. Meat Science 17: 55-72.
- SEIDEMAN, S.C. and THEER, L.K. (1986). Relationships of instrumental textural properties and muscle fiber types of the sensory properties of beef. Journal of Food Quality 9: 251-261.
- SEIDEMAN, S.C., CROUSE, J.D. and CROSS, H.R. (1986). The effect of sex condition and growth implants on bovine muscle fiber characteristics. Meat Science 17: 79-95.
- SEMLEK, M.A. and RILEY, M.L. (1974). The effect of post slaughter aging on tenderness. Journal of Animal Science 38: 1328 (Abstract).
- SENTS, A.E., WHITEMAN, J.V. and WALTERS, L.E. (1981). Carcass characteristics of ram lambs at four slaughter weights. Animal Science Research Report, Oklahoma Agricultural Experiment Station, Oklahoma, U.S.A., pp. 57-60.
- SENTS, A.E., WALTER, L.E. and WHITEMAN, J.V. (1982). Performance and carcass characteristics of ram lambs slaughtered at different weights. Journal of Animal Science 55: 1360-1369.
- SHARMA, J.S. (1983). Genetic and phenotypic analysis of some carcass traits of lambs. Indian Journal of Animal Science 53: 258-260.

- SHARP, G.L., HILL, W.G. and ROBERTSON, A. (1984). Effects of selection on growth, body composition and food intake in mice. I. Responses in selected traits. Genetic Research 43: 75-92.
- SHELBY, C.E., HARVEY, W.R., CLARK, R.T., QUESENBERRY, J.R. and WOODWARD, R.R. (1963). Estimates of phenotypic and genetic parameters in ten years of Miles City R.O.P. steer data. Journal of Animal Science 22: 346-353.
- SHELTON, M. and CARPENTER, Z.L. (1972). Influence of sex, stilbestrol treatment and slaughter weight on performance and carcass traits of slaughter lambs. Journal of Animal Science 34: 203-207.
- SHORTHOSE, W.R., POWELL, V.H. and HARRIS, P.V. (1986). Influence of electrical stimulation, cooling rates and aging on the shear force values of chilled lamb. Journal of Food Science 51: 889-928.
- SIMON, O., BERGNER, H. and MUNCHMEYER, R. (1982). Studies on the range of tissue protein synthesis in pigs: the effect of thyroid hormones. British Journal of Nutrition 48: 571-586.
- SINK, J.D. and SMITH, P.W. (1972). Changes in the lipid soluble carbonyls of beef muscle during aging. Journal of Food Science 37: 181-182.
- SINK, J.D. (1973). Lipid-soluble components of meat flavor/odors and their biochemical origin. American Oil Chemists Society Journal 50: 470-474.
- SINK, J.D. and CAPORASO, F. (1977). Lamb and mutton flavor: contributing factors and chemical aspects. Meat Science 1: 119-127.
- SINNETT-SMITH, P.A., DUMELOW, N.W. and BUTTERY, P.J. (1983). Protein turnover in sheep treated with trenbolone acetate and zeranol. Proceedings of the Nutrition Society 42: 58A.
- SIVACHELVAN, M.N. and DAVIES, A.S. (1981). Antenatal anticipation of postnatal muscle function. Journal of Anatomy 132: 545-555.
- SIVACHELVAN, M.N. and DAVIES, A.S. (1986). Growth changes in the myofibres and connective tissue of ovine muscle before and after birth. Anatomia, Histologia, Embryologia 15: 49-57.
- SJOSTROM, L., BJORNTORP, P. and VRANA, J. (1971). Microscopic fat cell size measurements on frozen-cut adipose tissue in comparison with automatic determinations of osmium-fixed fat cells. Journal of Lipid Research 12: 521-530.

- SLEPER, P.S., HUNT, M.C., KROPF, D.H., KASTNER, C.L. and DIKEMAN, M.E. (1983). Electrical stimulation effects on myoglobin properties of bovine longissimus muscle. Journal of Food Science 48: 479-483.
- SMITH, C., KING, J.W.B. and GILBERT, N. (1962). Genetic parameters of British Large White bacon pigs. Animal Production 4: 128-143.
- SMITH, C. and ROSS, G.J.S. (1965). Genetic parameters of British Landrace bacon pigs. Animal Production 7: 291-301.
- SMITH, G.C. and CARPENTER, Z.L. (1970). Lamb carcass quality. III. Chemical, physical and histological measurements. Journal of Animal Science 31: 697-706.
