SELECTION FOR BEEF CATTLE CARCASS AND MEAT QUALITY TRAITS

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This thesis is dedicated to my Mum,

Mirja Anita Charteris

who never thought her son could make a career of being a bull expert

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ABSTRACT

Carcasses in the Japanese beef market are rewarded for increased yield and superior meat quality traits such as marbling, fat colour, meat colour and firmness and texture of meat. Due to the relatively high cost of feedlotting New Zealand compared with North America and Australia, genetic improvement may provide a low-cost alternative for improving beef quality destined for the Japanese market. The objectives of this study were to characterise meat quality traits for a sample of New Zealand pasture-finished beef cattle and determine the potential rate of genetic gain for these traits through selection.

Records on 24 146 Angus and 5 632 Hereford carcasses processed at Manawatu Beef Packers between March 1993 and August 1994 which had been evaluated for beef marbling standard (BMS), beef fat standard (BFS) and beef colour standard (BCS) were used to derive overall meat quality score. Overall meat quality score in the Japanese grading system is determined by the lowest grade from: semi-objective assessment for BMS, BFS and BCS; and subjective assessment for meat brightness, firmness and texture, fat lustre and quality. Subjective measures of meat and fat quality are not routinely recorded at this plant and therefore overall meat quality score could only account for the three recorded items. The majority of Angus and Hereford carcasses (84.0 and 82.9%) had an overall meat quality score of 1 (inferior) and no carcasses had score 5 (excellent).

Improvement of one grade in BMS (or BFS) for Angus carcasses decreased the proportion of score 1 carcasses to 12.8% (or 74.7%) and improved overall meat quality score from an average of 1.17 to 1.96 (or 1.29). A change of one grade in BMS (or BFS) for Hereford carcasses decreased the proportion of score 1 carcasses to 16.1% (or 66.8%) and changed overall meat quality score from an average of 1.18 to 1.90 (or 1.35).

Selection based on a well-designed progeny test would take 5 (or 9) years to improve BMS (or BFS) by one grade. Biological factors introduce a lag of at least six years from

the start of test matings until there can be widespread harvest of beef cattle with improved meat quality. Selection for BMS can improve overall meat quality score more effectively and more rapidly than selection for other meat quality traits.

Some Angus sires used in New Zealand are sourced from North America where sire expected progeny differences (EPD) for carcass traits are based on performance of feedlot finished progeny. Sires may rank differently based on progeny records from feedlot-finished cattle (North America) and pasture-finished progeny performance in New Zealand. The objective of this study was to determine importance of genotype by environment interaction effects when sires from a New Zealand Angus progeny test programme were evaluated based on pasture-finished and feedlot-finished progeny records.

Fourteen Angus sires were evaluated for live weight, carcass and meat quality traits based on records from pasture and feedlot finished steer progeny. Estimated breeding values (EBV's) of sires were obtained using a Best Linear Unbiased Prediction (BLUP) procedure. Correlations between sire EBV's estimated from pasture and feedlot-finished progeny records ranged from -0.16 (for meat colour) to 0.50 (for subcutaneous fat depth). There were no significant ($P<0.05$) sire by environment interaction effects, which may have due to differences in site and method of measurement of traits and different slaughter facilities. Rank correlations between sire EBV's ranged from -0.13 (for fat colour) to 0.49 (for subcutaneous fat depth). Small negative rank correlations between sire EBV's were obtained for five of the eight traits analysed indicating sires tended to rank differently based on pasture or feedlot finished progeny records.

Keywords: Angus, Hereford, selection, marbling, fat colour, meat colour, progeny test, feedlot, pasture, genotype by environment interaction

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Profitability of beef cattle farms in New Zealand can be improved through increased production, improved product quality and cost minimisation. This can be achieved through management such as timing of farming operations, efficient pasture utilisation, improved animal health and by means of genetic improvement (Garrick, 1994). Genetic improvement can be achieved through selection for one or a combination of traits and/or through crossbreeding. Traits improved through selection or crossbreeding may include live weight, growth, fertility and carcass characteristics.

Breeding bulls purchased by commercial beef cattle farmers usually arise from registered beef cattle breeding herds. Selection goals within registered beef cattle breeding herds impact on genetic change in commercial beef cattle herds. In recent years, selection within registered herds in New Zealand has focussed on improvement of growth and live weight traits. These selection goals are supply driven, that is, they increase quantity of beef produced per animal. Consumer purchase decisions for beef products are based on characteristics including taste, juiciness, tenderness, value for money and convenience of preparation (Morgan *et al.,* 1991; Fenwick, 1994). In this respect, selection goals within registered beef cattle herds in New Zealand are poorly aligned with consumer requirements.

Selection goals aimed at increasing consumer demand for beef products should include some measure of meat quality. Within registered herds, selection goals have given little regard to improving meat quality traits or attempted to quantify the relative importance of different meat quality traits for export markets such as Japan. Meat quality traits are expressed post-slaughter, therefore it is impractical to select animals breeding purposes on the basis of these measurements. Measures on the live animal such using ultrasonography or progeny testing sires or identification of major genes influencing carcass and meat quality may assist selection of superior breeding cattle for these traits.

Genetic evaluation of beef cattle within many registered beef cattle herds in New Zealand is undertaken using Breedplan (Nicol *et al.,* 1985) or Group Breedplan (Graser *et al.,* 1987). Estimated breeding values (EBV) are calculated using a Best Linear Unbiased Prediction (BLUP) multiple trait animal model. Traits included in the Breedplan / Group Breedplan genetic evaluation have been predominantly weight or weight gain related. Few New Zealand beef cattle breeders have obtained within-herd Breedplan EBV's for carcass traits (Ousley and Paterson *pers comm.,* 1995). Progeny test programmes have been initiated by various beef cattle breed societies to evaluate sires for a range of growth and carcass characteristics. To date, the efficacy of selecting superior New Zealand bred sires using progeny testing has been minimal.

Some Angus sires used in New Zealand are sourced from North America where sire expected progeny differences (EPD) for carcass traits are based on performance of feedlot finished progeny. Sires may rank differently based on progeny records from feedlot-finished cattle (in North America) and pasture-finished progeny performance in New Zealand. The environment under which sires or their progeny are evaluated will be important if there is a low correlation between sire EBV's for growth and carcass traits estimated from feedlot-finished progeny performance and EBV's estimated from pasture-finished progeny performance.

The New Zealand beef carcass grading and classification scheme is currently under review. A favourable result of the review process would see beef cattle farmers rewarded for high lean meat content of carcasses or for meat quality traits such as marbling, fat colour and meat colour which are important considerations in the Japanese beef market. Financial motivation would be provided to supply cattle with superior carcass quality characteristics, thus registered breeders may attract premium prices for bulls with superior carcass merit. Selection strategies for carcass and meat quality characteristics within registered herds would be encouraged. Little regard has been given to potential increases in farm profit and beef industry benefit from selection for carcass and meat quality traits.

In regard to the above questions, this thesis has the following objectives:

1. To determine the relative importance of some meat quality traits according to Japanese beef market requirements.

2. To determine genotype by environment interaction effects when sires are evaluated for carcass and meat quality traits based on feedlot-finished and pasture-finished progeny records.

CHAPTER 2

REVIEW OF LITERATURE

2.0 Beef cattle farming in New Zealand

Beef cattle farming in New Zealand involves breeding cows managed on pasture all year round and progeny that are usually finished for slaughter on pasture. In contrast, many overseas countries, due to climate or available grain supplies house beef cattle indoors or finish cattle in feedlots on grain-based diets prior to slaughter. New Zealand farmers have through experience learned to integrate their animal and pasture resources (Nicol and Nicoll, 1987), often beef cattle are managed with other livestock species, notably sheep (McCall, 1994) and more recently deer. Timing of beef cattle farming operations such as date of calving and slaughter or sale of progeny are influenced by pasture supply and quality which are determined by pasture management and climatic factors.

2.1 Beef export trade

New Zealand produces approximately 560 000 tonnes of beef per year, less than one percent of world production (New Zealand Meat Producers Board, 1993a). New Zealand's beef industry is export oriented, domestic consumption accounts for 88 000 tonnes annually (16%) of total production. Exports comprise 6.5% of world beef exports, making New Zealand the fourth largest beef exporting nation. For the year ended June 1994, New Zealand's total beef exports were worth NZ $1.4 billion, total meat export earnings were NZ $3.7 billion in that same year. Total pastoral agricultural export earnings in the year ended June 1994 were NZ $8.3 billion, exports receipts for the agricultural sector being NZ $9.5 billion, or approximately 50% of total export earnings (New Zealand Meat and Wool Boards Economic Service, 1994).

Cattle destined for the North American manufacturing grade market are distributed between Friesian bulls, cull beef and dairy cows and cuts of beef from steers and heifers unsuitable for prime markets. Friesian bulls arising from the dairy industry produce a suitable carcass with high pH, high water holding capacity and 90-95% chemical lean content (Morris *et al.,* 1991). In contrast, beef destined for Asian markets is from predominantly Angus and Hereford breeds and their crosses. Exports of New Zealand beef by volume and value to five major export markets are shown in table 2.1.

Table 2.1 Shipments by volume and value to the five major beef export markets for New Zealand beef (Nicol 1994).

	Tonnes shipped	% total volume	Value ($m, FOB)	% total value	Value $/kg, FOB
US	214 140	69.3	931.5	64.9	4.35
Canada	31 370	10.2	123.0	8.6	3.92
South Korea	17 050	5.5	32.5	2.3	1.90
Japan	12 200	4.0	82.4	5.7	6.75
Taiwan	8 765	2.8	63.0	4.4	7.17

The United States is the most important beef market in terms of volume and total value of beef exports. Price received per kilogram of beef exported is lower in the US and Canadian markets than for Japanese and Taiwanese markets, since beef exported to the North American market is predominantly manufacturing grade whilst predominantly most beef exported to Asia is destined for prime (table) beef markets. Beef is exported to the South Korean market in carcass form, hence the low price per kilogram.

2.2 Beef cattle production

Total beef cattle numbers in 1993 were 4.48 million. The New Zealand beef cattle industry can conveniently be divided into two sectors (Nicol and Nicoll, 1987);

1. Beef breeding cow herds with their output of weaned calves for eventual slaughter or replacement.
2. Growing and finishing cattle for slaughter. Cattle included in the finishing sector may arise from either beef breeding cow herds or from dairy herds. Cattle originating from dairy herds contribute approximately 40% of the annual adult cattle kill in New Zealand (Morris *et al.,* 1991), or 53% of beef produced (Webby and Thomson, 1994).

2.2.1 *The beef breeding cow*

In 1993, the national beef breeding cow herd numbered 1.45 million, comprising 32% of the national beef cattle herd (Webby and Thomson, 1994). Efficient beef breeding cow herds give the maximum weight of calf weaned per unit land required to feed them (McMillan and McCall, 1991). This can be achieved through attaining both a high calving percentage and high calf weaning weight. Beef breeding cows are complementary to the performance of other stock classes (Nicol and Nicoll, 1987). Seasonal feed demand profile of beef breeding cows, their ability to utilise surplus low quality feed and buffer against periods of low feeding (Pleasants *et al.,* 1994a) and act as a source of income stabilisation by farmers is highly regarded (Webby and Thomson, 1994).

2.2.2 *Beef cattle finishing*

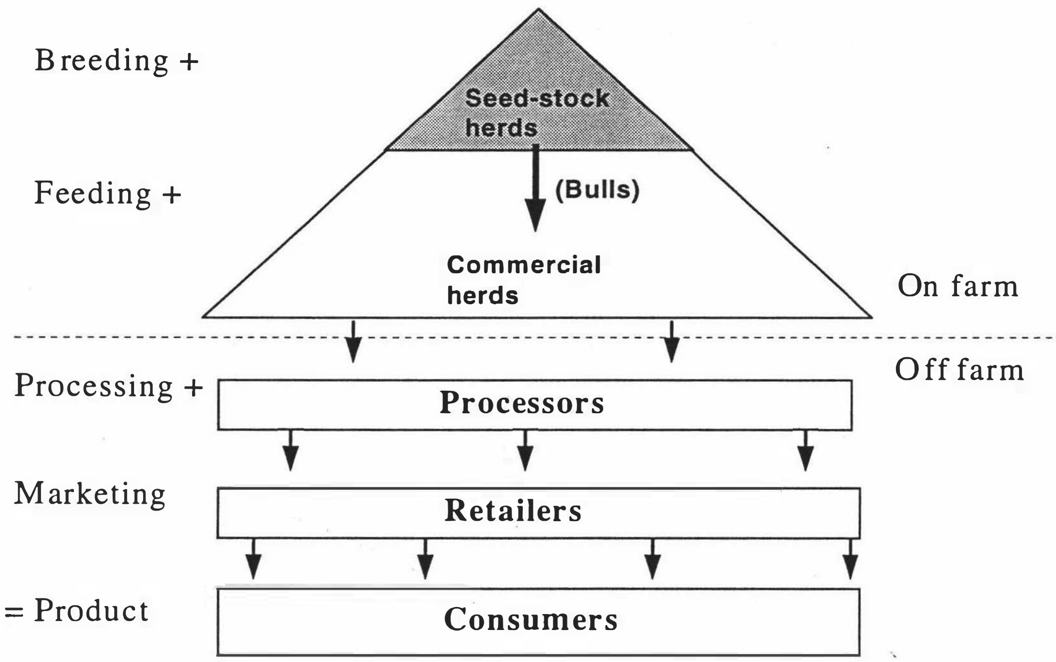
In New Zealand, the majority of beef steers are retained for a second winter and are probably 27-34 months of age at slaughter (Parker, 1994). Between 1984 and 1993 average North Island steer and heifer carcass weights have ranged from 275 to 295 kg. (Parker, 1994). In New Zealand, steers are rarely grown to maximum growth potential on pasture (Parker, 1994), since maximum animal performance does not equate with maximum financial returns, in addition, pattern of animal demand may not match with pasture supply or quality and target steer performance may not be clearly defined. Determinants of biological efficiency of finishing beef cattle on pasture were identified as pasture utilisation and feed conversion efficiency (McCall and Marshall, 1991). Few New Zealand beef cattle are feedlot finished, in 1993 approximately 10 000 cattle were finished on a feedlot-finished (New Zealand Meat Producers Board, 1993b).

2.3 Structure of the New Zealand beef industry

The New Zealand beef industry is tiered with inputs to the development of the beef product envisaged as beginning in registered herds, culminating in form of the beef product finally consumed (figure 2.1) (Harris *et al.,* 1984; Newman and Ponzoni, 1994).

Sectors above the dotted line occur on farm, and off-farm (below). Retailers and consumers are sectors in the beef industry which market and consume the beef product respectively and send pricing signals to other participants in the beef industry.

Figure 2.1 Simplified beef industry structure



2.3.1 *Registered herds*

At the top of the beef industry hierarchical structure are registered (or seedstock) breeding herds. Registered breeders identify and select genetically superior cattle. Registered herds can be termed nucleus and multiplier herds (Garrick, 1993; Harris and Newman, 1994). Multiplier herds transfer genetic improvement initiated in the nucleus herds by providing sufficient numbers of bulls to service the commercial beef industry. Registered breeders sell breeding cattle (usually bulls) to commercial beef cattle farmers. Therefore farmers in the commercial beef sector import genetic change from registered breeders (Blair and Garrick, 1994). Registered breeders should develop selection objectives enabling them to supply bulls which satisfy the requirements of commercial beef cattle farms (Ponzoni and Newman, 1989).

Approximately 70 000 registered breeding cows occur in the registered sector of the beef cattle industry (Blair and Garrick, 1994), comprising 4.8% of total beef breeding cows. Hereford and Angus account for 20 000 and 26 000 of these registered breeding cows respectively (Paterson and Ousley *pers comm.,* 1994). Cattle in registered herds are separated from commercial beef cattle herds through provision of a registration barrier thereby preventing cattle from commercial beef cattle herds entering registered herds. Registered herds may exist offshore, Garrick (1993) suggested that due to semen imported from the United States and Canada, some registered herds in the New Zealand Angus breeding industry are effectively located in North America.

