MATURATION AND RIPENING OF 'DOYENNE DU COMICE' PEARS

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To my wife Mary, who gave me

the most precious treasures

in my life: herself and our children

Abstract

Characterisation of fruit quality attributes before and at harvest, during coolstorage and during ripening was made using standard and new, non-destructive devices during both the 1996 and 1997 seasons. Fruit firmness was linearly related to time when measured either by 'Kiwifirm' or penetrometer before harvest.

Destructive techniques, the penetrometer and the texture analyser, were used to measure firmness and compared with non-destructive devices, the Kiwifirm and the softness meter. It is suggested that expressing rates of softening will be much more straightforward using a device such as the Kiwifirm. This device and the softness meter provided firmness data for pears that were too soft to measure by penetrometer.

The effects of harvest date (1, 11 and 21 March, 1996) and three crop loads on fruit maturity after a period of 6 weeks in coolstorage were investigated. Fruit size increased considerably during the 20 days before harvest, suggesting that periodical harvests need to be made in order to pick optimum size fruit each time. Maturity at harvest influenced the quality of 'Comice' stored at 0°C in air. Fruit from different harvests behaved differently in terms of softening behaviour and colour changes after 6 weeks in coolstorage. Crop load did not affect fruit quality attributes assessed after coolstorage.

The characterisation of the nature and degree of within-tree and between tree fruit variability in harvest maturity and final ripening behaviour of 'Doyenne du Comice' pear was assessed by measuring firmness and colour. These attributes were measured non-destructively on fruit from different positions on the trees, and subsequently measured at harvest and during ripening at 20°C after 7 weeks in coolstorage at 0°C in air. Fruit behaved differently in terms of softening behaviour and colour changes depending on their position on the tree. Fruit maturity was delayed when fruit came from shaded areas, fruit from inner locations were greener than fruit from the outside and top positions.

Selective picking and the association of harvest and ripening data may be important in making predictions that could reduce variability in fruit quality in the market place.

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1. INTRODUCTION

Pears are an attractive option for fruit growers in New Zealand. Pears exports for the year ended 30 June 1995 were valued at $12.5 million which was a 115% increase over 1994 (Witters, 1995). Although the volume of New Zealand pears is small compared to apple production, it is recognised that pears offer exciting opportunities for niche marketing in the future.

'Doyenne du Comice' (Comice) is one of the most attractive export cultivars in the New Zealand pear industry. A problem associated with the commercial development of this cultivar has been recognised: fruit quality variation in the market place. Fruit with different levels of firmness, rates of softening, colour and total soluble solids content are some of the problems reported. Some of these problems may greatly be reduced by improvements in the postharvest cool chain, but it is suspected that significant variation may arise in the orchard, linked with preharvest factors such as fruit position within the tree canopy and crop load on the tree.

Fruit development can be affected by position within the tree; several components of fruit quality are correlated with fruit growth (Chalmers, 1985). The complexity of the nature of quality and the diversity of factors affecting fruit on the tree, make it necessary to analyse variation of fruit quality in terms of a number of attributes. Moreover, these attributes are usually highly correlated since biological systems contain many components which are interrelated. The use of multivariate analyses is particularly well-adapted to this type of situation (Broschat, 1979).

In the current study, maturation and ripening behaviour of 'Comice' pears have been characterised to determine if there are any correlations between non-destructive and destructive maturity assessments that might eventually be used to segregate pears on the grading line. These characterisations could be important in making predictions that could reduce variability in fruit quality in the market place.

It is known that the harvest date or harvesting at the proper stage of fruit maturity has a great influence on the quality of fruit stored for a long period (Eccher Zerbini *et al.* 1993; Elgar *et al.* 1997). Little is known about effects of fruit position within the tree, crop load and harvest date on fruit quality after storage. In the present study these relationships were analysed.

The objectives of the present study were to:

- characterise maturation and ripening of 'Comice' pears, particularly softening behaviour;
- investigate the influence of harvest date, position on tree and crop load on quality of 'Comice' pears after coolstorage;
- determine the effects of crop load and fruit position on the tree on maturity of 'Comice' pears at harvest and after coolstorage.

2. LITERATURE REVIEW

2.1 Maturation and Ripening Processes in Pear

One of the most important points in a pear commercial supply chain is to deliver to the consumer fruit which ripen with good eating quality. Eating quality of fruit after storage depends on the maturity stage of fruit at harvest and on storage and ripening conditions (Eccher Zerbini *et al.* 1996). For these reasons, pear maturation and ripening are important processes from a commercial point of view.

Maturation was defined by Watada *et al.* (1984) as "the stage of development leading to the attainment of physiological or horticultural maturity". Similarly, physiological maturity was defined as the stage of development when the fruit will continue ontogeny even if detached from the plant, and horticultural maturity as the stage of development when the fruit possess the prerequisites for utilisation by consumers. According to these authors, pear maturation can overlap with other stages of development as indicated by broken lines in Figure 2.1.