- SMITH, G.C., CARPENTER, Z.L., KING, G.T. and HOKE, K.E. (1970a). Lamb carcass quality. I. Palatability of leg roasts. Journal of Animal Science 30: 496-502.
- SMITH, G.C., CARPENTER, Z.L., KING, G.T. and HOKE, K.E. (1970b). Lamb carcass quality. II. Palatability of rib, loin and sirloin chops. Journal of Animal Science 31: 310-317.
- SMITH, G.C., ARANGO, T.C. and CARPENTER, Z.L. (1971). Effects of physical and mechanical treatments on the tenderness of the beef longissimus. Journal of Food Science 36: 445-449.
- SMITH, G.C. and CARPENTER, Z.L. (1973). Postmortem shrinkage of lamb carcasses. Journal of Animal Science 36: 862-867.
- SMITH, G.C., PIKE, M.I., CARPENTER, Z.L., SHELTON, M. and BOWLING, R.A. (1974). Quality indicators and palatability attributes of goat carcasses. Journal of Animal Science 39: 175 (Abstract).
- SMITH, G.C. and CARPENTER, Z.L. (1976). Eating quality of meat animal products and their fat content. In: Fat Content and Composition of Animal Products. Symposium on changing the National Academy of Science, pp. 147-182.
- SMITH, G.C., DUTSON, T.R., HOSTETLER, R.L. and CARPENTER, Z.L. (1976). Fatness, rate of chilling and tenderness of lamb. Journal of Food Science 41: 748-756.
- SMITH, G.C., SAVELL, J.W., DUTSON, T.R., HOSTETLER, R.L., TERRELL, R.N., MURPHEY, C.E. and CARPENTER, Z.L. (1980). Effects of electrical stimulation on beef, pork, lamb and goat meat. Proceedings of the 26th European Meeting of Meat Research Workers, Vol. 2, p. H-5.

- SMITH, G.C., CARPENTER, Z.L., CROSS, H.R., MURPHEY, C.E., ABRAHAM, H.C., SAVELL, J.W., DAVIS, G.W., BERRY, B.W. and PARRISH Jr., F.C. (1984). Relationship of USDA marbling groups to palatability of cooked beef. Journal of Food Quality 7: 289-308.
- SMITH, J.H. (1963). Relation of body size to muscle cell size and number in the chicken. Poultry Science 42: 283-290.
- SMITH, K.J., LEATHERWOOD, J.M. and EISEN, E.J. (1983). Effects of preweaning and postweaning feed restriction on the development of polygenic obese mice. Growth 47: 35-52.
- SMITH-PILLING, S.H. and BARTON, R.A. (1954). Overfat ewe mutton is a serious problem. New Zealand Journal of Agriculture 88: 98-102.
- SNEDECOR, G.W. and COCHRAN, W.G. (1980). Statistical Methods. 7th ed. Ames, Iowa, U.S.A.: The Iowa State University Press.
- SNYDER, H.E. and AYRES, J.C. (1961). The autoxidation of crystallized beef myoglobin. Journal of Food Science 26: 469-474.
- SNYDER, H.E. (1964). Measurement of discoloration in fresh beef. Journal of Food Science 29: 535-539.
- SOLOMON, L.W. and SCHMIDT, G.R. (1980). Effect of vacuum and mixing time on the extractability and functionality of pre- and post-rigor beef. Journal of Food Science 45: 283-287.
- SOLOMON, M.B., KEMP, J.D., MOODY, W.G., ELY, D.G. and FOX, J.D. (1980). Effect of breed and slaughter weight on physical, chemical and organoleptic properties of lamb carcasses. Journal of Animal Science 51: 1102-1107.
- SOLOMON, M.B., MOODY, W.G., KEMP, J.D. and ELY, D.G. (1981). Effect of breed, slaughter weight and sex on histological properties of ovine muscle. Journal of Animal Science 52: 1019-1025.
- SOLOMON, M.B. (1986). Response of bovine muscle to restraint and electrical stimulation. Journal of Animal Science 62: 147-154.
- SOLOMON, M.B., LYNCH, G.P. and BERRY, B.W. (1986). Influence of animal diet and carcass electrical stimulation on the quality of meat from youthful ram lambs. Journal of Animal Science 62: 139-146.
- SORINMADE, S.O., CROSS, H.R. and ONO, K. (1978). The effect of electrical stimulation on lysosomal enzyme activity, pH decline and beef tenderness. Proceedings of the 24th Meeting of the European Meat Research Workers, E9: 1.