2.3.2 *Commercial beef cattle herds*

The commercial beef cattle farming sector is that in which the majority of New Zealand's approximately 1.45 million beef breeding cows are managed. Cattle from both the registered and commercial sector are slaughtered at processing facilities. Due to larger numbers, cattle from the commercial sector contribute substantially more to the number of cattle slaughtered than do cattle from the registered sector. Cattle in the registered sector are purebred (through requirements for registration), in contrast, cattle on commercial beef farms may be either purebred or crossbred.

2.3.3 *Processing and retail sector*

Within the processing sector of the beef industry, cattle are slaughtered, and carcasses are then processed into a specified number of cuts based on market requirements. For meeting South Korean market requirements, carcasses are processed into four quarters (Korean quarter-beef) and are exported in this form. Farmers are paid per carcass based on objective and subjective measurement criteria determined by beef carcass grading and classification. Processors market the beef product to retailers, therefore the processor must supply a product of a consistent quality relative to price to remain competitive (Anderson, 1994). Beef retailers prepare and market the beef product for sale to the final consumer. The retailer (supermarket, butcher, restaurant, convenience food outlet) may either be in New Zealand (the domestic market), or overseas.

2.3.4 *Beef consumer*

Consumers purchase a beef product based on appearance, quality and price criteria (Morgan *et al.,* 1991; Fenwick, 1994). Criteria upon which purchase decisions are made may include perceived tenderness, juiciness and taste in addition to convenience of preparation and value for money. Desirability of beef product varies according to end use. In Japan, beef is displayed in thin slices in supermarket shelves which can lead to discolouration, blood dripping, meat drying and poor consumer acceptance (Chadee and Mori, 1993). High marbling (intramuscular fat content) beef is said to provide protection from drying out during display (Chadee and Mori, 1993) thereby enhancing consumer acceptance. Consumer driven, consistent quality products appear to be the requirement of modern beef industries (Kemp, 1994).

2.3.5 *Carcass grading and classification*

Pricing signals from retailers and consumers are transmitted to the farming sectors through prices received for cattle as determined by beef carcass grading and classification. In this respect, carcass grading and classification should be aligned to requirements of the marketplace (Barton, 1982). Carcass grading and classification criteria include age, sex, carcass weight, subcutaneous fat depth, and conformation (New Zealand Meat Producers Board, 1992). Current payment emphasis primarily on carcass weight was considered too imprecise an indicator of lean meat yield for the producer or for the breeder (Nicoll and Morris, 1993). Future changes to beef carcass grading and classification system need to include financial reward for cattle with superior meat quality traits and more direct payment for increased lean meat yield.

2.3.6 *Product and information flow*

Within the beef cattle industry, there is a physical transfer of beef product (or genes) down through the industry, in the form of live cattle (above the dotted line in figure 2.1) and processed beef product (below). Analogous to a transfer of physical beef product (and genes) down through the industry, there should be information feedback from the consumer and retailer through the processing sector to commercial beef cattle farmers and registered breeders. When characteristics can be readily identified, superior animals should receive a price premium and these price premiums should transfer back through the industry to where genetic improvement was initiated (Woodward *et al.,* 1992; Amer, 1994; Kemp, 1994). Flow of information from the consumer to registered breeders is often slow and unclear due to the large number of intermediary participants in the beef industry (Carrick, 1987; Pleasants *et al.,* 1994b; Woodward, 1994). It was considered that brand marketing beef products (such as Certified Angus Beef, in the United States) would provide incentive for improved information feedback through different sectors of the beef industry (Amer, 1994).

Beef of a specific quality is the end product of the industry (Tier and Graser, 1994). Beef quality specifications of importance to a particular sector of the beef industry may not be of importance to other sectors. Retailers in the United States beef industry consider excessive subcutaneous fatness as their primary concern for beef products, in contrast, processors identify hide problems as their primary concern (Ritchie, 1994). Relative importance of different beef quality criteria probably increase the further removed participants are in the beef industry, perhaps largest differences exist between showring criteria (within the registered sector) and requirements of the beef consumer. Differing quality concerns between participants in the industry contribute to unclear signals for genetic improvement within registered herds (Bendall and Bendall, 1993; Pirchner, 1993).

2.4 Beef cattle carcass traits

Beef cattle carcass traits can be categorised as weight, yield and meat quality related. These characteristics are of primary importance to beef cattle farmers, processors and consumers respectively. Carcass yield characteristics refer to the yield of saleable meat product (meat plus specified amounts of fat) produced per carcass or per unit carcass weight. The term meat quality has different definitions between countries and processors, it can be defined in terms of consumer requirements or more objectively such as chemical lean content (Dikeman, 1994). A definition of meat quality may include four major areas; visual quality, eating quality, nutritional quality and safety (Dikeman 1986, Kemp 1994). Green (1991) described the ideal carcass as yielding a maximum percentage of retail muscle, a minimum percentage of bone and enough fat to meet the minimum market requirements.

2.4.1 *Carcass weight*

With current beef cattle grading and classification (New Zealand Meat Producers Board, 1992), carcass weight is the strongest determinant of price received per carcass and is therefore of importance to the beef cattle farmer. Carcass weight used for payment purposes in New Zealand is the actual (hot) carcass weight, measured immediately post-slaughter. In the New Zealand beef carcass grading and classification system, within each fat and muscling class there are up to nine carcass weight ranges. There is a step-wise price increment (per kg carcass weight) as carcasses move into a higher weight range, thus carcasses of similar weight may be priced differently. Inconsistent price signals between carcass weight ranges create difficulties for farmers establishing target carcass weights.

2.4.2 *Carcass yield*

Yield traits provide an estimate of weight or percentage of saleable beef product per carcass processed. Yield traits are important to meat processors since an increase in lean meat yield will result in an increase in weight of saleable meat product per carcass processed. A commonly used measure of yield is dressing percentage (carcass weight/live weight x 100). Since increased dressing percentage can be affected by an increase in carcass fat or bone content, it is not a good predictor of value of the carcass. Dressing percentage indiscriminately rewards the deposition of lean or fat on the carcass (Brink, 1992), and may encourage producers to overfeed cattle resulting in excess fat.
Carcass muscularity is defined as the thickness of muscle relative to skeletal dimensions and conformation is a visual assessment of the thickness of fat and muscle in relation to skeletal measures (Abdullah *et al.,* 1993). Carcass conformation in a beef grading and classification system is an indirect indicator of carcass meat yield. The New Zealand

beef carcass grading and classification system has three conformation classes (1,2,3) based on visual assessment of the degree of convexity of the hind quarter when the carcass is hanging (New Zealand Meat Producers Board, 1992). Payment per carcass is determined by conformation rather than yield of lean meat. A more accurate prediction of lean meat yield may be obtained through equations incorporating fat depth and eye muscle area taken at the 11/12th rib intersection in addition to carcass weight (Shackelford, 1995).

Subcutaneous fat depth is measured as the depth of subcutaneous fat over the fourth quarter of the eye muscle at the 12th rib (New Zealand Meat Producers Board, 1992). In practice, company graders use subcutaneous fat depth in addition to visual assessment of fat content of the whole carcass as a guide when determining fat class of a carcass. Measurement of the degree of fat cover for carcass grading and selection purposes is important since:

- Yield of lean meat decreases as fat content increases (Woods *et al.,* 1986)
- Consumer trends are away from high fat content meats due to health concerns (Savell *et al.,* 1989).
- Fat is a waste product when it is trimmed from meat prior to cooking. Consumers believe they are not receiving value for money when a large portion of the beef product is wasted due to trimming.
- Inefficiencies arise from producing excess fat. Actual cost of waste fat to the United States beef industry was estimated at US $4.4 billion dollars in 1991, $2.0 billion to produce and another $2.4 billion to transport and trim (Woodward, 1994).
- Due to its insulating properties, increased subcutaneous fat depth may prevent the effects of cold-shortening post-slaughter thereby decreasing meat toughness (Dikeman, 1986).

2.4.3 *Meat quality traits*

Meat quality traits are of importance to consumers since they affect purchase (and repurchase) decisions and satisfaction of consumption. Consumers perceive that yellow fat may be associated with older animals or animals that are diseased (Forrest, 1981; Kirton, 1989). The chemical constituent of pasture known to cause yellowing of fat colour have been identified as carotenoid pigments, the primary pigment causing yellowing of fat colour being β-carotene (Forrest, 1981). Cattle finished on grain consume less carotene and so produce a non-pigmented white fat. Similarly, meat colour is an important visual trait affecting consumer purchase of a beef product which can be improved through feedlot finishing (Schroeder *et al.,* 1980). Beef that is not a bright, attractive red colour can be perceived by consumers as not fresh, prone to spoilage or from an older animal and therefore less tender (Dikeman, 1986).

Marbling is a term used to describe intramuscular fat content. An increase in marbling is generally associated with enhanced cooking and palatability attributes (Dikeman, 1986). Koohmaraie *et al.* (1994) noted that although there is a positive association between marbling and beef tenderness, juiciness and flavour, the association is weak. Similarly, Cundiff *et al.* (1986) found that high levels of marbling required to grade USDA choice were not justified in terms of eating quality (juiciness, tenderness) of beef. In the important beef export market of Japan, the method of cooking (broiling) requires that beef has a high marbling content to avoid rapid cooking and the production of offensive odours (Chadee and Mori, 1993).

Consumers consider tenderness to be the most important aspect of meat eating quality (Dikeman, 1986; Koohmaraie *et al.,* 1994; Purchas, 1994). The United States beef industry task force identified increasing consistency and quality of beef product as important to improving market share, with a reduction in consumer satisfaction (primarily related to toughness) by 50% required by 1997 (Woodward, 1994). Koohmaraie *et al.* (1994) found that marbling and connective tissue content accounted for only 20% of observed variation in tenderness, the remainder being influenced by processes occurring postmortem, including chilling, ageing and cooking procedures.

Other meat quality traits include flavour and juiciness. Flavour of meat is highly influenced by environmental factors such as nutritional regime, age at slaughter and post-slaughter management (Dikeman, 1986). Less desirable flavour of beef from pasture finished as opposed to feedlot-finished cattle has been attributed to lower fat content, or different fatty acid composition of beef from the former group of animals (Melton *et al.,* 1982). Assessment of juiciness and flavour rely on cooking meat for a specified period in a precise manner and subsequent sensory evaluation by a trained taste panel.

2.5 Beef cattle breeding programmes

The structure of beef cattle breeding programmes provides an indication of how selection occurs within registered herds. The general structure of beef cattle breeding programmes can be described as follows (Harris *et al.,* 1984):

1. Definition of the selection objective. This is a description of traits which impact on income and expenditure in commercial herds and a measure of their relative economic value.
2. Choosing appropriate selection criteria to select superior cattle.
3. Organising a genetic evaluation, allowing genetically superior cattle to be identified.
4. Using recorded information to make selection decisions. Cattle should be selected based on genetic merit for economically important traits, ideally selection decisions should be consistent with the selection objective.
5. Mating selected individuals to be parents of the next generation.

2.5.1 *Establishment of selection objectives*

The definition of the selection objective is an important first step in the development of an organised breeding programme. One of the dangers of not establishing a selection objective is that the implementation of an effective genetic evaluation system could result in the selection of traits in an undesirable direction or in a sub-optimal manner (Ponzoni, 1989). The selection objective can be defined as the weighted combination of economically important traits of beef cattle in the production system (Ponzoni and Newman, 1989; Newman *et al.,* 1992). The selection objective should increase the profitability of both the registered breeder and commercial beef cattle farmer and provide benefit to the consumer.

2.5.2 *Industry participants defining the selection objective*

An increase in production or decrease in costs in commercial beef herds may not result in improved product quality which reaches the consumer. The establishment of selection objectives should involve input from registered breeders, commercial farmers, consumers, retailers, processors and scientists, although this seldom occurs in practice (Blair and Garrick, 1994). One of the major difficulties in the development of a comprehensive selection objective is that each of the participants in the beef industry will have different objectives, some of which may conflict. Upton *et al.* (1988) suggested that different selection objectives may be appropriate for each sector of the beef industry.

Ponzoni (1989) suggested that selection objectives should be designed to maximise benefit to the entire industry. In practice, genetic improvement decisions are limited to registered breeders through defining their selection objectives and commercial beef cattle farmers which make selection and culling decisions (Amer 1994). If individual breeders establish their own selection objectives they have more resolve to follow them (Upton *et al.,* 1988; Barwick, 1993). Newman and Ponzoni (1994) suggest that breeders feel more comfortable defining a selection objective using target phenotypic gains for certain traits than via explicitly derived relative economic values.

The establishment of the selection objective consists of four stages (Ponzoni and Newman, 1989):

1. Definition of the breeding, production and marketing system for commercial beef farms which helps identify source, frequency and timing of major areas of income and expenses for the commercial beef cattle farm.

2. Identification of sources of income and expenditure for commercial beef cattle farms, accounting for inputs such as food, husbandry and marketing costs as well as outputs such as income from sale of surplus offspring and cull cows.
3. Determination of traits influencing income and expenditure. For most beef cattle herds this may include fertility, growth rate, feed intake, carcass and meat quality traits.
4. Derivation of the economic value for traits in the selection objective. If adopting a multiple trait selection objective, genetic progress is maximised by weighting each trait by its appropriate relative economic value. Relative economic values can be affected by input/output price fluctuations and the time horizon over which genetic change in the trait is likely to occur in the population (Amer, 1994).

Although selection objectives have been derived for beef cattle breeding in New Zealand with relative economic values for economically important traits (Newman *et al.,* 1992), there has been little evidence of implementation of these selection objectives in the beef cattle breeding industry (Blair and Garrick, 1994). However, it was suggested (Ponzoni and Newman, 1989) that establishment of selection objectives can provide a reliable guide to identification of economically important traits to include in selection objectives and provide indicators for further areas of research. Few researchers have attempted to incorporate meat quality traits with appropriate relative economic values into selection objectives (Kemp, 1994). Blair and Garrick (1993) noted that farmer "satisfaction" with the animals in their herd may require the inclusion of non-production traits into a selection objective.

2.6 Implementing selection objectives for beef cattle breeding

2.6.1 *Selection objectives for beef cattle breeding in New Zealand*

Up until the 1960's selection objectives for registered beef cattle breeders were dominated by phenotypic measures of conformation and appearance which did not necessarily correlate with economically important traits. In addition selection decisions were often based on pedigree information (Nicoll and Morris, 1993). The selection objectives of an open-registered Angus breeding scheme (Nicoll and Johnson, 1986) included adjusted weaning weight, adjusted yearling weight, net dam fertility and maternal weaning weight. Benefits from selection of approximately $1 per cow per year were predicted from a selection objective including carcass weight for each class of cattle slaughtered and number of calves weaned per cow mated (Morris, 1980). Baker and Morris (1981) outlined selection strategies for breeders of terminal sire and for maternal breeds of cattle. Traits included in the selection objective of Newman *et al.* (1992) were number of calves weaned, steer, heifer and cow carcass weights and steer, heifer and cow feed intake.

Carcass weight was thus the only carcass trait included in the recent study of Newman *et al.,* (1992), probably due to the current beef carcass grading and classification system rewarding farmers primarily for increased carcass weight with little regard to meat quality. Blair and Garrick (1994) suggested that greater account of fat distribution and fat colour may be important for establishing selection goals aimed at meeting Asian beef market requirements. There remains further scope for defining selection objectives for breeds with different production roles in New Zealand such as terminal sire breeds and maternal breeds (Nicoll and Morris, 1993).