Harvesting pears at the proper stage of maturity can have a great influence on their subsequent quality, for example fully mature fruit can reach a fully ripe stage, but immature fruit cannot. Fruit with full maturity are also less susceptible to physiological disorders (Wang, 1982; Reid, 1992).

Pears are not acceptable to consumers at physiological maturity. Ripeness is achieved only after a period of coolstorage, and after the pears have reached their climacteric (Westwood, 1993). During fruit ripening, which corresponds to the latter part of fruit maturation, changes in fruit texture and colour occur which make fruit more susceptible to physical damage.

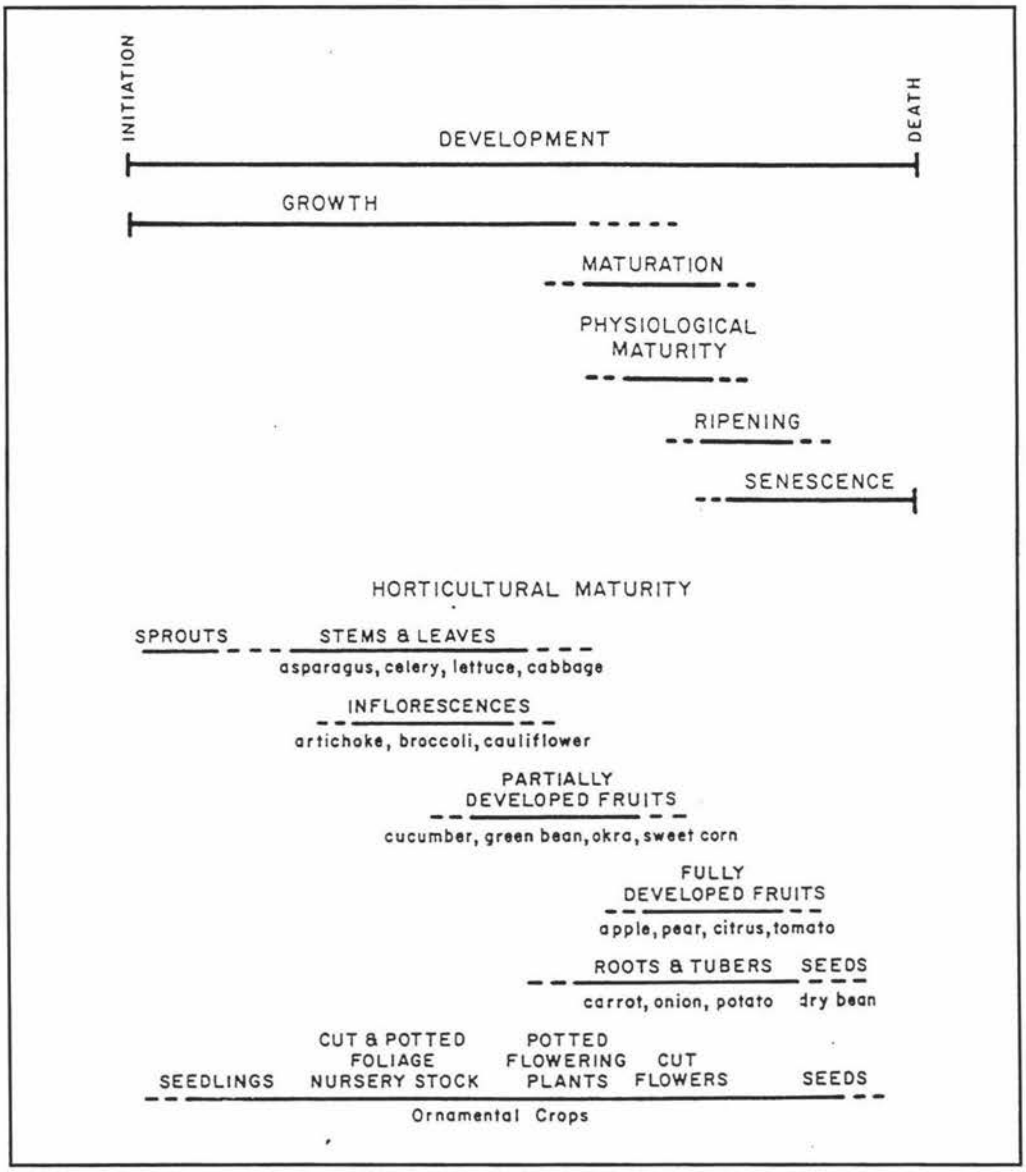


Figure 2. 1 Stages of development and senescence based on physiological processes of some horticultural products (from Watada *et al.* 1984).