- SOUTHAM, E.R. and FIELD, R.A. (1969). Influence of carcass weight upon composition and consumer preference for lamb. Journal of Animal Science 28: 584-588.
- SPINDLER, A.A., MATHIAS, M.M. and CRAMER, D.A. (1980). Growth changes in bovine muscle fibre types as influenced by breed and sex. Journal of Food Science 45: 29-31.
- STANDAL, N., VOLD, E., TRYGSTAD, O. and FOSS, I. (1973). Lipid mobilisation in pigs selected for leanness or fatness. Animal Production 16: 37-42.
- STANDAL, N. (1979). Selection for low backfat and high growth rate and vice versa for 9 generations: effect on quantity and quality of lean meat. In: Muscle Function and Porcine Meat Quality. A Symposium of N.J.F. Acta Agriculturae Scandinavica, Supplementum 21: 117-121.
- STAUN, H. (1963). Various factors affecting number and size of muscle fibres in the pig. Acta Agriculturae Scandinavica 13: 293-322.
- STAUN, H. (1968). Diameter and number of muscle fibres and their relation to meatiness and meat quality in Danish Landrace pigs. In: Beretning Fra Forsogslaboratoriet-Uagivet af Statens Husdyrbrugsudvalg, Trykti Frederiksberg Bogtrykkeri, pp. 102-121.
- STEEL, R.G.D. and TORRIE, J.H. (1981). Principles and Procedures of Statistics. New York, U.S.A.: McGraw-Hill Book Company, Inc., p. 481.
- STEELE, N.C., FROBISH, L.T. and KEENEY, M. (1974). Lipogenesis and cellularity of adipose tissue from genetically lean and obese swine. Journal of Animal Science 39: 712-719.
- STEIN, J.M. and PADYKULA, H.A. (1962). Histochemical classification of individual skeletal muscle fibres of the rat. American Journal of Anatomy 110: 103-115.
- STEINE, T. (1982). Factors affecting genetic progress in sheep improvement programmes. 2nd World Congress on Genetics Applied to Livestock Production, Madrid, Spain, pp. 665-675.
- STICKLAND, N.C., WIDDOWSON, E.M. and GOLDSPINK, G. (1975). Effects of severe energy and protein deficiencies on the fibres and nuclei in skeletal muscle of pigs. British Journal of Nutrition 34: 421-428.
- STRANGE, E.D., BENEDICT, R.C., GUGGER, R.E., METZGER, V.G. and SWIFT, C.E. (1974). Simplified methodology for measuring meat color. Journal of Food Science 39: 988-992.

- STRINGER, W.C., HEDRICK, H.B., CRAMER, C.L., EPLEY, R.J., DYER, A.J., KRAUSE, G.F. and WHITE, R.H. (1968). Effect of full-feeding for various periods and sire influence on quantitative and qualitative beef carcass characteristics. Journal of Animal Science 27: 1547-1558.
- STROMER, M.H. and GOLL, D.E. (1967). Molecular properties of post-mortem muscle. II. Phase microscopy of myofibrils from bovine muscle. Journal of Food Science 32: 329-331.
- SUNDSTOL, F., STANDAL, N. and VANGEN, O. (1979). Energy metabolism in lines of pigs selected for thickness of backfat and rate of gain. Acta Agriculturae Scandinavica 29: 337-345.
- SUZUKI, A. (1971a). Histochemical classification in individual skeletal muscle fibres in the sheep. I. On M. semitendinosus, M. longissimus dorsi, M. latissimus dorsi and M. gastrocnemius. Japanese Journal of Zootechnical Science 42: 39-54.
- SUZUKI, A. (1971b). Histochemical classification in individual skeletal muscle fibres in the sheep. II. On M. serratus ventralis, M. supraspinatus, M. semimembranosus and M. triceps brachii. Japanese Journal of Zootechnical Science 42: 463-473.
- SUZUKI, A. (1972). Histochemical classification in individual skeletal muscle fibres in the sheep. III. On the M. masseter. Japanese Journal of Zootechnical Science 43: 161-166.
- SUZUKI, A. and TAMATE, H. (1974). Histochemical classification of skeletal muscle fibres in the cattle. Acta Histochemistry Cytochemistry 7: 319-327.
- SUZUKI, A., OHWADA, S. and TAMATE, H. (1978). The presence of intrafibre fat droplets in muscle fibre types and the distribution and size of these fibre types in four muscles of Japanese black and Holstein cattle. Japanese Journal of Zootechnical Science 49: 262-269.