2.6.2 *Overseas selection objectives for beef cattle breeding*

Some beef cattle producing nations include measures of meat quality in their beef carcass grading and classification criteria (such as marbling in the United States beef carcass grading system), therefore selection objectives of some registered breeders are established to select for meat quality traits. Selection objectives derived for beef cattle breeders in Australia included carcass weight as the only carcass trait in that objective (Ponzoni and Newman 1989). Carcass weight was defined for steers, heifers and cows. Carcass traits included in BREED-OBJECT (a computer software programme allowing relative economic values to be customised for each breeder) were dressing percentage, saleable meat percentage and fat depth (Barwick, 1993; Barwick *et al.,* 1994).

Relative economic values for trait complexes were calculated for reproduction (R), growth (G) and carcass traits (C) (Barwick *et al.,* 1994) for a beef production system in Australia where pasture finished cattle are slaughtered at 15 months of age at a live weight of 420 kg. Differences in the relative economic importance of these trait complexes were R:G:C = 5.9:2:1. The low relative economic importance of carcass compared with reproduction and growth traits may explain why few selection objectives have included carcass and meat quality traits.

In the United States, few beef cattle breed societies are providing expected progeny differences (EPD) for meat quality traits. Wilson (1992) noted that genetic evaluations for carcass traits have been conducted on a small scale across herds by the beef cattle industry in the United States. In addition, Dikeman (1994) suggested that due to low numbers of cattle evaluated within only a few breed societies and long generation interval of cattle, genetic progress for meat quality traits from a beef industry viewpoint will be slow. During the last twenty years in the United States beef industry, average carcass weight has increased with no change in subcutaneous fat depth and a decrease in marbling score (Lorenzen *et al.,* 1993). The authors suggested that long-term carcass trends may indicate selection goals and management decisions aimed at improving quality and consistency of beef.

The United States Angus Association has sponsored a carcass evaluation programme since 1974 (Wilson *et al.,* 1993). Carcass data gathered from this program is used to publish a biannual sire evaluation for carcass merit. However few sires have been evaluated, currently only 1.1% of North American Angus sires (788 of 68 841, 395 with published EPD) have any sort of carcass information (Green *et al.,* 1994). This sire evaluation is available to New Zealand Angus breeders and has formed the basis of some selection decisions for sires purchased from North America (Williamson *pers comm.,* 1993). At least one Angus herd in the United States (Summitcrest) actively promotes breeding bulls on the basis of carcass EPD's, (Bergfeld 1994).

Inclusion of fat depth into a selection objective for feedlot production systems was questioned (Amer *et al.,* 1994). Fat depth is an important criterion for improvement since it represents a waste product, however relative economic values applied to fatness will be dependant on market requirements and can be controlled largely by management regime, especially the age and weight at slaughter.

A large scale progeny test in Australia for beef carcass quality traits desirable for the Japanese beef market was described by Baud (1991). Sire breeds included were Angus, Hereford, Polled Hereford and Murray Grey represented by progeny from 93 sires. Results indicated that only five of the sires represented excelled for growth rate, muscling and marbling. Minimal commercial differences occurred between sires for meat and fat colour. The requirement for marbling amongst Japanese consumers has encouraged establishment of Canadian progeny test programmes designed to identify sires which are superior for marbling (Wilton, 1986). In Britain, the Meat and Livestock Commission (MLC) has a selection index to maximise the financial margin between the value of saleable meat and cost of feed taking account of calving difficulties (Simm and Steane 1988). Carcass traits included in the selection objective are muscle score and subcutaneous fat depth measured ultrasonically.

2.7 Genetic improvement

Performance recording of beef cattle in New Zealand began in the 1960's under the auspices of the Sheep and Beef cattle survey, and later developed into Beefplan in 1973 (Callow, 1993). Beefplan provided Best Linear Predictions (BLP) of genetic merit for individual animals (Garrick *pers comm.,* 1995) and was objective-based since it allowed individual breeders to specify the relative importance of traits being evaluated. Current genetic evaluation of beef cattle within many registered beef cattle herds in New Zealand is undertaken using Breedplan (developed in Australia), (Nicol *et al.,* 1985) or Group Breedplan (Graser *et al.,* 1987). Estimated breeding values (EBV) are calculated using a Best Linear Unbiased Prediction (BLUP) multiple trait animal model (Tier and Graser, 1994).

Genetic evaluations provide a means to achieve selection goals as well as merchandising cattle on a quantifiable basis (Pollak 1988). On an industry basis, most breeds have been applying selection emphasis on weaning, 400-day and 600-day weights (Nicoll and Morris, 1993). For example, using 1993 Angus Group Breedplan adjusted phenotypic means, the estimated rates of genetic improvement for birth weight, 200-day growth and 400-day weight and 600-day weight from 1982 to 1992 represented 0.82, 0.75, 0.82 and 0.67% of the mean. Genetic improvement rates in the Hereford breed are similar (Nicoll and Morris, 1993). Similar live weight and growth focussed selection objectives to the New Zealand beef cattle breeding industry have been reported for Australia (Upton *et al.,* 1988), Britain (Simm and Steane, 1988), the United States (Hazel *et al.,* 1994; Kemp, 1994) and Canada (Amer *et al.,* 1992).

As consequence of positive genetic correlations between growth and live weight traits and mature size, selection for growth rate would result in an increase in mature cow size Koch *et al.,* 1982). Increased mature cow results in increased beef breeding cow maintenance requirements and decreased potential farm stocking rate. Thus, benefits from selection for live weight and growth traits are partially negated by increased feed requirements. Failure to include feed costs in the selection objective will lead to overestimation of economic benefit from selection for growth and live weight traits (Ponzoni, 1989; Ponzoni and Newman, 1989). Due to negative genetic correlations with some meat quality traits, continued selection for growth traits in beef cattle breeding programmes may result in negative consumer acceptance of beef products at some time in the future (Lundstrom, 1986).

Limited numbers of Angus and Hereford registered herds in New Zealand have obtained Breedplan EBV's for eye muscle area (EMA), subcutaneous fat depth and subsequently estimated lean meat yield (kg and %) (Ousley and Paterson *pers comm* 1995). Lack of Breedplan accredited ultrasound technicians in New Zealand (presently only one) has prevented widescale adoption of ultrasound measurements which would enable incorporation of carcass EBV's in Group Breedplan genetic evaluations.

Progeny test programmes have been initiated by New Zealand Angus (Angus Carcass Evaluation and Progeny Test, ACEPT), Blonde d' Aquitane, Hereford, Salers and Charolais breed societies to evaluate bulls for a range of growth and carcass characteristics. Despite breed society promotional effort, efficacy of selecting superior New Zealand bred sires from progeny testing has been minimal. Reduced efficacy of progeny tests have resulted from too few sires evaluated, poor accuracy of sire evaluation, discontinuation of the progeny test following one evaluation or unavailability of sires following evaluation. Opportunity exists for greater coordination of progeny tests within and between breed societies.

Genetic gain within registered herds is transferred to commercial beef cattle herds through sale of breeding bulls. The rate of transfer of genetic gain from registered to commercial beef cattle herds is termed genetic lag. Garrick (1993), noted that for typical beef cattle herds with a generation interval of 5 years, the genetic lag will be ten years indicating that the genetic merit of cattle in the commercial sector of the beef industry will be of similar genetic merit to cattle in the registered sector ten years previously.

2.8 Motivation for genetic improvement

Genetic gains achieved in registered herds accrue to other participants in the beef industry through sale of bulls to commercial herds. Commercial beef cattle farmers are in business to make a profit, this can be influenced by the purchase of breeding stock (usually bulls) from registered breeders which result in increased income, decreased expenses, (or both) (Harris and Newman, 1994). The commercial beef cattle producer can be motivated to pay more for bulls if resulting progeny increase profit for the commercial herd. Thus, registered breeders are encouraged to continue genetic improvement if superior cattle are sold for premium prices (Bendall and Bendall, 1993).

The current New Zealand beef carcass grading and classification scheme rewards farmers for cattle with higher carcass weights, decreased fat depth and average (usually grade 2) conformation. Since farmers are rewarded for increased carcass weight, breeding bulls are probably sourced with increased growth and liveweight characteristics. Live weight at time of sale accounted for the majority of sale price at the 1993 National Angus bull sale. Carcass weight premiums and genetic trends overseas have probably motivated genetic improvement for live weight and liveweight gain traits among registered breeders in New Zealand (Nicoll and Morris, 1993).

Motivation for genetic improvement of carcass and meat quality traits will have to be provided by pricing signals from beef carcass grading and classification which identifies cattle of superior grades and rewards producers of cattle with superior grades (Dikeman 1986,1994; Newman *et al.,* 1994; Kemp, 1994). Moves toward a total quality management approach within New Zealand's beef industry, evidenced by registrations of beef cattle processing facilities under the ISO 9000 series and establishment of Quality Beef Supplies (Read, 1994) may encourage expansion and development of quality-oriented genetic evaluation in the future (Anderson, 1993).

Elimination of inefficiencies of US $280 per steer or heifer slaughtered occurring in the United States beef industry was provided as motivation for improvement in carcass quality and consistency through selection and management (Green *et al.,* 1994). In the United States, Angus breeders have been slow to offer bulls to enter progeny test programmes since breeders are generally not rewarded for selling sires with superior carcass characteristics (Wilson *et al.,* 1990). Implementation of value-based marketing in the United States beef industry will result in more accurate measurement and reimbursement for quality, primarily freedom from extramuscular fat (Woodward, 1994; Green *et al.,* 1994). This payment system would encourage registered beef cattle breeders to provide genetically superior cattle for important carcass and meat quality traits (Harris and Newman, 1994).

2.9 Selection for carcass and meat quality traits

Kemp (1994) considered it is time to pause and critically examine the need and method for genetic improvement of meat quality in cattle. There are problems associated with selection for carcass and meat quality traits within registered herds, some of which are: (Dikeman, 1986, 1994; Tier and Graser, 1994)

1. Carcass and meat quality traits which are of primary importance to retailers or consumers may not be included in beef carcass grading and classification, therefore do not directly affect income of commercial beef cattle farmers.
2. Due to low frequency of pedigree recording, use of multiple sire mating or confounding of sire with management group, little useful data for genetic evaluation purposes are collected in the commercial beef cattle industry. Considerable costs may be incurred collecting suitable carcass data for genetic evaluations (Woodward *et al.,* 1992).
3. Most meat quality traits cannot be evaluated, at least not accurately, in breeding animals.
4. Few registered cattle from registered breeding herds are themselves slaughtered at market weight or age, hence useful carcass and meat quality measures are not directly available on these animals.
5. In addition, Woodward (1994) recognised that beef cattle breed societies generally spend a major portion of their annual budget on livestock shows and promotions and very little on research.

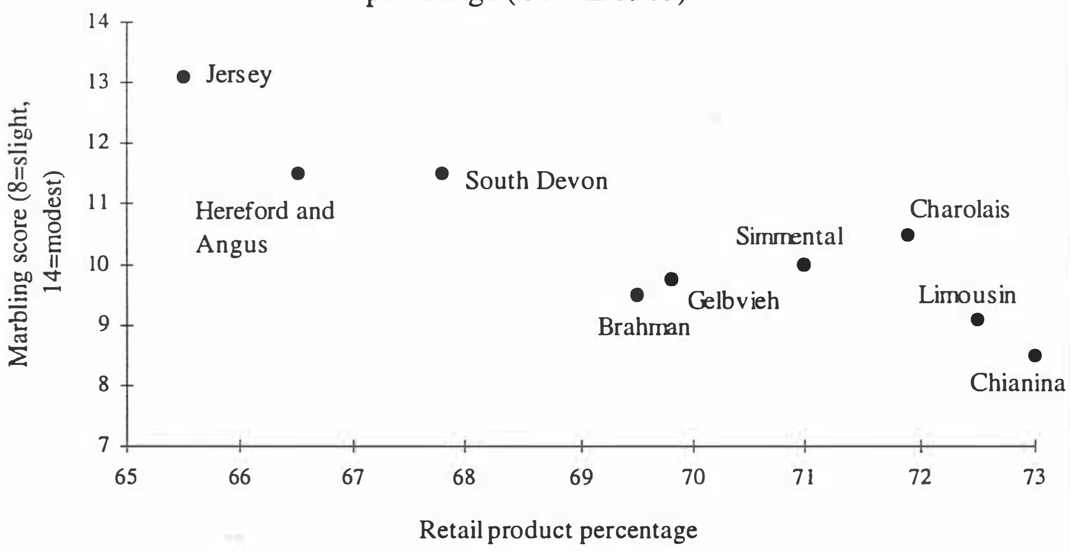
Collecting adequate carcass data would require commitment from commercial beef cattle farmers who may perceive little benefit but significant costs associated with recording pedigree and performance information. In addition, there needs to be transfer of information from the registered breeder to commercial farmer and vice versa to obtain an accurate genetic evaluation based on progeny slaughtered in the commercial sector (Tier and Graser, 1994). Financial motivation for commercial farmers collecting pedigree information and carcass data needs to arise through more specific discrimination between genotypes by processors and suitable premiums paid by processors or finishers for cattle which decrease costs and have superior carcass and meat quality attributes.

2.9.1 *Selection between breeds*

Breed differences in performance characteristics are an important genetic resource for improving efficiency of beef production and meeting market requirements (Cundiff *et* *al.,* 1986a; 1994; Koch *et al.,* 1976). However as noted by Kemp (1994), more time is required before definitive statements can be made regarding breed superiority for a number of meat quality traits. Breeds superior for lean meat yield and dressing percentage (such as Limousin, Belgian Blue and Piedmontese) are generally inferior for marbling and have a lower percentage of animals grading as prime compared to early maturing breeds (Koch *et al* 1976, Cundiff *et al.,* 1986b,1994; Newman *et al.,* 1994) (figure 2.2).

Belgian Blue and Piedmontese sired progeny had lower marbling and lower percentage of cattle grading choice than Angus or Hereford sired cattle, however there was no difference in meat tenderness, flavour or juiciness between the two breed groups (Cundiff *et al.,* 1994). In a national beef quality audit in the United States, Lorenzen *et al.* (1993) found that Jersey cattle had significantly ($P<0.05$) higher marbling and subcutaneous fat depth than traditional beef cattle breeds and *Bos indicus* cattle. Carcass desirability for the Japanese beef market from Jersey cattle due to high marbling levels may be offset by low lean meat yield and the propensity of Jersey cattle to produce yellow fat, especially from pasture finishing conditions (Barton and Pleasants, 1993; Purchas *et al.,* 1992).

Figure 2.2 Relationship between marbling score and retail product percentage (Cundiff 1983)



Earlier maturing breeds have a higher fat depth and lower lean meat yield at a constant carcass weight than do late maturing breeds (Marshall *et al.,* 1990; Amer, 1994). In a comparison between beef cattle breeds slaughtered at Manawatu Beef Packers in New Zealand, Garrick (1994) found that British breeds had higher subcutaneous fat depth at a similar carcass weight than did Exotic x British breeds and cattle of dairy origin.

Level of genetic variation for carcass traits between breeds was considered to be similar to that within breeds (Green, 1991) (Table 2.2). This suggests there is opportunity to make genetic improvement for carcass traits through selection between in addition to within breeds. However, due to difficulties of measurement of carcass traits on breeding animals within breeds, Cundiff (1992) recommended that breeds can be more quickly selected to match market requirements and with greater degree of precision than within breed selection. Genetic variation between a Jersey steer and a Chianina steer would be equivalent to 30% of total retail product (Cundiff, 1991).

Table 2.2 Relativity of genetic variation between breeds for carcass parameters in beef cattle (Green, 1991)

Trait	Number of additive genetic standard deviations between breeds
Retail product (%)	5.8
Retail product weight (458 days)	8.2
Marbling score	5.3

Selection emphasis for carcass and meat quality traits (such as marbling) will differ between breeds. Eight generations (40 years) of single trait selection for marbling would be required to increase marbling in Chianina to the level of that in Angus (Kemp, 1994). In the process however, due to negative genetic correlations, lean meat yield of the Chianina would decrease. Due to difficulties of measurement of marbling on the live animal, most rapid genetic improvement would occur through crossbreeding programmes where breeds with marbling superiority such as Wagyu or Jersey are utilised (Dikeman, 1986). For similar long-term feedlot finishing (552 days) American Wagyu steers had significantly ($P<0.05$) higher marbling and meat firmness, texture and colour score (assessed by Japanese grading standards) than Angus steers (Lunt *et al.,* 1993). There were no significant differences ($P>0.05$) between Wagyu and Angus steers for fat colour, lustre and quality as assessed by Japanese criteria. A crossbreeding programme suggested by Dikeman (1994) would be to mate an early maturing dam breed known for high marbling and meat palatability to a high growth rate terminal sire breed which produces a high lean meat yield.

2.9.2 *Inclusion of carcass traits into genetic evaluations*

The inclusion of carcass traits into the Breedplan genetic evaluation was initiated with the inclusion of eye muscle area, rib and rump (Ausmeat P8 site) fat depth. These measures were first incorporated into the Australian Angus genetic evaluation in 1990 and Australian Hereford genetic evaluation in 1991 (Sundstrom and Inglis, 1994). Estimated lean meat (%) estimated lean meat yield (kg) EBV's are estimated from regression analysis using information from eye muscle area measurements, fat depth and live weights. Genetic evaluations in North America include marbling, which can be measured on the live animal using ultrasound. Researchers in Australia are considering inclusion of marbling and meat tenderness in Breedplan genetic evaluations (Graser *pers comm.*, 1994).

Inclusion of carcass traits in genetic evaluations may differ between breeds and be determined by the basis of payment to farmers through carcass grading and classification. It may be useful to include only component traits in a genetic evaluation such as eye muscle area or subcutaneous fat depth to allow breeders to improve these traits. In contrast EBV's for a composite trait (such as lean meat yield) may be an important selection criteria if that trait is a strong determinant of price received per carcass. Green *et* al. (1994) considered it important that breeders account for correlated changes in overall carcass value when selecting for EBV's which are components of total carcass merit. Most meat quality traits are moderately to highly heritable (Table 2.3), therefore if difficulties of measurement were overcome and farmers financially rewarded for meat quality traits, genetic gains could be achieved through selection (Green *et al.*, 1994).

Table 2.3 Heritabilities of meat quality traits for beef cattle (Dikeman, 1994)

Trait	Heritability range
Subcutaneous fat depth	0.24 to 0.68
Longissimus muscle area	0.41 to 0.59
Meat yield (%)	0.35 to 0.57
Marbling	0.17 to 0.73
Myoglobin (meat colour)	0.24 to 0.80
Muscle pH	0.20
Meat texture	0.28
Tenderness	0.09 to 0.70
Flavour	0.06 to 0.43
Juiciness	0.06 to 0.24

2.9.3 *Genetic parameters for carcass and meat quality traits*

It was suggested (Benyshek *et al.,* 1994) that implementation of value-based marketing in the United States will require accurate estimates of genetic parameters of carcass and meat quality traits for their inclusion into genetic evaluations. A positive genetic correlation between marbling score and meat tenderness (0.74), between marbling and meat juiciness (0.6) and between marbling and meat flavour (0.79) have been found (Rouse, 1994). The perceived need for genetic improvement in tenderness has led to an increase in objective measurement of marbling and incorporation of marbling into genetic evaluations for diverse beef cattle breeds (Kemp 1994). However, Renand *et al.* (1994) found positive genetic correlations between lean meat yield and thermal solubility of collagen and between lean meat yield and higher glycolytic enzymatic activity, suggesting that selection for increased yield would also improve tenderness but decrease marbling and juiciness.

Through genetic correlations, selection for increased live weight may result in increased longissimus muscle area. Based on records from 9450 steer and 1220 heifer carcasses an estimate of the genetic correlation between eye muscle area (EMA) and carcass weight (CWT) of 0.49 was obtained (Wilson *et al.,* 1993). The genetic correlation between carcass weight and subcutaneous fat depth was 0.38, suggesting selection for increased carcass weight would result in increased subcutaneous fat depths. Woodward *et al.* (1992) suggested that due to difficulties measuring economically important carcass traits such as lean meat yield, selection for some combination of growth traits would be more effective than selection for these carcass traits directly.

Heritability estimates ranging from 0.62 to 0.67 for yield of retail product, fat trim and bone were obtained by Shackelford *et al.* (1995) from 1100 feedlot finished steers of various breeds in the United States. These measures were also estimated using prediction equations incorporating longissimus muscle area and fat depth measures from the 9-10-11th rib and carcass weights. The correlation between heritabilities from prediction equations and actual yields ranged from 0.92-0.99. The authors concluded that selection based on prediction equations would be very effective in changing actual yields of retail product, fat trim and bone.

Genetic correlation between subcutaneous fat depth and marbling score was -0.13, (Wilson *et al.,* 1993), suggesting marbling score could be selected whilst not increasing subcutaneous fat depth. In contrast, Lamb *et al.,* (1990) found a genetic correlation of 0.21 between marbling and subcutaneous fat depth suggesting a decrease fat depth would be associated with a decrease in marbling. There is a negative genetic correlation between carcass lean meat yield and marbling (Koch *et al.,* 1982; Woodward *et al.,* 1992; Dikeman, 1994). Koch *et al.* (1992) estimated that six generations of single trait selection for retail lean meat yield would be required to decrease marbling score by one phenotypic standard deviation. Due to the negative genetic correlation between marbling and lean meat yield, Green *et al.* (1994) suggested that there is a need to couple an EPD for meat quality (such as marbling) and an EPD for lean meat yield. This could be accomplished by expressing a meat quality EPD for marbling at a specified target lean meat yield.

Estimates of genetic parameters for carcass and meat quality traits are scarce, especially genetic correlations between meat quality and maternal traits (Menissier, 1994; Kemp, 1994). MacNeil *et al.* (1984) obtained negative genetic correlations between carcass traits and reproduction traits (Table 2.4). Therefore, animals with higher carcass weight, lower fat depth and higher lean meat yield would be associated with females which are heavier and older at puberty, have a higher birth weight and mature cow live weight. In addition, Bruns (1994) noted that across breeds there are negative associations between carcass lean meat yield and maternal ability, breeds such as Charolais, Chianina and Piedmontese tend to be poor in milk production. These negative genetic correlations suggest that production efficiency would be maximised by establishing separate sire and dam lines which are superior for carcass traits and female reproductive and maternal traits respectively.

Table 2.4 Genetic correlations between measures of carcass merit and reproductive efficiency (MacNeil *et al.,* 1984)

Female trait	Carcass weight	Fat depth	Lean meat yield
Age at puberty	0.17	-0.29	0.30
Weight at puberty	0.07	-0.31	0.08
Services/conception	0.61	0.21	0.28
Gestation length	0.03	-0.07	0.13
Calving difficulty	-0.31	-0.31	-0.02
Birth weight	0.37	-0.07	0.30
Mature weight	0.21	-0.09	0.25

2.9.4 *Number of traits included in genetic evaluation*

The efficacy of increasing the number of traits included in the Australian Breedplan genetic evaluation were examined by Nitter *et al* (1994). Increased profit of $1.59 per commercial beef breeding cow was obtained from selection for carcass traits within registered herds using EBV's from ultrasound scanning of bulls for eye muscle area and subcutaneous fat depth. Genetic gain in a multiple trait selection objective increased more substantially when carcass and fertility traits were included in the genetic evaluation than when only carcass traits were included. The authors recommended that inclusion of carcass and fertility traits into the genetic evaluation would increase genetic response for the selection objective and increase profit for commercial beef cattle farms.

Some breeders have difficulty interpreting EBV's/EPD's used in current genetic evaluations, Woodward (1994) suggested that the inclusion of new carcass EPD's in genetic evaluations may require the development of a single index incorporating growth, maternal, reproduction and carcass EPD's to simplify selection decisions for breeders.

In Britain, the Meat and Livestock Commission (MLC) has a selection index to maximise the financial margin between the value of saleable meat and cost of feed taking account of calving difficulties (Simm and Steane 1988). Carcass traits included in the selection objective are muscle score and subcutaneous fat depth measured ultrasonically.

2.10 Measurement on the live animal

The inclusion of carcass traits into selection objectives is limited by the lack of a simple and accurate measure of carcass traits on the live animal. For measurement of carcass composition, ultrasonography appears to have the widest acceptance world-wide (Whittaker *et al.,* 1992). The reason for using ultrasonography on beef cattle is to record live animal measurements that will, when combined with other measurements such as live weight accurately describe body composition and allow the prediction of genetic differences between individual animals for carcass traits (Wilson, 1992). Ultrasonography can be used to measure eye muscle area, subcutaneous fat depth and marbling. It was reported (Green *et al.,* 1994) that ultrasound measures of fat depth controlled almost all of the predictive variation in lean meat yield whilst measures of eye muscle area contributed a minor amount to the prediction of lean meat yield.

Koch *et al.*(1982) suggested the expected result of selection for increased liveweight gain and decreased fat depth using ultrasound would increased be lean meat yield. Compared to steers from a control herd, Malkus *et al.* (1994) found that steers from a herd selected for selected for increased eye muscle area EPD and lower fat depth EPD (using the United States Angus) sires had significantly lower fat depth ($P<0.06$), higher eye muscle area ($P<0.01$), higher carcass weight and marbling grade ($P<0.01$).

The use of ultrasound measures on bulls for breeding purposes may pose difficulties when making selection decisions. Cundiff (1991) noted that the correlation between subcutaneous fat depth as measured using ultrasound and fat depth measured post-slaughter was the same for both bulls and steers when fed to achieve a relatively high level of fat thickness. At low levels of fatness, as would be likely for bulls in breeding condition, correlations between live and carcass estimates of fat thickness would be low (Koch *et al.,* 1982; Cundiff, 1991). Due to low variation for subcutaneous fat depth in young breeding bulls, Wilson (1992) suggested that efficacy of selection for fat depth would be low. Furthermore, Green *et al.* (1994) suggested that subcutaneous fat depth measured on yearling bulls may be a physiologically different trait to fat depth measured on progeny at 27 to 30 months at slaughter.

The use of real time ultrasound technologies capable of assessing intramuscular and intermuscular fat depth in addition to subcutaneous fat depth and incorporation of these measures into a genetic evaluation was considered to be of great benefit to breeders seeking to change carcass composition (Eller, 1990; Wilson *et al.,* 1990). Brethour (1990) reported a technique in which speckle scores from ultrasound images of the longissimus muscle at the 12th rib were determined. Speckle scores were significantly correlated ($P<0.01$) with marbling grade for 11 of 14 groups of cattle evaluated. Wilson *et al.* (1994) noted that many questions need to be addressed for assessing efficacy of ultrasound measures on bulls for genetic evaluation purposes, including the need to determine the correct age to scan bulls, the effect of sexual maturity, nutritional status required for evaluation and efficacy of scanning older bulls.

Wilson (1992) suggested four areas of research which could be used to enhance the usefulness of ultrasonography to predict body composition of the live animal:

1. Determination of measurements made on the live animal and carcass that are predictive of body composition.
2. Development of appropriate procedures for dealing with differences in mean and variances in fatness due to management effects (age and live weight at scanning, feeding management etc).
3. Development of growth models within breed and sex which will enable adjustment of scan records to a common end-point (carcass weight or subcutaneous fat depth).
4. Estimation of heritabilities and genetic correlations for ultrasound measurements to be incorporated into genetic evaluations.

2.11 Gene mapping

Difficulties arise obtaining adequate numbers of sires and commercial cows for progeny testing, in addition to variable degrees of success with ultrasound scanning bulls for traits such as marbling (Taylor *et al.,* 1991). These factors have been considered sufficient to justify the initially high cost of identifying genetic markers for carcass quality traits. Once a marker has been identified, there may be a subsequent low cost associated with animal genotyping. Ax and deNise (1991) suggested the possibility of identifying genetic markers associated with connective proteins which would increase toughness of meat. In addition, marker assisted selection offers benefits that superior dams and sires can be evaluated and animals selected at juvenile stage.

Tenderness of beef can be affected by the calcium dependant enzymes (calpains) and their inhibitor (calpastatin). The calpains are naturally occurring enzymes which work postmortem to break down muscle proteins resulting in a more tender beef product. Calpastatin activity at 24 hours postmortem was found to have a heritability of 0.65 and was highly genetically correlated with Warner-Bratzler shear force. Green *et al.* (1994) noted that current research work had identified five genotypes in a three allele system for the calpastatin enzyme with differences of 21% in overall sensory palatability and 28% in shear force between the extremes. Further research is continuing into genetic markers identifying genetic control of beef tenderness and other beef carcass traits.

2.12 Net beef cattle industry benefit from selection for carcass and meat quality traits.

Genetic improvement of beef carcass and meat quality characteristics affects demand and supply in the beef industry. Amer and Fox (1992) showed that the effect of genetic improvement that resulted in either a one percent increase in beef supply or a one percent increase in demand for beef resulted in approximately a one percent increase in gross value of the beef product. This level of improvement for the Canadian beef industry was equivalent to (Can) $2.28 million.

The benefits from genetic improvement are highly dependant on elasticity of demand for beef products by consumers. If the demand curve is elastic, an increase in demand for the beef product will result in supply increases but there would be no change in beef product price since there would be few substitutes for the beef product. The result of genetic improvement which increases supply of the beef product will result in benefits to the beef producer. Amer and Fox (1992) estimated that an elastic demand for beef would result in 98% of benefits from genetic improvement accruing to beef producers. In contrast, if the demand curve for beef is inelastic, an increase in demand for beef would be associated with a decrease in beef product price as consumers seek alternatives such as pork or chicken. The benefits from genetic improvement which increase the quantity of beef supplied would result in almost all of the benefit accruing to consumers through lower retail prices for beef.

The market for which genetic improvement is intended should be identified carefully. Beef exported to the Japanese market incurs price differentials based on yield and quality criteria. Manufacturing grade beef in the Japanese beef market has a large number of substitutes (Uri and Lin, 1992), subsequently an in increase in supply of this beef may result in a decrease in beef price. In contrast, the highest quality beef in the Japanese market has few substitutes and would be affected little by an increase in supply or price fluctuations for other protein sources. Strategies for genetic improvement of beef cattle with respect to meeting Japanese market requirements should be to enforce an increase in the demand for the beef product by increasing quality of the beef product supplied. Such selection strategies would need to include measures of carcass and meat quality.

CHAPTER 3

CHARACTERISATION AND SELECTION FOR MEAT QUALITY TRAITS FOR NEW ZEALAND ANGUS AND HEREFORD BEEF CATTLE

Abstract

Records on 24 146 Angus and 5 632 Hereford carcasses processed at Manawatu Beef Packers between March 1993 and August 1994 which had been evaluated for beef marbling standard (BMS), beef fat standard (BFS) and beef colour standard (BCS) were used to derive overall meat quality score. Overall meat quality score in the Japanese grading system is determined by the lowest grade from: semi-objective assessment for BMS, BFS and BCS; and subjective assessment for meat brightness, firmness and texture, fat lustre and quality. Subjective measures of meat and fat quality are not routinely recorded at this plant and therefore overall meat quality score could only account for the three recorded items. The majority of Angus and Hereford carcasses (84.0 and 82.9%) had an overall meat quality score of 1 (inferior) and no carcasses had score 5 (excellent). This study reports the effects of selection to improve Japanese overall meat quality score by single trait improvement of the three meat quality attributes. A change of one grade in BMS (or BFS) for Angus carcasses decreased the proportion of score 1 carcasses to 12.8% (or 74.7%) and improved overall meat quality score from an average of 1.17 to 1.96 (or 1.29). A change of one grade in BMS (or BFS) for Hereford carcasses decreased the proportion of score 1 carcasses to 16.1% (or 66.8%) and changed overall meat quality score from an average of 1.18 to 1.90 (or 1.35).