- SUZUKI, A., SAWAKI, T., HOSAKA, M., IKARASHI, Y. and NONAMI, Y. (1985). Postmortem changes of connectin in chicken skeletal muscle. Meat Science 15: 77-83.
- SWATLAND, H.J. (1976). Recent research on postnatal muscle development in swine. Proceedings of the 29th Annual Reciprocal Meat Conference, pp. 86-104.
- SWATLAND, H.J. (1982). The challenges of improving meat quality. Canadian Journal of Animal Science 62: 15-24.
- SWATLAND, H.J. (1984). Structure and Development of Meat Animals. Englewood Cliffs, New Jersey, U.S.A.: Prentice-Hall, Inc.

- SWIFT, C.E. and BERMAN, M.D. (1959). Factors affecting the water retention of beef. I. Variations in composition and properties among eight muscles. Food Technology 13: 365-370.
- SZCZESNIAK, A.S. and TORGESON, K.W. (1965). Methods of meat texture measurement viewed from the background of factors affecting tenderness. Advance in Food Research 14: 33-165.
- SZCZESNIAK, A.S. (1968). Correlations between objective and sensory texture measurements. Food Technology 22: 49-54.
- SZOCS, E., NAGY, A. and CSIBA, A. (1982). Effect of genotype and age on quality of beef. Proceedings of the 28th European Meeting of Meat Research Workers, pp. 393-396.
- TAKAHASHI, G. and SAITO, H. (1979). Post-mortem changes in skeletal muscle connection. Journal of Biochemistry 85: 1539-1542.
- TAKAHASHI, G., LOCHNER, J.V. and MARSH, B.B. (1984). Effects of low-frequency electrical stimulation on beef tenderness. Meat Science 11: 207-225.
- TAKAHASHI, G., WANG, S.M., LOCHNER, J.V. and MARSH, B.B. (1987). Effects of 2-Hz and 60-Hz electrical stimulation on the microstructure of beef. Meat Science 19: 65-76.
- TANNOR, B., CLARK, N.G. and HANKINS, O.G. (1943). Mechanical determination of the juiciness of meat. Journal of Agricultural Research 66: 403-412.
- TATUM, J.D., SMITH, G.C., BERRY, B.W., MURPHY, C.E., WILLIAMS, F.L. and CARPENTER, Z.L. (1980). Carcass characteristics, time on feed and cooked beef palatability attributes. Journal of Animal Science 50: 833-840.
- TATUM, J.D., SMITH, G.C. and CARPENTER, Z.L. (1982). Interrelationships between marbling, subcutaneous fat thickness and cooked beef palatability. Journal of Animal Science 54: 777-784.
- TAUBER, F.W. and SIMON, S. (1963). Changes in the color of meat under various processing conditions. Food Technology 17: 105-107.
- TAYLOR, D.G. and CORNELL, J.G. (1985). The effects of electrical stimulation and aging on beef tenderness. Meat Science 12: 243-251.
- TAYLOR, St C.S., MASON, M.A. and McCLELLAND, T.H. (1980). Breed and sex differences in muscle distribution in equally mature sheep. Animal Production 30: 125-133.

- TEMPEST, W.M. and BOAZ, T.G. (1977). The influence of the Tasmanian Fine-woolled Merino on carcass characteristics of lambs. Livestock Production Science 4: 191-202.
- TESS, M.W., DICKERSON, G.E., NIENABER, J.A. and FERRELL, C.L. (1984a). The effects of body composition on fasting heat production in pigs. Journal of Animal Science 58: 99-110.
- TESS, M.W., DICKERSON, G.E., NIENABER, J.A., YEN, J.T. and FERRELL, C.L. (1984b). Energy costs of protein and fat deposition in pigs fed ad libitum. Journal of Animal Science 58: 111-122.
- TESS, M.W., DICKERSON, G.E., NIENABER, J.A. and FERRELL, C.L. (1986). Growth development and body composition in three genetic stocks of swine. Journal of Animal Science 62: 968-979.
- THERIEZ, M., VILETTE, Y. and CASTRILLO, C. (1982). Influence of metabolizable energy content of the diet and of feeding level on lamb performances. I. Growth and body composition. Livestock Production Science 9: 471-485.