Selection based on a well-designed progeny test would take 5 (or 9) years to improve BMS (or BFS) by one grade. Biological factors introduce a lag of at least six years from the start of test matings until there can be widespread harvest of beef cattle with improved meat quality. Selection for BMS can improve overall meat quality score more effectively and more rapidly than selection for other meat quality traits.

Keywords: Angus, Hereford, selection, marbling, fat colour, meat colour.

3.1 Introduction

Carcass suitability for the Japanese beef market is based on carcass yield and overall meat quality score (Anon, 1988). Carcass yield in the Japanese beef carcass grading scheme (classified as A,B,C) is determined by measurements of eye muscle area, subcutaneous fat depth, intermuscular fat thickness and left-side carcass weight measured at the 6th/7th rib section. Overall meat quality score (classified as 1-5) is determined by: i). beef marbling, ii). meat colour and brightness, iii). firmness and texture of meat, and iv). colour, lustre and quality of fat (Appendix I.1-5). Overall meat quality score is determined by the lowest grade amongst the four quality characteristics. Carcass grade in the Japanese beef grading system is determined by yield grade and overall meat quality score (Appendix I.6).

There is a lack of published information describing meat quality attributes of grass-fed carcasses from New Zealand destined for the Japanese beef market. Only recently have meat quality measures important for the Japanese beef market been routinely assessed at commercial beef slaughter premises. The objective of this study was to describe the current distribution of Angus and Hereford carcasses according to overall meat quality score and to determine the relative benefits of three single trait selection options aimed at improving carcass quality based on Japanese grading criteria.

3.2 Materials and methods

3.2.1 *Collection of carcass data*

Manawatu Beef Packers routinely record beef marbling standard (BMS), beef fat standard (BFS) and beef colour standard (BCS) on beef carcasses destined for the Asian market. These records were summarised for 24 146 Angus and 5 632 Hereford carcasses processed between March 1993 and August 1994. Carcass quality assessments are made (following chilling of carcasses for 12-24 hours) at the intersection of the 11/12th rib by visual comparison to official standards using standard marbling chips and meat and fat colour chips. Measures at the 11/12th rib differ from the site of measurement (6/7th rib) preferred by the Japanese beef carcass grading scheme. Subjective measures of meat brightness, firmness and texture, and fat lustre and quality are not routinely recorded at this facility, consequently overall meat quality score could only be determined from BMS, BFS and BCS.

3.2.2 *Determination of overall meat quality score*

BMS ranges from 1 (inferior, little or no visible marbling) to 12 (excellent, abundant marbling). BFS ranges from grade 1 (excellent-white colour) to 7 (inferior, dark yellow colour). BCS 3-5 is considered excellent (cherry-red) with 1-2 (light pink) and 6-7 (dark red) being inferior. Overall meat quality score was based on a 1 (inferior) to 5 (excellent) scale and was determined by the lowest ranking grade from BMS, BFS and BCS (Table 3.1). Highest overall meat quality score was given to carcasses exhibiting abundant marbling, white fat and intermediate meat colour.

TABLE 3.1 Determinants of overall meat quality score

Overall meat quality score.	Grade		
	BMS	BFS	BCS
1 (inferior)	1	7	
2	2	6	1,7
3	3,4	5	6,2
4	5,6,7	4	5,3
5 (excellent)	8-12.	1,2,3	4

3.2.3 *Selection for meat quality characteristics*

The effect of a one grade improvement in each of BMS, BFS and BCS on the distribution of carcasses within each overall meat quality score was evaluated. Selection was based on a simulated progeny test, aimed at identifying superior sires from bulls born within a 200 cow registered breeding herd. Assumptions were that 80 yearling bulls were test mated to commercial beef cows with resulting progeny slaughtered at two years of age and evaluated for BMS, BFS and BCS. Accuracy of selection (r_{TI}) for meat quality traits was assumed to be 0.8. For heritabilities of 0.2, 0.3, or 0.4, the number of progeny required to obtain an $r_{TI} = 0.8$ would be 35, 23 or 16, respectively.

A heritability of 0.3 was chosen for BMS, similar to 0.27 obtained by Koots *et al.* (1994) from a review of published literature estimates. A heritability of 0.3 was assumed for BFS and BCS. Genetic standard deviations (σ_g) were derived from the above heritabilities and assumed phenotypic standard deviations of two grade units for BMS and one grade unit for each of BFS and BCS.

The top 3 of the 80 progeny tested bulls were selected each year to be sires within the registered herd. These three sires were mated in the registered herd for one year and two of these sires mated in each of two subsequent years respectively. Genetic gain per year (ΔG/yr) was calculated using the equation $\Delta G = r_{TI}\ \bar{i}\ \sigma_g / L$ (see Blair and Garrick 1994).

3.3 Results

3.3.1 *Characterisation of meat quality characteristics*

The 24 146 Angus carcasses evaluated had a mean carcass weight of 312.6 kg (standard deviation, s.d.= 31.9 kg) and mean subcutaneous fat depth of 8.9 mm (s.d.= 6.3 mm). The 5 632 Hereford carcasses had a mean carcass weight of 310.6 kg (s.d.= 31.6 kg) and mean subcutaneous fat depth of 9.3 mm (s.d.= 6.5 mm). Carcass quality measurements for Angus carcasses are summarised in Table 3.2. The majority of Angus carcasses (97.8%) fell within the three poorest marbling grades (BMS 1-3) and 94.1% fell within the three poorest fat colour grades (BFS 5-7). The majority of Angus carcasses (82.2%) had good meat colour (BCS, 3-5) with the remainder having grade 6-7 which is considered too dark. The frequency and percentage of Angus and Hereford carcasses within each BMS, BFS and BCS grade are shown in Appendix II.1-8.

TABLE 3.2 Distribution of Angus grass-fed beef carcasses according to Japanese quality criteria

Grade	Beef marbling standard		Beef fat standard		Beef colour standard	
	Frequency	%	Frequency	%	Frequency	%
1	18030	74.7	0	0	0	0
2	4376	18.1	2	0	19	0.1
3	1277	5.3	45	0.2	19	0.1
4	323	1.3	1734	6.6	1339	5.1
5	99	0.4	10647	40.2	20391	77.1
6	25	0.1	9936	37.6	4255	16.1
7	14	0.1	4095	15.4	436	1.5
Mean	1.4		5.6		5.1	
s.d	0.7		0.8		0.5	

Hereford carcasses are summarised in Table 3.3 for marbling, fat colour and meat colour. The distribution of Hereford carcasses for meat quality characteristics was similar to that for Angus. However, a lower percentage of Hereford carcasses than Angus (65.5 vs 74.7%) had the poorest marbling grade (BMS=1) and a higher proportion of Hereford carcasses (24.2 vs 15.5%) had the poorest fat colour grade (BFS=7). Mean BMS and BCS were the same for both breeds with mean BFS differing slightly (5.6 and 5.7 for Angus and Hereford respectively).

TABLE 3.3 Distribution of Hereford grass-fed beef carcasses according to Japanese quality criteria

Grade	Beef marbling		Beef fat standard		Beef colour standard	
	Frequency	%	Frequency	%	Frequency	%
1	3760	65.5	0	0	0	0
2	1460	25.4	2	0	1	0
3	308	5.4	11	0.2	13	0.2
4	64	1.1	324	4.8	346	5.2
5	29	0.5	2101	31.4	4496	67.1
6	11	0.2	2493	37.2	1631	24.4
7	0		1623	24.2	67	1.0
Mean	1.4		5.7		5.1	
Std dev	0.7		1.2		0.9	

3.3.2 *Characterisation of overall meat quality score*

Average overall meat quality score for Angus carcasses was 1.17 and 98.7% of carcasses fell within the two poorest overall meat quality scores (1-2). The effect of a one grade improvement in each of BMS, BFS and BCS on overall meat quality score for Angus carcasses is shown in Table 3.4. Improvement by one grade in BMS or BFS for Angus carcasses would decrease the proportion of carcasses with overall meat quality score 1 (84%) to 12.8% or 74.7% respectively and improve mean overall meat quality score from 1.17 to 1.95 or 1.29 respectively.

Improving BCS by one grade did not affect the proportion of carcasses within each overall meat quality score since BMS and BFS limited improvement in overall meat quality score and average BCS was near to the optimum.

TABLE 3.4 Actual overall meat quality score (March 1993-May 1994) and effect of improvement by one grade for BMS, BFS and BCS on overall meat quality score for Angus carcasses.

	Actual		Effect of improvement of one grade in:					
			BMS		BFS		BCS	
Score	Frequency	%	Frequency	%	Frequency	%	Frequency	%
1 (inferior)	20287	84.0	3101	12.8	18030	74.7	20287	84.0
2	3539	14.7	19335	80.1	5259	21.8	3538	14.7
3	319	1.3	1704	7.0	851	3.5	320	1.3
4	1	0	6	0.1	6	0	1	0
5 (excellent)	0	0	0	0	0	0	0	0
Mean overall meat quality score	1.17		1.96		1.29		1.19	1.17

For Hereford carcasses, average overall meat quality score was 1.18, 98.8% of carcasses had the two lowest overall meat quality scores, (1-2). Improving BMS or BFS by one grade improved overall meat quality score from 1.18 to 1.90 or 1.35 respectively and decreased the proportion of carcasses with overall meat quality score 1, (82.9%) to 16.1% or 66.7% respectively (table 3.5).

TABLE 3.5 Actual overall meat quality score and effect of improvement by one grade for BMS, BFS and BCS on overall meat quality score for Hereford carcasses.

	Actual		Improvement of one grade in:					
			BMS		BFS		BCS	
Score	Frequency	%	Frequency	%	Frequency	%	Frequency	%
1 (inferior)	4469	82.9	908	16.1	3760	66.7	4669	82.9
2	893	15.9	4359	77.4	1776	31.5	889	15.9
3	68	1.2	357	6.4	94	1.8	72	1.2
4	2		8	0.1	2	0	2	0
5 (excellent)	0	0	0	0	0	0	0	0
Mean overall meat quality score	1.18		1.90		1.35		1.18	

3.3.3 *Genetic gain*

Single trait selection using a well-designed progeny test, would result in genetic gain for BMS of 0.21 grade units per year. Single trait selection for either BFS or BCS would improve the selected trait by 0.1 units per year. That is, 4.7 years would be required to improve BMS and 9.4 years required to improve BFS and BCS by one grade unit respectively.

Single trait selection for BMS or BFS would require 6.5 years or 62.7 years to improve overall meat quality score by one unit respectively. The longer time interval required to improve overall meat quality score through selection for BFS being a consequence of both the lower rate of genetic gain for BFS, and BMS being the major limiting factor to overall meat quality score. Lower genetic gain for BFS was due to its lower genetic standard deviation in comparison to BMS, a consequence of being assessed on a 1-7 scale than on a 1-12 scale. .

3.4 Discussion

Few pasture-finished Angus and Hereford cattle graded well based on overall meat quality score as determined by Japanese beef carcass grading. The limiting trait for improvement in overall meat quality score was marbling (BMS). Similarly, data from carcasses of beef cattle finished on pasture in Victoria Australia, Baud (1991), showed that only 42% of carcass were acceptable for marbling (BMS≥3), whilst 94 and 89% were acceptable for meat colour and fat colour respectively (BCS and BFS not specified). A mean BMS scores of 2.4 was obtained for Angus steers which had been feedlot finished for 400 days prior to slaughter at mean carcass weight 341 kg in Tasmania (Hopkins *et al.,* 1991).

From a small (n=56) sample of carcasses from pasture-finished steers in South Australia, Hopkins and Roberts (1993) found that the majority (52) were considered acceptable for marbling, 54 for fat colour and all carcasses were suitable for meat colour. At a mean (±s.d) carcass weight (324 ±28.3 kg), mean marbling, fat colour and meat colour scores were 3.3, 3.3 and 3.5 respectively. The lower mean BMS score of feedlot finished cattle (2.4) (Hopkins, 1991) than for pasture finished cattle (3.3) (Hopkins and Roberts, 1993) suggested there may be differences in assessment of BMS or there were differences in the genetic potential of cattle to produce marbled beef between the two studies.

Data from Richmond-Pacific (Hastings), indicates that BFS was the greatest constraint to meeting specifications for Asian markets (Wright, 1994; Anon 1995). This contrasts with the present study and may be due to different finishing environments (Manawatu compared with Hawkes Bay), different relative importance being placed on meat quality characteristics between the two studies or different measurement techniques. Further research may be required to determine the influence of factors such as region, month of slaughter and age at slaughter of pasture finished beef cattle on meat quality characteristics important to the Japanese beef market. In addition, there may be requirements for improved standardisation of assessment of BMS, BFS and BCS between processing facilities.

Muir *et al.* (1992), found that three mobs of rising 3-year old Angus steers (mean carcass weight range 341.7-363.4 kg) had BMS of 3.2 to 4.3 which are higher than the average for the present data set (1.4). The higher BMS of carcasses in the study of Muir *et al.* (1992), may be correlated to higher carcass weights and/or higher mean fat depth

(16.6 mm) compared to 9.0 mm in the present study. It was predicted, (Muir *et al.*, 1992) that highly marbled beef can be produced from Angus cattle finished on pasture, however, in light of present evidence from a large data set, these predictions may be optimistic.

Assuming carcasses are of average yield grade (B), the majority of carcasses (98.7%) would be expected to grade B1 or B2. Chilled carcasses imported to Japan from grain-fed cattle (200-300 days) would grade either B2 or B3, with those from the United States usually B3 and from Australia mostly B2 or C2 (Chadee and Mori, 1992). Large price variations exists between carcasses within a particular yield grade based on overall meat quality score (Chadee and Mori, 1992), suggesting it would be financially rewarding for beef exporters to provide a beef product with higher overall meat quality score.

This investigation showed that BMS and BFS should be included as traits in the selection objective when the goal of selection is to increase quality of beef as assessed by the Japanese beef carcass grading system. Marbling would be a more important trait for selection than fat colour since it was the major limiting factor in the determination of overall meat quality score. However, Chadee and Mori (1993), noted that meat colour and meat firmness and texture are equally as important determinants of beef price in the Japanese beef market. Single trait selection strategies aimed at improving marbling may therefore result in little or no premiums received for the beef product due to other quality factors.

Single trait selection for marbling should include consideration of selection response in other economically important traits due to negative genetic correlations. There is a negative genetic correlation between marbling and lean meat yield (Koch *et al.,* 1982; Lamb *et al.,* 1990; Cundiff 1992) suggesting single trait selection for marbling may improve overall meat quality score but decrease yield grade. At least six generations of single trait selection for lean meat yield would be required to decrease marbling by one genetic standard deviation (Koch *et al.,* 1982). Greatest opportunity to improve meat quality traits through selection would arise from crossbreeding programmes, exploiting breeds with known superiority for marbling or other meat quality traits (Dikeman, 1986; Cundiff, 1992) such as Wagyu (Lunt *et al.,* 1993). Barton and Pleasants (1993) found that beef breeds had significantly ($P<0.05$) more carcasses with white fat than dairy breeds, suggesting that fat colour can be influenced by appropriate breed choice.

Selection for BMS improved overall meat quality score more effectively than selection for BFS or BCS alone. A long time (4.7 and 9.4 years) would be required to improve BMS or BFS one grade unit through single trait selection. The rate of genetic gain achieved may be optimistic due to high selection intensity resulting from few bulls being selected (3) from a large number tested (80). A reduction in accuracy of selection from 0.8 to 0.4 (decreasing number of progeny per sire from 26 to 5) would increase the number of years required to improve BMS and BFS by one grade from 4.7 and 9.4 years to 7.5 and 14.9 years respectively. If the breeder chose to retain the top 3 progeny tested bulls each year for breeding purposes, but tested only 20 bulls, the number of years required to improve BMS and BFS by one grade would increase from 4.7 and 9.4 years to 6.5 and 13.0 years respectively.

In addition, a lag of at least seven years would occur before there would be widespread benefit from these selection decisions in the commercial beef cattle industry. Wade and Carrick (1994), found no net benefit to the Australian commercial beef industry (after 20 years of selection) from progeny testing Hereford bulls above the rate of genetic gain achievable using phenotypic information on the sires themselves. Extra income incurred through progeny testing was negated by cost of evaluation and increased generation interval. Efficacy of selection of superior New Zealand bred sires for carcass and meat quality traits using progeny test information has been minimal due to i). low numbers of progeny evaluated per sire, ii). unavailability of sires following conclusion of the progeny test or iii). discontinuation of progeny test following only one evaluation.

Selection for carcass and meat quality traits of importance to Asian beef markets will only arise if registered breeders are rewarded for their efforts by selling more breeding bulls at a higher price (Newman *et al.,* 1994; Green *et al.,* 1994). Producers can be motivated to pay more for breeding bulls with superior carcass and meat quality characteristics if they are rewarded by increased profits resulting from sales of progeny of superior bulls. Such rewards can only be achieved by inclusion of BMS, BFS and BCS in beef carcass grading and classification.

3.5 Conclusions

Selection can be employed to improve meat quality traits of importance to the Japanese market. Selection should concentrate primarily on improving BMS and secondarily on BFS if improving overall meat quality score is financially rewarding for beef cattle producers.

CHAPTER 4

GENOTYPE BY ENVIRONMENT INTERACTION EFFECTS IN BEEF CATTLE SIRE EVALUATION

Abstract

Fourteen Angus sires were evaluated for weight, carcass and meat quality traits based on records from pasture and feedlot finished steer progeny. Estimated breeding values (EBV) of sires were obtained using a Best Linear Unbiased Prediction (BLUP) procedure. Correlations between sire EBV's estimated from pasture and feedlot progeny records ranged from -0.16 (meat colour) to 0.50 (subcutaneous fat depth). There were no significant ($P<0.05$) sire by environment interaction effects, probably due to low numbers of progeny evaluated per sire. Rank correlations between sire EBV's ranged from -0.13 (fat colour) to 0.49 (subcutaneous fat depth). Small negative rank correlations between sire EBV's were obtained for five of the eight traits analysed indicating sires tended to rank differently based on pasture or feedlot finished progeny records. Some Angus sires used in New Zealand are sourced from North America where sire expected progeny differences (EPD) for carcass traits are based on performance of feedlot finished progeny. Sires may rank differently based on progeny records from feedlot-finished cattle (in North America) and pasture-finished progeny performance in New Zealand.

Keywords: Angus, progeny test, feedlot, pasture, genotype by environment interaction

4.1 Introduction

A genotype by environment interaction exists when phenotypic differences due to genotype differ from one environment to another. Genotype by environment interaction effects are important considerations in animal evaluation. Animals evaluated in one environment may rank differently, or the magnitude of differences between estimated breeding values between animals may change when evaluated in another environment (Dickerson, 1962; Bondoc and Smith, 1993). Determination of genotype by environment interaction may therefore help avoid selection of animals which are inappropriate for particular management conditions (Bondoc and Smith, 1993). The aim of this study was to evaluate the importance of sire by environment interactions using data from a New Zealand Angus progeny test in which sires were evaluated based on pasture-finished and feedlot-finished progeny records.

4.2 Review of literature

4.2.1 *Genotype by environment interaction*

Genotype by environment interactions have been classified (Hohenboken, 1986) as interactions among:

- small (or large) genetic differences and small environmental differences and,
- interactions among small (or large) genetic and large environmental differences.

The first two types of interaction are probable in management situations but are difficult to quantify, since, by definition, small environmental effects form a continuum. Interactions among large genetic and large environmental effects can be of two kinds:

- Those involving change in rank among genetic groups (a genetic group may be sires within a breed or different breeds).
- Those involving change in the size of differences between the genetic groups but no corresponding change in rank between the genetic groups (a scale effect).

A change in rank is potentially more important than change in magnitude of estimated breeding value (EBV) differences between environments since sire or breed choices in one environment may be inappropriate in another environment. This may be of particular importance for sire selection between countries. Low correlation between sire EBV's between countries may exist due to large differences in environment or differences in selection objectives between breeding industries in different countries (Buchanan and Nielson, 1969; Hohenboken, 1986). Scale effects may cause over or underestimation of genetic superiority of some sires compared to others but there would be no rank change of sires evaluated.

Frequently, the environment under which registered beef sires are managed and selected is superior in terms of nutrition and animal health than on commercial beef cattle farms into which sires are sold (Dickerson, 1962; Hohenboken, 1986). Buchanan and Nielson (1969) suggested that genotype by environment interactions may be of greater importance in beef cattle breeding industries compared to pig, poultry and dairy situations since there is greater environmental variation within beef industries than within the monogastric or dairy industries. Baker and Morris (1984) noted that for pasture-based grazing systems, widescale modification of the environment (such as feedlotting) is infeasible, thus if important genotype by environment interaction effects occur, it is more feasible to select the genotype suitable for the environment than vice-versa.

Bondoc and Smith (1993) considered that if r_{NC} (the correlation between genetic merit in nucleus and commercial herds) is low, selection in nucleus herds will contribute little to genetic improvement in commercial herds. The adverse effects of low genetic correlation between nucleus and commercial herds can be minimised by matching the environmental conditions of the two tiers (Rae, 1982; Hohenboken, 1986; Webb and Curran, 1986). The expectation of a great increase in heritability would be the only justification for selection in an environment other that in which the animal is expected to live (Falconer, 1952). Bondoc and Smith (1993) suggested that if r_{NC} is low, the registered section of the breeding industry may fragment into smaller units, each of which share a common environment with a sector of the commercial industry.

4.2.2 *Genotype by environment interaction considerations for genetic evaluation*

It may be useful to discriminate between fixed and random environments in developing models for breeding value (BV) prediction (Notter, 1991). In practical terms, fixed environments can be considered as regularly occurring, unambiguous environments such as between countries. The objective of genotype by environment interaction analysis in the situation of fixed environmental effects would be to provide EBV's for candidates in each environment and to base selection decisions on EBV's unique to each environment. In contrast, random environments (such as occurs between years) are less repeatable and do not provide opportunity for environment-specific breeding programmes. Instead the goal is prediction of mean BV across environments, but after accounting for random genotype by environment interaction. Notter *et al.* (1992) found important genotype by environment interaction effects for weaning weight for Angus cattle in Australia. The authors suggested there may need to be some accommodation of genotype by environment interaction effects in genetic evaluation, but development of herd-specific genetic evaluation would not be justified.

4.2.3 *Genotype by environment interaction effects in beef cattle populations*

Studies of genotype by environment interaction for weaning weight in beef cattle have generally involved estimation of sire by environment analysis of variance (Notter *et al.*, 1992). Environmental effects include regions, herds and contemporary groups. In most cases, sire by region interactions have not been significant, whereas sire by herd interactions consistently have been large and significant (Notter *et al.*, 1992). In addition, Bertrand *et al.* (1985) noted that an important source of sire by environment interaction may be due to an enhanced correlation among progeny due to non-random mating of sires or due to preferential feeding of calves.

Woodward and Clark (1950) reported no significant sire x herd of origin interaction for liveweight gain to weaning for calves from 11 Hereford sires. When calves from the different properties were grouped together and feedlot finished prior to slaughter, there were significant ($P<0.05$) sire by feedlot interactions for average daily gain. For 30 Angus and Hereford sires progeny tested in the United States, Wilson *et al.* (1972) found no significant ($P<0.05$) sire by environment interactions for growth, live weight and carcass traits (subcutaneous fat thickness, longissimus muscle area, lean meat yield %). A significant ($P<0.01$) sire by region interaction was identified for weaning weight for North American Simmental sires but no significant sire by region interaction for birth weight (Nunn *et al.*, 1978).

From analysis of Simmental (birth weight and weaning weight) and Maine Anjou (weaning weight) data in the United States, Buchanan and Nielson (1969) obtained correlations between sire EBV's across regions ranging from 0.3 to 0.8. Sire by region interactions for a large data set from United States Hereford cattle were determined by Bertrand *et al.* (1985). Estimated correlation of sire expected progeny difference (EPD) for weaning weight across regions was 0.64. Based on data from the American Simmental Association, Nunn *et al.* (1978) found genetic correlations of sires progeny performance across regions in the United States ranging from 0.86 to 1.00 for birth weight and from 0.73 to 0.78 for weaning weight.

Substantial rank changes between sires occurred between regions (Bertrand *et al.,* 1985). Due to re-ranking of sires, the authors suggested that in addition to a national Hereford sire evaluation, a separate sire evaluation may be appropriate for some regions.

Lagholz and Thies (1987) compared 24 progeny groups of Friesian (German Black Pied) sires on both a short (300 day concentrate feeding indoors) and long (300 days pasture +300 days concentrate feeding indoors) feeding management regime. There were significant ($P<0.05$) interactions between sires and feeding regimes for carcass weight and carcass weight gain. Due to small negative rank correlations between sires between the two feeding regimes, the authors recommended that sires should be evaluated based on progeny performance in an environment which is as similar to commercial farm conditions as possible. Soto-Murillo *et al.* (1993) found considerable sire re-ranking based on crossbred progeny performance for weaning weight, frame score and muscle score when finished in two different pasture management regimes (tall fescue hay vs maize silage during winter months).

DeNise and Ray (1987) compared estimated breeding values of a sample of United States Hereford sires for which female progeny were evaluated under pastoral conditions and male progeny evaluated under moderate energy density grain-based conditions (Table 4.1).

Table 4.1 Correlations (r) and rank correlations (r_s) among Hereford sire expected progeny differences (EPD)based on progeny performance of heifers managed under pastoral grazing conditions and bulls managed on a moderate energy density grain-based diet (DeNise and Ray, 1987)

	Feedlot traits (bulls)					
	Initial weight		Final weight		140-day gain	
Pasture traits (heifers)	r	r_s	r	r_s	r	r_s
Weight						
12 mo	0.38	0.32	0.45	0.52	0.42	0.51
20 mo	0.42	0.33	0.53	0.55	0.51	0.55
24 mo	0.34	0.25	0.37	0.32	0.31	0.30
Daily gains						
8-12 mo	0.27	0.24	0.14	0.09	-0.03	-0.03
12-20 mo	0.26	0.21	0.35	0.36	0.27	0.31
20-24 mo	-0.02	0.02	-0.06	0.02	-0.09	-0.01

Sire by environmental interaction effects were significant ($P<0.05$) for final weight and 140-day weight gain (for bulls) and 8-12 month weight gain for heifers (shaded). However, there was a net weight loss during the 8-12 month period for heifers (weaning shock). Most correlations were positive between EBV's for sires with female progeny under pastoral conditions and male progeny under grain-based test conditions. The authors suggested selection of female progeny under pastoral conditions would result in a positive correlated response in live weight gain in male progeny finished under grain-feeding conditions. Genetic correlations between sire means of 0.01 for average daily gain (weaning to 12 months) and 0.04 (average daily gain 12-18 months) for half-sib steer progeny finished on feedlot and heifer progeny reared on pasture in South Africa (Theron *et al.,* 1994). The authors suggested that growth traits measured under feedlot and pasture conditions may be two different traits and should not be ignored in the estimation of breeding values and design of breeding plans.

Tilsch *et al.* (1989) determined sire by sex/environmental interactions for crossbred progeny from Fleckvieh (1), Charolais (2) and Fleischfleckvieh (1x2) sires represented by 50 progeny groups in Germany. Correlations between sire EBV's when evaluated from station tested male progeny (90% concentrate diet from months 5-15 at slaughter) and field tested female progeny (70% concentrate diet from months 2-16 at slaughter) ranged from 0.19 for daily carcass weight gain to 0.41 for kidney fat percentage. Correlation between sire EBV's for live weight at slaughter and carcass weight were 0.19 and 0.3 respectively.

4.2.4 *Determination of genotype by environment interaction*

An indication of whether sires rank differently based on progeny evaluated in different environments can be gained from the product-moment correlation between averages for the two genetic groups in two environments. Rank correlation provides an estimate of the correlation of genetic group ranking for a trait in two environments (Snedecor and Cochran, 1968). Both types of correlation are limited to comparisons of genetic groups in only two environments.

Falconer (1952) first proposed that the interaction of genotype and environment could be studied by computing the genetic correlation of the same trait in two separate environments. For the purpose of analysis, one trait in two separate environments could be considered as two separate traits. If the estimated genetic correlation between the two traits approaches unity, then similar loci are affecting the trait in a similar manner in two environments and thus there is little evidence of genotype by environment interaction (Falconer, 1952; Robertson, 1959; Dickerson, 1962). If the genetic correlation is significantly less than one, different loci are affecting the trait in the same manner in each environment, the trait would be considered as two separate traits. Robertson (1959) suggested a genetic correlation for one trait estimated in two different environments of below 0.8 would be of biological or economic importance. In addition, it was suggested that a genetic correlation of below 0.6 would be required to demonstrate a statistically significant difference between the trait evaluated in two environments.

Notter and Diaz (1993) noted that observed correlations between EBV's calculated for the same animal in two environments are a function of:

1. the additive genetic correlation between performances in the two environments,
2. selection in each environment,
3. the accuracy of BV prediction in each environment,
4. relationships between animals within and across environments, and
5. covariances among BV predictions arising from the estimation of fixed effects in Best Linear Unbiased Prediction (BLUP) predictions of an animals BV.

If EBV's for the same animal in each environment were derived using only data in each environment, correlations among predicted BV across environments should provide information about r_G (the genetic correlation for that trait across environments). Observed correlations in such situations are usually less than one, but as noted by Notter and Diaz (1993), the expected value of the correlations is also less than one, even if the underlying genetic correlation is unity. Thus, correlations between observed genetic correlations should be interpreted relative to their expected values.

Under certain conditions, the correlation between EBV's in the two environments ($r_{\hat{G}1\hat{G}2}$) is $r_{TI1}\, r_G\, r_{TI2}$. And r_G can be represented as $r_G = r_{\hat{G}1\hat{G}2} / r_{TI1}\, r_{TI2}$ The conditions include (Notter and Diaz 1993):

1. no environmental correlation between performance in the different environments;
2. no relationship among parents of measured animals;
3. no other covariances among EBV's within either environment;
4. sires are chosen at random.

Assumption 1 is usually met if different animals are measured in different environments such as on a feedlot or pasture finishing regime. Assumptions 2 and 4 can be met through choice of sires and dams (if the pedigree of dams is known). Due to costs associated with progeny testing, sires entering a progeny test are usually selected on the basis of their own genetic merit, phenotype or ancestry performance, thereby violating assumption 4. Assumption 3 will not normally hold for BLUP, but will approximately hold for some conditions (Notter and Diaz, 1993). It was suggested (Robertson, 1959) that optimum (minimum number of progeny required to estimate r_G, with a maximum standard error of 0.2) group size for an estimate of r_G (when r_G is within the expected range of 0.5-1.0) would be approximately $500/h^2$. For heritability of 0.25, this would require inclusion of approximately 2000 half-sibs in the analysis.

4.3 Materials and methods

4.3.1 *Carcass data collection*

Data in this study were from live weight and carcass records from 300 steers from the New Zealand Angus Association progeny test (Angus Carcass Evaluation and Progeny Test, ACEPT). All steers were identified by sire. Contemporary groups were defined by herd of origin and date of slaughter. Steers were slaughtered following a period of finishing on either a feedlot or on pasture.