- THOMPSON, J.M., PATTIE, W.A. and BUTTERFIELD, R.M. (1977). An evaluation of the "scanogram" as an ultrasonic aid in assessing carcass composition of five sheep. Australian Journal of Experiment Agriculture and Animal Husbandry 17: 251-255.
- THOMPSON, J.M., ATKINS, K.D. and GILMOUR, A.R. (1979a). Carcass characteristics of heavyweight crossbred lambs. II. Carcass composition and partitioning of fat. Australian Journal of Agricultural Research 30: 1207-1214.
- THOMPSON, J.M., ATKINS, K.D. and GILMOUR, A.R. (1979b). Carcass characteristics of heavyweight crossbred lambs. III. Distribution of subcutaneous fat, intermuscular fat, muscle and bone in the carcass. Australian Journal of Agricultural Research 30: 1215-1221.
- THOMPSON, J.M. and ATKINS, K.D. (1980). Use of carcass measurements to predict percentage carcass composition in crossbred lambs. Australian Journal of Experimental Agriculture and Animal Husbandry 20: 144-150.
- THOMPSON, J.M. (1982). Genetic manipulation of fatness in lamb carcass. Proceedings of the Australian Society of Animal Production 14: 54-60.
- THOMPSON, J.M. and BUTTERFIELD, R.M. (1987). Changes in body composition relative to weight and maturity of Australian Dorset Horn rams and wethers. IV. Adipocyte volume and number in dissected fat partitions. Animal Production (submitted).

- THOMPSON, J.M., BUTTERFIELD, R.M. and PERRY, D. (1987a). Food intake, growth and body composition in Australian Merino sheep selected for high and low weaning weight. Animal Production 45: 49-60.
- THOMPSON, J.M., BUTTERFIELD, R.M. and REDDACLIFF, K.J. (1987b). Food intake, growth and body composition in flocks of Australian Merino sheep selected for high and low weaning weight. V. Adipocyte volume and number in the dissected fat partitions. Animal Production (submitted).
- THORNTON, R.F., HOOD, R.L., JONES, P.N. and RE, V.M. (1979). Compensatory growth in sheep. Australian Journal of Agricultural Research 30: 135-151.
- THORNTON, R.F., HOOD, R.L., ROWE, R.W.D. and JONES, P.N. (1983). The cellular and metabolic organization of ovine subcutaneous adipose tissue. Australian Journal of Agricultural Research 34: 447-452.
- THORNTON, R.F., TUME, R.K., LARSEN, T.W. and JOHNSON, G.W. (1984). The cellularity of ovine adipose tissue. Proceedings of the Australian Society of Animal Production 15: 758.
- THORSTEINSSON, S.S. and BJORNSSON, H. (1982). Genetic studies on carcass traits in Iceland twin ram lambs. I. Estimates of genetic parameters on carcass traits, live weight at weaning and carcass weight. Livestock Production Science 8: 489-505.
- TICHENOR, D.A., MOODY, W.G. and KEMP, J.D. (1969). Fibre and fat cell diameters in two ovine muscles. Journal of Animal Science 29: 128 (Abstract).
- TIMON, V.M. and BICHARD, M. (1965). Quantitative estimates of lamb carcass composition. I. Sample joints. Animal Production 7: 173-182.
- TIMOSON, B.F. and DUDENHOEFFER, G.A. (1985). The effect of severe dietary protein restriction on skeletal muscle fibre number, area and composition in weanling rats. Journal of Animal Science 61: 416-422.
- TOPEL, D.G., RUST, R.E., WILSON, D.G. and CHRISTIAN, L.L. (1975). Comparison of a lean and fat line of swine for muscle processing characteristics. Journal of Animal Science 40: 598-603.
- TRAYHURN, P., JAMES, W.P.T. and GURR, M.I. (1979). Studies on the body composition, fat distribution and fat cell size and number of 'Ad', a new obese mutant mouse. British Journal of Nutrition 41: 211-221.

- TRUSCOTT, T.G., WOOD, J.D. and MacFIE, H.J.H. (1983a). Fat deposition in Hereford and Friesian steers. I. Body composition and partitioning of fat between depots. Journal of Agricultural Science, Cambridge 100: 257-270.
- TRUSCOTT, T.G., WOOD, J.D. and DENNY, H.R. (1983b). Fat deposition in Hereford and Friesian steers. II. Cellular development of the major fat depots. Journal of Agricultural Science, Cambridge 100: 271-276.
- TRUSCOTT, T.G., HUDSON, J.E. and ANDERSON, S.K. (1984). Differences between observers in assessment of meat colour. Proceedings of the Australian Society of Animal Production 15: 762.
- TSAI, T.C. and OCKERMAN, H.W. (1981). Water binding measurement of meat. Journal of Food Science 46: 697-707.
- TULLOH, N.M. (1964). The carcass compositions of sheep, cattle and pigs as functions of body weight. In: Tribe, D.E. (ed.), Carcass Composition and Appraisal of Meat Animals. Technical Conference, University of Melbourne, 1963. Melbourne, Victoria, Australia: East Melbourne CSIRO, pp. 5.1-5.16.
- TUMA, H.J., VENABLE, J.H., WUTHIER, P.R. and HENRICKSON, R.L. (1962a). Relationship of fibre diameter to tenderness and meatness as influenced by bovine age. Journal of Animal Science 21: 33-36.
- TUMA, H.J., HENRICKSON, R.L., STEPHENS, D.F. and MOORE, R. (1962b). Influence of marbling and animal age on factors associated with beef quality. Journal of Animal Science 21: 848-851.
- TUMA, H.J., COVINGTON, R.C., GRANT, D.L. and KROPF, D.H. (1967). Effect of bovine marbling and maturity on chemical and histological traits and tenderness. Journal of Animal Science 26: 1471 (Abstract).
- TUME, P.K. (1979). Post-mortem electrical stimulation of muscle and its effect on sarcoplasmic reticulum adenosine triphosphatase. Australian Journal of Biological Sciences 32: 163-176.
- TUME, P.K. (1980). Effect of post-mortem electrical stimulation on ovine sarcoplasmic reticulum residues. Australian Journal of Biological Sciences 33: 43-52.
- URBAIN, W.M. (1952). Oxygen is key to the color of meat. Provisioner 127: 140-141. (Cited by Seideman et al., 1984).
- VALIN, C., TOURILLE, C., OUAL, A. and LACOURT, A. (1981). Effects of electrical stimulation on aging and eating quality of beef. Sciences des Aliments 1: 467-476.

- VAN DEN OORD, A.H.A. and WESDORP, J.J. (1971). Analysis of pigments in intact beef samples. A simple method for the determination of oxymyoglobin and ferric myoglobin in intact beef samples using reflectance spectrophotometry. Journal of Food Science 6: 1-13.
- VEZINHET, A. and PRUD'HON, M. (1975). Evolution of various adipose deposits in growing rabbits and sheep. Animal Production 20: 363-370.
- VIGNERON, P., NOUQUES, J., BACOU, F., VALIN, C. and ASHMORE, C.R. (1984). An attempt to correlate early muscle characteristics with carcass traits at slaughter in lambs. Livestock Production Science 11: 195-205.
- VOYLE, C.A. (1969). Some observations on the histology of cold shortened muscle. Journal of Food Technology 4: 275-281.
- VOS, M.P.M. and SYBESMA, W. (1971). Relation between meat quantity and meat quality of market pigs. Proceedings of the 2nd International Symposium, Condition Meat Quality in Pigs, Zeist, 1971, Pudoc, Wageningen, pp. 278-281.
- WALTER, C.L. (1975). Meat colour: the importance of haem chemistry. In: Cole, D.J.A. and Lawrie, R.A. (eds.), Meat. London, England: Butterworths, pp. 385-401.
- WALTER, M.J., GOLL, D.E., KLINE, E.A., ANDERSON, L.P. and CARLIN, A.F. (1965). Effect of marbling and maturity on beef muscle characteristics. I. Objective measurements of tenderness and chemical properties. Food Technology 19: 841-845.
- WASSERMAN, A.E. and GRAY, N. (1965). Meat flavor. I. Fractionation of water-soluble flavor precursors of beef. Journal of Food Science 30: 801-807.
- WASSERMAN, A.E. and TALLEY, F. (1968). Organoleptic identification of roasted beef, veal, lamb and pork as affected by fat. Journal of Food Science 33: 219-223.
- WEBB, N.B., KAHLENBERG, O.J., NAUMANN, H.D. and HEDRICK, H.B. (1967). Biochemical factors affecting beef tenderness. Journal of Food Science 32: 1-7.
- WEIR, C.E. (1960). Palatability characteristics of meat. In: The Science of Meat and Meat Products. San Francisco, California, U.S.A.: W.H. Freeman and Company.