Steer growth, carcass and meat quality measurements were made for 139 steers that entered 5-Star Beef feedlot in mid-December 1992. Following finishing on grain for 200 days, steers were slaughtered at Sockburn in mid-July 1993. In September 1993, a second mob of steers (115) were slaughtered at Sockburn following a similar period of feedlot finishing at 5-Star Beef Feedlot. The distribution of sires across feedlot and pasture-finished progeny groups is presented in Appendix III.1.

In addition to feedlot finished progeny, steers were also finished on pasture near Gisborne and Taumaranui in the North Island. Twenty steers from the Taumaranui mob were slaughtered at Manawatu Beef Packers (MBP) plant, Feilding in March 1994. Carcass and meat quality measurements were taken following a chilling period of 24 hours. Thirty five steers from the Gisborne mob were slaughtered at Richmond-Pacific, Hastings in April 1994, carcass and meat quality measurements were taken following a period of chilling of 24 hours. Of the 23 sires evaluated, 14 were represented by both pasture-finished and feedlot finished progeny.

4.3.2 *Estimation of genetic merit*

Progeny records were analysed using mixed model procedures to obtain Best Linear Unbiased Predictions (BLUP, see Garrick 1991) of genetic merit of the 23 sires represented. Mixed model equations accounted for fixed effects of farm of origin and date of slaughter. Sire was fitted as a random genetic effect. Estimated breeding values (EBV) were obtained for sires for growth, live weight, carcass and meat quality traits as shown in Garrick *et al.* (1994). Estimated breeding values were reported separately for based on feedlot-finished progeny or pasture finished progeny records. It was assumed that sires were randomly allocated to dams in terms of age of dam and dam's genetic merit and there was no preferential treatment of groups of steers within any of the original farm sources.

4.3.3 *Accuracy of sire evaluation*

Accuracy of sire evaluation was expressed as the correlation between true and estimated genetic merit (r_{TI}), using Best Linear Prediction (BLP) methodology, (see Van Vleck *et al.,* 1987).

$$\text{Accuracy of sire evaluation} = r_{TI} = \sqrt{\frac{2n_p}{n_p + (4 - h^2)/h^2}}$$

where: n_p = number of pasture finished progeny evaluated per sire (equivalently, n_F = number of feedlot finished progeny evaluated per sire), h^2 is heritability for the trait. For each trait analysed, heritability was assumed to be 0.25, accuracy of sire evaluation reduces to:

$$r_{TI} = \sqrt{\frac{n_p}{n_p + 15}} \quad \text{and } r_{TI}^2 = \frac{n_p}{n_p + 15}$$

Prediction error variance (PEV) is equivalent to ($1-r_{TI}^2$)

$$1 - r_{TI}^2 = \frac{15}{n_p + 15}$$

and standard error of prediction (SEP) is given by:

$$\sqrt{\frac{15}{n_p + 15}}$$

4.3.4 *Correlation between EBV's for sires evaluated separately from either pasture or feedlot finished progeny records*

The correlation between EBV's for sires were calculated for each trait evaluated from both pasture or feedlot progeny records. Rank correlations between EBV's estimated from pasture finished and feedlot finished progeny were estimated the traits analysed. (Table 4.4). Rank correlation r_s (Snedecor and Cochran 1968) is the ordinary correlation coefficient between the ranked values of EBV estimated from feedlot and pasture finished. Rank correlations were estimated as:

$$r_s = 1 - \frac{6\sum d^2}{n(n^2 - 1)}$$

Where: d was the difference between EBV ranking's between pasture and feedlot finished cattle and n is the number of pairs (n= 14 sires). Rank correlations ranges from -1 (complete discordance) to +1 (complete concordance).

4.3.4.1 Expected correlation between EBV's for sires for one trait evaluated in two environments

Correlations between estimated breeding values for 14 sires should be compared with expected correlation between EBV's. The expected correlation between EBV's of 14 sires was determined for different combinations of progeny numbers using Monte Carlo simulation. The procedure for obtaining expected correlations between EBV's of sires estimated in two environments was:

1. A random sample (n=14) was taken from a normally distributed population -N(0,1), to obtain a true breeding value (BV_i) for each of 14 bulls (i = 1,...14)
2. Estimated breeding values for each of 14 sires based on pasture and feedlot finished progeny records (EBV_P and EBV_F) were estimated as:

$$EBV_{Pi} = BV_i \left(\frac{n_P}{n_P+15}\right) + \left(\sqrt{\frac{15}{n_P+15}}\right) Z_i \text{ and}$$

$$EBV_{Fi} = BV_i \left(\frac{n_F}{n_F+15}\right) + \left(\sqrt{\frac{15}{n_F+15}}\right) Z_i$$

where: Z_i is a random number (peculiar to each standard error of prediction, SEP) drawn from a normal distribution -N(0,1).

3. Correlation between EBV_{Pi} and EBV_{Fi} was calculated.

Steps 1-3 were repeated for 1000 iterations. The mean correlation between EBV's from 1000 iterations is equivalent to the expected correlation between EBV's based on given numbers of progeny records per sire under repeated random sampling. From the distribution of correlations between EBV's, the critical point below which 5% of correlations between EBV's occurred was determined (P crit, $P<0.05$). Thus, if actual correlations between EBV's (from ACEPT data) were below P level ($P<0.05$), the probability that a lower correlation between EBV's occurred due to chance effects alone would be less than 5%.

Steps 1-3 were repeated for different combinations of progeny numbers represented on both feedlot and pasture. For actual numbers of progeny analysed per sire, steps 1-3 were repeated for 5000 iterations.

4. Steps 1-3 were repeated for assumed genetic correlations between true breeding values (BV) of 0.5, 0.7, 0.9, and 1.0. Expected correlation between EBV's for sires evaluated based on different numbers of progeny evaluated in each environment and

different assumed genetic correlations between traits are presented in Appendix III.2.1-3.

4.3.4.1 Expected correlation between EBV's for sires, assuming sires had been selected prior to entering the progeny test

The previous analysis assumed sires had been randomly drawn from a population to enter the progeny test. In practice, due to considerable costs and time delays associated with progeny testing, sires are usually selected based on their own performance or their relatives performance prior to entering a progeny test. An analysis was undertaken assuming bulls had been selected prior to entering the progeny test based on EBV's determined from their own performance. A random sample of bulls (n=14, 20, 50, 100, 1000, 2000) were drawn from a normal distribution -N(0,1) to obtain true BV's for each of n bulls in the population. For each random sample of bulls, the 14 highest ranking bulls (based on EBV's) were selected to enter the progeny test. The proportion of bulls selected to enter the progeny test differed as more bulls were made available for selection (range: 14 from 14 bulls selected to 14 from 2000 bulls selected).

EBV's were obtained for each of n bulls based on their own performance were estimated as:

$$\mathrm{EBV} = \mathrm{BV}_i\,(b) + \mathrm{SEP}\ \ Z_i$$

where: for evaluation of animal itself based on one record, $b = h^2 = 0.25$ and standard error of prediction (SEP) is $2h^2$ (=0.5). For each of n bulls in the population, the 14 highest ranking bulls were selected to enter the progeny test based on EBV. The true BV for each of these 14 selected bulls was inserted into step 1 (above) for progeny test analysis using actual numbers of ACEPT sired progeny. Steps 1 to 3 were repeated for each proportion of bulls selected.

4.4 Results and discussion

4.4.1 *Liveweight, carcass and meat quality measures*

Phenotypic means and standard deviations for most traits were higher for feedlot finished than pasture finished steers (Table 4.2). However, steers finished on pasture had both higher mean dressing percentage (+5.82%) and eye muscle area (+55.88 cm^2) than feedlot finished steers. Similarly, Priyanto *et al.* (1993) found that pasture finished steers had a significantly higher ($P<0.01$) proportion of muscle than feedlot finished steers. Carcass and meat quality characteristics of pasture and feedlot finished ACEPT sired steers are shown in Table 4.2. Progeny in different environments were slaughtered at different carcass end-points (carcass weight and fat depth). A valid comparison of sires between environments may require adjustment to constant end-points (either carcass weight or fat depths).

Table 4.2 Live weight, carcass and meat quality characteristics of pasture and feedlot finished steers as reflected by Japanese grading standards

	Live weight (kg)	Carcass Wt (kg)	Dressing out (%)	EMA (cm^2)	Subcutaneous fat depth (mm)	BMS (1-12)	BCS (1-7)	BFS (1-7)	pH (1-14)
Pasture									
mean	572.8	337.0	58.7	85.2	7.2	1.7	4.7	5.3	5.6
S.D	36.4	24.2	1.1	6.0	2.7	0.6	0.7	0.8	0.2
Feedlot									
mean	744.0	425.0	52.9	29.3	30.9	2.7	3.6	3.1	5.7
S.D	53.6	31.6	1.3	4.7	7.1	0.8	0.9	0.3	0.1

Live weight — Taken immediately prior to slaughter (pasture-finished) or taken at the feedlot 3-4 days prior to slaughter.

Carcass Wt — Hot carcass weight (kg) recorded immediately after dressing.

Dressing % — The ratio of hot carcass weight to live weight expressed as a percentage.

EMA — Eye muscle (longissimus dorsi) area (cm^2) measured between the sixth and seventh ribs (Sockburn) or between 11/12th ribs (Richmond and MBP).

Subcutfat depth — Tissue depth (mm) taken on the hot carcass between the 6/7th rib (Sockburn) and 11/12th rib (Richmond and Manawatu Beef Packers) on a line between the hip and point of the shoulder

pH — Ultimate muscle pH, a measure of the muscle acidity.

BMS Beef Marbling Standard (marbling) obtained with assistance from standard charts, scored from 1 (low marbling) to 12 (very high marbling)

BFS Beef fat standard (fat colour) obtained from visual appraisal involving colour, lustre and quality of fat. Whiter fat has a score 1 and the yellower fat has a score 7 (creamy yellow).

BCS Beef colour standard (meat colour) prepared as seven continuous standards ranging from 1 (pale pink) to 3-5 (very good) to 7 (dark).

There were differences between carcass measurements taken at the two North Island slaughter premises and measurements taken at Sockburn. Carcasses evaluated at Sockburn were cut between the 6th and 7th rib, (the site of preference for estimating yield of carcasses for the Japanese beef market, Anon 1988), whereas measurements were made between the 11th and 12th rib for steers evaluated at North Island slaughter premises. Cameron *et al.* (1993) found comparable measures of BMS, BCS and BFS of feedlot finished Angus steers assessed at the 12/13 rib intersection with steers which were measured at the 6/7th rib intersection in a previous study (Lunt *et al.,* 1991). In contrast, Hopkins and Roberts (1993) reported that low correlations (not specified) between meat quality measures taken between 6/7 th and 11/12 have been found.

Larger EMA for pasture finished cattle is probably a function of different measurement site 12/13 rib as opposed to 6/7th rib in addition to influence of nutritional regime. There were also differences in measurement technique between North Island slaughter premises. Meat quality measures of BMS, BFS and BCS were evaluated under standard light conditions at Richmond-Pacific but not at MBP.

4.4.2 *Association between sire EBV's estimated from feedlot-finished and pasture finished progeny records*

Association between EBV for Angus sires for traits measured on progeny finished on both 5-Star Beef feedlot and under pastoral grazing at two North Island localities are shown in appendices III.3.1-8. Correlations and rank correlations between sire EBV's are shown in Table 4.3.

Table 4.3 Correlation coefficient between sire EBV's and rank correlation between EBV's for sires whose progeny were evaluated on both pasture and feedlot

Trait EBV	Correlation between sire EBV based on pasture and feedlot progeny records	Rank correlation between sire EBV based on pasture and feedlot progeny records
Carcass weight (kg)	-0.15	-0.02
Dressing percentage	0.34	0.40
Beef fat standard (BFS)	0.03	-0.13
pH	0.19	-0.10
BMS (1-12)	0.23	0.35
Eye muscle area (cm^2)	-0.08	-0.09
Subcutaneous fat depth (mm)	0.50	0.49
BCS (1-7)	-0.16	0
Mean	0.11	0.11

Observed correlations between EBV_P and EBV_F ranged from -0.16 (for BCS) to 0.50 (for subcutaneous fat depth). Rank correlations for sire EBV's ranged from -0.13 (BFS) to 0.46 (subcutaneous fat depth). For five of the eight traits evaluated, rank correlations for sires were negative suggesting sire re-ranking when progeny were evaluated based on records from feedlot-finished or pasture-finished progeny. Traits with highest positive rank correlation (subcutaneous fat depth and dressing percentage) were probably less prone to differences in measurement technique between slaughter facilities than BMS, BFS or BCS which are measured semi-subjectively. Similar low rank correlations between sires with progeny in a pasture-feedlot (600 days) or feedlot (300 days) finishing regime were reported for liveweight gain and carcass traits (Langholz and Thies, 1987).

The range of genetic correlations between sire EBV's in the present study (-0.16 to 0.50) were considerably lower than genetic correlations between sire EPD's found in other studies. Genetic correlations between weaning weight for Hereford cattle evaluated in different regions of the United States ranged from 0.39 to 1.0 (Bertrand *et al.*, 1985) and from 0.3 to 0.8 for birth and weaning weight in Simmental cattle and weaning weight in Maine Anjou cattle in the United States (Buchanan and Nielson, 1969). Similarly, Nunn *et al.* (1978) obtained genetic correlations of Simmental sire progeny performance among regions ranging from 0.86 to 1.0 for birth weight and from 0.73 to 0.78 for weaning weight. For progeny numbers per sire ranging from 18 to 30 for three sire breeds tested in Germany, Tilsch *et al.*, (1989) obtained correlations between sire EBV's ranging from 0.16 to 0.36. Lower correlations between sire EBV's in the present study compared with previous studies may be due to lower accuracy of sire evaluation and measurement differences between slaughter facilities.

Notter *et al.* (1992), noted that the extent and nature of connection between environments may influence the precision of estimates of sire x environment interaction from field data. In designed trials random allocation of sires to environments can be accomplished and sires can be represented equally in each environment. In the present study, there were more feedlot-finished progeny than pasture-finished progeny per sire (Appendix III.1).

Expected correlations between EBV's were determined assuming genetic correlations between the traits of 0.5, 0.7, 0.9 and 1.0 (Table 4.4 and Appendices III.2.1-3). For each genetic correlation, the expected correlation between sire EBV's was determined for different numbers of feedlot (n_F) and pasture (n_P) finished progeny.

Table 4.4 Effect of genetic correlation between traits on expected genetic correlation estimates of sire EBV's for sires whose progeny were evaluated on feedlot or on pasture

Genetic correlation	Mean genetic correlation between sire EBV's	P crit (P<0.05)
0.5	0.14	-0.36
0.7	0.20	-0.32
0.9	0.25	-0.22
1.0	0.27	-0.23

Expected correlation between sire EBV's for an assumed genetic correlation of unity (r_G=1.0) is 0.27. For the traits analysed, mean observed correlation between EBV was 0.11, with a range from -0.16 to 0.50. Reasons for correlations between EBV's being lower than expected include:

1. There was a true genotype by environment interaction for the traits analysed in two different environments (r_G<1.0).

2. Differences in timing, site and method of measurement for carcass and meat quality traits between slaughter facilities.
3. Sires included in the progeny test were not chosen at random, rather they were nominated for inclusion by individual breeders, probably on the basis of a combination of genetic, phenotypic and pedigree information.

The genetic correlation between EBV's below which 5% of correlations would be expected to occur (P crit, P<0.05) was -0.23 (Table 4.4). Experiment-wise, none of the actual genetic correlations between EBV's were less than -0.23, therefore no significant (P<0.05) correlation between sire EBV's were detected for the traits analysed. This suggests that for the given number of progeny analysed, there was no significant (P<0.05) sire by environment interaction as determined by correlation analysis. Since there was no significant (P<0.05) correlation between EBV's detected under an experiment-wise analysis, there would be no significant sire by environment interaction would be expected undertaking and comparison-wise analysis ($P<\frac{0.05}{8}$).