- WEISS, G.M., TOPEL, D.G., EWAN, R.C., RUST, R.E. and CHRISTIAN, L.L. (1971a). Growth comparison of a muscular and fat strain of swine. I. Relationship between muscle quality and quantity, plasma lactate and 17-hydroxycorticosteroids. Journal of Animal Science 32: 1119-1123.

- WEISS, G.M., TOPEL, D.G. and EWAN, R.C. (1971b). Growth comparison of a muscular and fat strain of swine. II. Protein solubility characteristics and M. longissimus and serum electrolyte. Journal of Animal Science 32: 1124-1127.
- WELLINGTON, G.H. (1968). Marbling in intensively produced Holstein steers. Journal of Animal Science 27: 1149 (Abstract).
- WENHAM, L.M., FAIRBAIRN, S.J., McLEOD, K., CARSE, W.A., PEARSON, A.M. and LOCKER, R.H. (1973). Eating quality of mutton compared with lamb and its relationship to freezing practice. Journal of Animal Science 36: 1081-1087.
- WEST, R.L. (1974). Red to white fibre ratios as index of double muscling in beef cattle. Journal of Animal Science 38: 1165-1175.
- WHITE, N.A., McGAVIN, M.D. and SMITH, J.E. (1978). Age-related changes in percentage of fibre types and mean fibre diameters of the ovine quadriceps muscle. American Journal Veterinary Research 39: 1297-1302.
- WHITING, R.C. (1980). Calcium uptake by bovine muscle mitochondria and sarcoplasmic reticulum. Journal of Food Science 45: 288-292.
- WIERBICKI, E. and DEATHERAGE, F.E. (1958). Determination of water-holding capacity of fresh meat. Journal of Agriculture and Food Chemistry 6: 387-392.
- WILL, P.A., HENRICKSON, R.L., MORRISON, R.D. and ODELL, G.V. (1979). Effect of electrical stimulation on ATP depletion and sarcomere length in delay-chilled bovine muscles. Journal of Food Science 44: 1646-1648.
- WILLIAM, C.F. and SOLBERG, M. (1971). Quantitative determination of metmyoglobin and total pigment in an intact meat sample using reflectance spectrophotometry. Journal of Food Science 36: 515-519.
- WILLIAMS, J.R. and HARRISON, D.L. (1978). Relationship of hydroxyproline solubilized to tenderness of bovine muscle. Journal of Food Science 43: 464-467 and 492.
- WILSON, B.R., PEARSON, A.M. and SHORLAND, F.B. (1976a). Effect of total lipids and phospholipids on warmed-over flavor in red and white muscles from several species as measured by thio-barbituric acid analysis. Journal of Agriculture and Food Chemistry 24: 7-11.
- WILSON, L.L., VARELA-ALVAREZ, H., RUGH, M.C. and BORGER, M.L. (1972). Growth and carcass characters of rams, cryptorchids, wethers and ewes subcutaneously implanted with Zeranol. Journal of Animal Science 34: 336-338.

- WILSON, L.L. (1975). Changes in carcass. Proceedings of the Meat Industry Research Conference, American Meat Science Association, pp. 9-17.
- WILSON, L.L., McCURLEY, J.R., ZIEGLER, J.H. and WATKINS, J.L. (1976b). Genetic parameters of live and carcass characters from progeny of Polled Hereford sires and Angus-Holstein cows. Journal of Animal Science 43: 569-576.
- WINGER, R.J., FENNEMA, O. and MARSH, B.B. (1979). Rate of pH decline in beef muscle stored at above- and below-freezing temperatures. Journal of Food Science 44: 1681-1685.
- WOLF, B.T., SMITH, C., KING, J.W.B. and NICHOLSON, D. (1981). Genetic parameters of growth and carcass composition in crossbred lambs. Animal Production 32: 1-7.
- WOLF, B.T. (1982). An analysis of the variation in the lean tissue distribution of sheep. Animal Production 34: 257-264.
- WOLF, B.T. and SMITH, C. (1983). Selection for carcass quality. In: Haresign, W. (ed.), Sheep Production. University of Nottingham. London, England: Butterworths, pp. 493-514.
- WONG, E., NIXON, L.N. and JOHNSON, C.B. (1975a). Volatile medium chain fatty acids and mutton flavour. Journal of Agriculture and Food Chemistry 23: 495-498.
- WONG, E., JOHNSON, C.B. and NIXON, L.N. (1975b). The contribution of 4-methyloctanoic (chircinoic) acid to mutton and goat meat flavour. New Zealand Journal of Agricultural Research 18: 261-266.