Consideration of genetic correlations between traits analysed may have important implications for breeding value prediction. Notter (1991) determined efficiencies of breeding value estimation with no consideration of genetic correlation between environments relative to when genetic correlation between environments is considered. When the goal is breeding value prediction in environment 1 (pasture finishing), and two progeny were evaluated in environment 1 and eight in environment 2 (feedlot finishing), the relative efficiency of breeding value estimation ranges from 0.79 (when r_G=0.3) and 0.92 (r_G=0.5) to 0.98 and 1.0 (when r_G=0.7 and 0.9 respectively).

Based on the analysis of Notter (1991), if a genetic correlation of less than unity exists between traits evaluated from pasture finished and feedlot finished progeny records and the majority of records are from feedlot finished animals, then omission of this genetic correlation will result in sub-optimal BV prediction when the goal of BV prediction is progeny performance in a pastoral environment. Therefore, unless genetic correlation between traits (r_G) can be accurately determined from adequate numbers of progeny records, (Robertson 1959, recommended 2000 half-sib progeny when h^2 = 0.25), EBV's should continue to be reported separately based on either feedlot or pasture finished progeny records.

If sire breeding values based on pasture-finished progeny records are only weakly associated with breeding values estimated from feedlot finished progeny records, breeders should exercise caution when marketing EBV's of sires originating from the United States where sires (or their progeny) are likely to have been evaluated under feedlot conditions. Webb and Curran (1986) suggested a source of genotype by environment interaction occurs between feeding management regimes in the pig industry. The authors suggested that genetic gains in gilts tested in ad-libitum feeding environments may have may have arisen through increased feed intake whilst genetic gain for increased growth rate under restricted feeding conditions may have arisen through increased feed conversion efficiency. Thus in the context of the present study, although the same traits were measured on progeny finished in pasture and feedlot environments, the physiological basis underlying their expression may differ. No significant differences between country of origin of sire (New Zealand vs United States) for growth rate or live weights were obtained for Angus calves reared on four different finishing regimes in the United States (Hohenboken and McClure, 1993).

The effect of selecting sires to enter the progeny test programme (based on their own performance) on expected genetic correlations between sire EBV's was determined (Table 4.5). As selection intensity increased, expected correlation between EBV's decreased and expected mean correlation between EBV's decreased. As intensity of selection of bulls entering the progeny test increased P crit ($P<0.05$) decreased. In practice, sires were nominated to enter the progeny test by individual breeders. It is likely that above average genetic merit sires entered the progeny test, this may partially account for observed correlation between EBV's for sires being less than expected.

Table 4.5 Correlation estimates of sire EBV's of sires selected to enter a progeny test based on their own performance records

Proportion of bulls selected	Selection intensity	Mean correlation between sire EBV's	P crit (P<0.05)
14 from 14	0	0.26	-0.35
14 from 20	0.45	0.14	-0.32
14 from 50	1.18	0.08	-0.38
14 from 100	1.57	0.06	-0.43
14 from 1000	2.53	0.03	-0.44
14 from 2000	2.78	0.02	-0.44

The effect of increasing progeny numbers per sire evaluated for different assumed genetic correlations between traits are shown in appendices III.2.1-3. Increased progeny numbers per sire in each environment were associated with an increase in expected correlation between sire EBV's due to increase in breeding value prediction. Increasing progeny evaluated per sire in each of two environments from 20 to 100 increased mean correlation between sire EBV's from 0.38 to 0.86 and increased P crit (P<0.05) from -0.07 to 0.7.

Notter and Diaz (1993) found that increased accuracy of evaluation of sires in both environments, decreased number of sires required to reject the null hypothesis that r_G=1.0. Minimum number of progeny required to reject the null hypothesis (r_G=1.0) occurred for accuracy of selection (r_{TI}) in both environments of 0.7-0.8 (Notter and Diaz, 1993). Higher minimum progeny numbers were required as true correlation between traits in both environments increased from r_G=0.5 (800 progeny) to r_G=0.8 (3200 progeny). Thus, even if the true genetic correlation between environments was low (r_G=0.5), the analysis of Notter and Diaz (1993) suggested that higher progeny numbers than included in the present study would be required to detect a sire by environment interaction if one exists.

4.5 Conclusions

Although correlations between sire EBV's were not significantly (P<0.05) different from expected values, the results provide weak evidence of sire by environment interaction based on sires progeny performance evaluated in pastoral and feedlot finishing regimes. Rank correlations between sires EBV's were negative for most traits analysed. Progeny numbers were low and distribution of progeny between feedlot and pasture was uneven. Further research would be required using a larger data base with more progeny per sire and more sires represented to determine if economically important sire by environment interaction effects exist when sires are evaluated based on both feedlot and pasture finished progeny records. This data base may be created through adequate genetic links with overseas (particularly North American and Australian) progeny test programmes.

If biologically and economically important sire by environment interactions are accurately determined, separate progeny testing programmes may be conducted in both pasture and feedlot finishing environments. A progeny testing programme maintained in both pastoral and feedlot environments may be feasible if adequate genetic linkages can be maintained between environments and feedlotting becomes an important management feature of New Zealand beef cattle production.

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APPENDIX I Japanese beef carcass grading

Table I.1 Evaluation of Beef Marbling Standard (BMS)

The beef marbling grade is based on 12 standards of beef marbling standard (BMS). And are generally classified into 5 grades from 1 (poor) to 5 (excellent). The chart below shows classification of BMS by grade.

Grade	Evaluation standard	BMS No
5	Excellent	8-12
4	Good	5-7
3	Average	3-4
2	Below average	2
1	Poor	1

Table I.2 Evaluation of Beef Fat Standard (BFS)

Fat colour of beef carcasses are evaluated based on the beef fat standard (BFS) which consists of seven BFS numbers grouped into five grades. Fat lustre and quality are evaluated simultaneously by visual appraisal. All three factors are considered in determination of the final grade.

Grade	Fat colour	BFS No.	Lustre and quality
5	Excellent	No.1-No.4	Excellent
4	Good	No1.-No.5	Good
3	Average	No1.-No.6	Average
2	Below average	No1.-No.7	Below average
1	Inferior	A grade except 5-2	

Table I.3 Evaluation of Beef Colour Standard (BCS)

Meat colour is evaluated by beef colour standard (BCS) which consists of 7 continuous standards. Meat brightness is evaluated by visual inspection and is also considered in deciding the final grade.

Grade	Evaluation standard	Colour BCS No	Brightness
5	Very good	No3.-No.5	Very good
4	Good	No2.-No.6	Good
3	Average	No1.-No.6	Average
2	Below average	No1.-No.7	Below average
1	Inferior	A grade except 5-2	

Table I.4 Evaluation of meat firmness and texture

Both meat firmness and texture are evaluated by visual appraisal. At the decision of the final grade, both factors are considered.

Grade	Firmness	Texture
5	Very good	Very fine
4	Good	Fine
3	Average	Average
2	Below average	Below average
1	Inferior	Coarse

Table I.5 Determinants of overall meat quality score

Overall meat quality score is determined is graded down to the lowest grade among the four items as follows:

Overall meat quality score	**3**
Beef marbling	4
Colour and brightness	4
Firmness and texture	3
Fat colour, lustre and quality	4

Table I.6 Carcass grade as determined by yield score and overall meat quality score in Japanese beef carcass grading

Final yield score and overall meat quality scores are indicated on carcasses by one class of the 15 combinations.

	Meat quality score				
Yield score	5	4	3	2	1
A	A5	A4	A3	A2	A1
B	B5	B4	B3	B2	B1
C	C5	C4	C3	C2	C1

The majority of domestically produced (Japanese) grain-fed Wagyu steers would grade A5, A4 or A3 (24.4, 25.2 or 17.3% respectively), (Anon 1988). The majority of imported beef from grain-fed steers from the United States or Australia would grade B3 or B2 (37.0 and 48.6%, respectively). Imported manufacturing grade beef which is shipped frozen would grade C1.

APPENDIX II. Carcass and meat quality characteristics of Angus and Hereford cattle slaughtered at Manawatu Beef Packers, AFFCO between March 1993 and August, 1994

Table II.1 Mean carcass and meat quality characteristics for Angus cattle processed at Manawatu Beef Packers between March 1993 and August 1994

Variable	Number of carcasses processed	Mean	Std Deviation
Carcass weight	26 459	312.6	31.9
GR fat depth	27 459	8.9	6.3
Meat colour	28 459	5.1	0.5
Fat colour	29 459	5.6	0.8
Marbling score	24 146	1.4	0.7

Table II.2 Distribution of marbling grade for Angus carcasses processed at Manawatu Beef Packers between March 1993 and August 1994.

Beef marbling standard (BMS)	Frequency	Percent	Cumulative freq	Cumulative %
1	18030	74.7	18030	74.7
2	4376	18.1	22406	92.8
3	1277	5.3	23685	98.1
4	323	1.3	24006	99.4
5	99	0.4	24105	99.8
6	25	0.1	24130	99.9
7	14	0.1	24144	100
8	1	0	24145	100
9	1	0	24146	100

Table II.2 Distribution of fat colour for Angus carcasses processed at Manawatu Beef Packers between March 1993 and August 1994.

Beef fat standard (BFS)	Frequency	Percent	Cumulative freq	Cumulative %
2	2	0	2	0
3	45	0.2	47	0.2
4	1734	6.6	1781	6.7
5	10647	40.2	12428	47
6	9936	37.6	22364	84.5
7	4095	15.5	26459	100

Table II.3 Distribution of Meat Colour for Angus carcasses processed at Manawatu Beef Packers between March 1993 and August 1994.

Beef colour standard (BCS)	Frequency	Percent	Cumulative freq	Cumulative %
2	19	0.1	19	0.1
3	19	0.1	38	0.1
4	1339	5.1	1377	5.2
5	20391	77.1	21768	82.3
6	4255	16.1	26023	98.4
7	436	1.6	26459	100

Table II.4 Mean carcass and meat quality measurements for Hereford carcasses processed at Manawatu Beef Packers between March 1993 and August 1994

Variable	Number of carcasses processed	Mean	Std Deviation
Carcass weight	6697	310.6	31.6
GR fat depth	6697	9.3	6.5
Meat colour	6697	5.1	0.9
Fat colour	6697	5.7	1.2
Marbling score	5742	1.4	0.7

Table II.5 Distribution of marbling grade for Hereford carcasses processed at Manawatu Beef Packers between March 1993 and August 1994

Beef Marbling Standard (BMS)	Frequency	Percent	Cumulative freq	Cumulative %
0	110	1.9	110	1.9
1	3760	65.5	3870	67.4
2	1460	25.4	5330	92.8
3	308	5.4	5638	98.2
4	64	1.1	5702	99.3
5	29	0.5	5731	99.8
6	11	0.2	5742	100

Table II.6 Distribution of fat colour for Hereford carcasses processed at Manawatu Beef Packers between March 1993 and August 1994

Beef colour standard (BCS)	Frequency	Percent	Cumulative %	Cumulative %
0	143	2.1	143	2.1
2	2	0	145	2.2
3	11	0.2	156	2.3
4	324	4.8	480	7.2
5	2101	31.4	2581	38.5
6	2493	37.2	5074	75.8
7	1623	24.2	6697	100

Table II.7 Distribution of meat colour for Hereford carcasses processed at Manawatu Beef Packers between March 1993 and August 1994

Beef colour standard (BCS)	Frequency	Percent	Cumulative freq	Cumulative %
0	143	2.1	143	2.1
2	1	0	144	2.2
3	13	0.2	157	2.3
4	346	5.2	503	7.5
5	4496	67.1	4999	74.6
6	1631	24.4	6630	99
7	67	1	6697	100

APPENDIX III

Appendix III.1 Number of ACEPT sired steers slaughtered by sire and mob and accuracy of estimated breeding values for grain-fed and pasture-fed analyses

Sire	Five Star Beef		Pasture finished		Total	Accuracy %[2]	
	Kill 1	Kill 2	Richmond	MBP[1]	progeny	Grain	Pasture
Merchiston Playboy	11				11	65	
Kaharau Express	8				8	59	
Kaharau Commander	9				9	61	
Ranui Wobern 871	7				7	56	
Cricklewood Aim	12				12	67	
Hi Energy 3 of Commodore	10				20	63	
Pono of Kawatiri	14				14	70	
Turihaua Sledge	5			10	5	50	
Cricklewood alone	16	11	1		28	80	25
Kaharau Northern Sky 830		6	2	2	10	53	46
Glenbold 811		9	3	2	14	61	50
Bruno of Lairdvale 667		9	1	1	11	61	34
Springdale Bruno 742		6			6	53	
Rawhiti Daniel 813		9	2	2	13	61	46
Ruru Spicer H14		6	3	1	10	53	46
Ranui Totara Drive 854		10	2	1	13	63	41
Te Mania Fortifier	7	11	1	2	21	73	41
Hingaia 599	3	5		3	11	59	41
Scotch Cap		5	4	1	10	50	50
Rito 2100	15	7	7	2	31	77	61
Kaharau High Drive 209	14	6	2	2	24	76	46
Springdale Solo		4	2		6	46	34
Bruno 652 of Lairdvale		11	5		16	65	50
Total	**131**	**115**	**35**	**19**	**300**		

1. MBP = Manawatu Beef Packers AFFCO slaughter facility, Feilding.

2. Accuracy determined as $\sqrt{\frac{n}{n+15}}$, where: n = number of feedlot or pasture evaluated progeny. Accuracy is expressed as a percentage.

Appendix II.2.1 Correlation between EBV's for two traits with differing genetic correlations and numbers of feedlot (n_F) and pasture (n_P) evaluated progeny

Genetic correlation	n_F	n_P	Mean	P crit (P<0.05)
r_G=0.5	10	5	0.16	-0.34
	20	5	0.18	-0.35
r_G=0.7	10	5	0.23	-0.31
	20	5	0.24	-0.17
r_G=0.9	10	5	0.28	-0.21
	20	5	0.33	-0.11
r_G=1.0	10	5	0.33	-0.18
	20	5	0.36	-0.11

Appendix III.2.2 Correlation between EBV's for two traits with differing genetic correlations and numbers of feedlot (n_F)and pasture (n_P) evaluated progeny

Genetic correlation	n_F	n_P	Mean	P crit (P<0.05)
r_G=0.5	10	10	0.19	-0.37
	20	10	0.24	-0.24
	30	10	0.26	-0.25
r_G=0.7	10	10	0.26	-0.24
	20	10	0.33	-0.15
	30	10	0.35	-0.17
r_G=0.9	10	10	0.36	-0.11
	20	10	0.43	-0.01
	30	10	0.45	-0.01
r_G=1.0	10	10	0.42	-0.04
	20	10	0.46	-0.04
	30	10	0.54	0.08

Appendix II.2.3 Correlation between EBV's for two traits with differing genetic correlations and numbers of feedlot and pasture evaluated progeny

Genetic correlation	n_F	n_P	Mean	P crit (P<0.05)
r_G=0.5	20	20	0.28	-0.25
	30	30	0.33	-0.17
	50	50	0.38	-0.25
	100	100	0.42	0
	1000	1000	0.48	-0.05
r_G=0.7	20	20	0.40	-0.04
	30	30	0.46	-0.03
	50	50	0.43	0.13
	100	100	0.60	0.29
	1000	1000	0.67	0.41
r_G=0.9	20	20	0.50	0.01
	30	30	0.59	0.23
	50	50	0.68	0.35
	100	100	0.77	0.56
	1000	1000	0.88	0.72
r_G=1.0	20	20	0.38	-0.07
	30	30	0.65	0.25
	50	50	0.76	0.35
	100	100	0.86	0.70
	1000	1000	0.98	0.95