- WOOD, D.F. and FROEHLICH, D.A. (1983). The effect of electrical stimulation on sensory and physical properties of steaks from three grades of Canadian beef commercial handling. Canadian Institute of Food Science and Technology Journal 16: 52-56.
- WOOD, J.D., ENSER, M.B. and RESTALL, D.J. (1975). Fat cell size in Pietrain and Large White pigs. Journal of Agricultural Science, Cambridge 84: 221-225.
- WOOD, J.D., MacFIE, H.J.H., POMEROY, R.W. and TWINN, D.J. (1980). Carcass composition in four sheep breeds: the importance of type of breed and stage of maturity. Animal Production 30: 135-152.
- WOOD, J.D., MacFIE, H.J.H. and BROWN, A.J. (1983a). Effect of body weight, breed and sex on killing-out percentage and non-carcass component weights in lambs. Meat Science 9: 89-99.

- WOOD, J.D., WHELEHAN, O.P., ELLIS, M., SMITH, W.C. and LAIRD, R. (1983b). Effects of selection for low backfat thickness in pigs, sites of tissue deposition in the body. Animal Production 36: 389-397.
- WOOD, J.D., JONES, R.C.D., FRANCOMBE, M.A. and WHELEHAN, O.P. (1986). The effects of fat thickness and sex on pig meat quality with special references to the problems associated with over leanness. II. Laboratory and trained taste panel results. Animal Production 43: 535-544.
- WOODHAMS, P.R., KIRTON, A.H. and JURY, K.E. (1966). Palatability characteristics of crossbred lambs as related to individual Southdown sires, slaughter age and carcass fatness. New Zealand Journal of Agricultural Research 9: 268-275.
- WU, F.Y., DUTSON, T.R., VALIN, C., CROSS, H.R. and SMITH, S.B. (1985). Aging index, lysosomal enzyme activities and meat tenderness in muscle from electrically stimulated bull and steer carcasses. Journal of Food Science 50: 1025-1028.
- YAMAMOTO, K., SAMEJIMA, K. and YASUI, T. (1977). A comparative study of the changes in hen pectoral muscle during storage at 4°C and -20°C. Journal of Food Science 42: 1642-1645.
- YAMAMOTO, K., SAMEJIMA, K. and YASUI, T. (1979). Changes produced in muscle proteins during incubation of muscle homogenates. Journal of Food Science 44: 51-55.
- YASUI, T., ISHIOBOROSHI, M. and SAMEJIMA, K. (1980). Heat-induced gelatin of myosin in the presence of actin. Journal of Food Biochemistry 4: 61-78.
- YATES, L.D., DUTSON, T.R., CALDWELL, J. and CARPENTER, Z.L. (1983). Effect of temperature and pH on the post-mortem degradation of myofibrillar proteins. Meat Science 9: 157-179.
- YEATES, N.T.M. (1964). Starvation changes and subsequent recovery of adult beef muscle. Journal of Agricultural Science, Cambridge 62: 267-272.
- YEN, J.J., TESS, M.W., POND, W.G. and DICKERSON, G.E. (1983). Digestibility and metabolism of dietary nitrogen and energy in contemporary, genetically lean and obese pigs as estimated by total fecal collection and acid insoluble ash. Journal of Animal Science 56: 426-430.
- YOUNG, L.D., PUMFREY, R.A., CUNNINGHAM, P.J. and ZIMMERMAN, D.R. (1978). Heritabilities and genetic and phenotypic correlations for prebreeding traits, reproductive traits and principal components. Journal of Animal Science 46: 937-949.

- YOUNG, O.A. (1984). The biochemical basis of fibre types in bovine muscle. Meat Science 11: 123-137.
- YOUNG, O.A. and BASS, J.J. (1984). Effect of castration on bovine muscle composition. Meat Science 11: 139-156.
- YU, L.P. and LEE, Y.B. (1986). Effects of postmortem pH and temperature on bovine muscle structure and meat tenderness. Journal of Food Science 51: 774-780.
- ZEECE, M.G., ROBSON, R.M., LUSBY, M.L. and PARRISH Jr., F.C. (1986). Effect of calcium activated protease (CAF) on bovine myofibrils under different conditions of pH and temperature. Journal of Food Science 51: 797-803.
- ZINN, D.W., DURHAM, R.M. and HEDRICK, H.B. (1970). Feedlot and carcass grade characteristics of steers and heifers as influenced by days on feed. Journal of Animal Science 31: 302-306.