2.1.1 Maturation

Maturation is the period between the fruit growth stage and senescence. It is difficult to delineate between growth and maturation as the maturation process commences before growth ceases (Figure 2.2). The latter part of maturation is ripening, and soon after, the final stage, senescence, ensues (Biale, 1964).

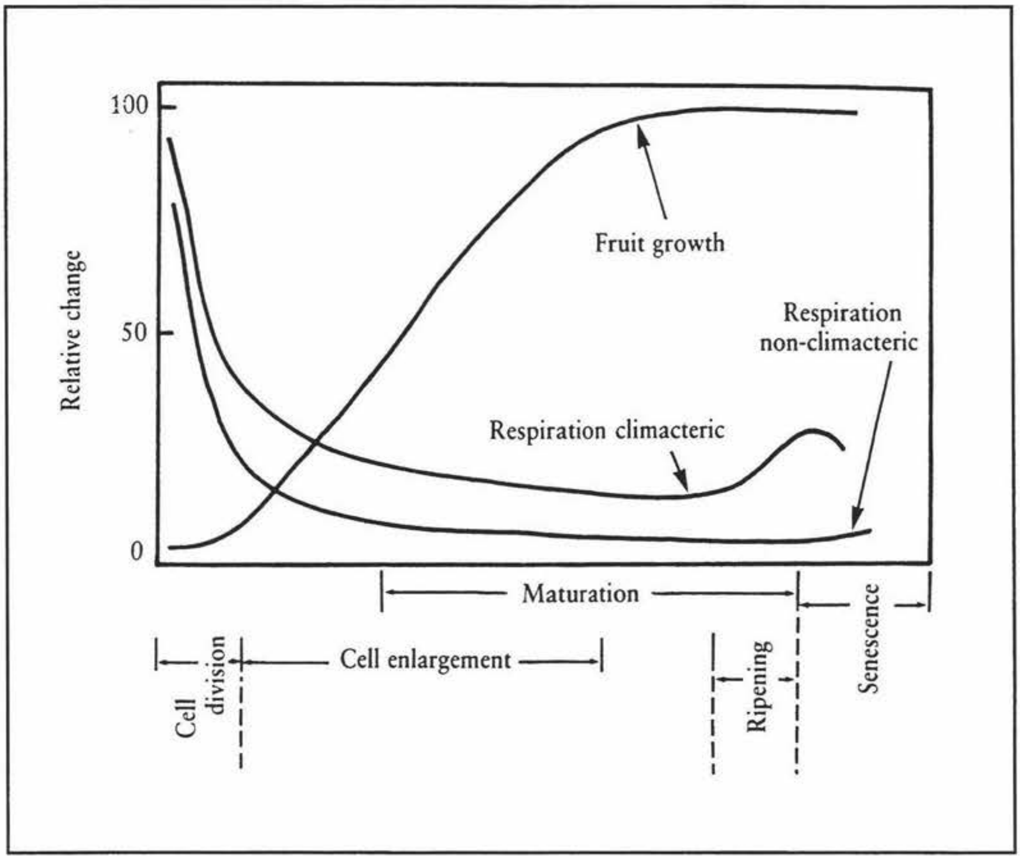


Figure 2. 2 Growth and respiration patterns of fruit during development (Biale,1964).

Maturation is a complex process in biochemical terms, that includes many reactions that are necessary to bring about many changes in a fruit. These changes have some impact on several attributes of fruit such as firmness, skin colour, size, composition and texture. These are used as harvesting criteria, but they are affected by uncontrolled factors such as seasonal and crop variations. There is a need for a "complex maturity index" which overcomes differences occurring from season to season, and takes into account only the variation due to the maturation processes (Eccher Zerbini *et al.* 1996).

During the latter part of fruit maturation, some changes in the fruit become evident which are associated with fruit ripening, for example, chlorophyll content, titratable acidity and fruit firmness decline. Other changes include an increase in total soluble solids (TSS) and darkening of the seed colour, initiation of the characteristic pigment of the fruit variety, and hydrolysis of starch which, in pipfruit, is initiated in the core of the fruit (Westwood, 1993).

Characterisation of maturation by different morphological, anatomical and physiological changes in 'Bartlett' pears has been studied (Bain, 1961; Mann and Singh, 1985; Eccher Zerbini et al. 1996). Fruit increased in size until approaching commercial maturity, when a further decrease in the growth of the long axis, short axis and cortex was seen. Fruit weight increased as long as the fruit remained on the tree, although the rate of increase was less after commercial maturity. Total sugar content increased throughout the pear life on the tree. Starch content increased and reached the maximum after commercial maturity and then decreased gradually. As the starch began to decrease after commercial maturity, reducing sugars also decreased and non-reducing sugars increased dramatically (Bain, 1961).

Wang *et al.* (1972) picked 'Anjou' pears at four different stages of maturity and found that the beginning of a distinct stage of maturity was not evident from changes in weight, firmness, soluble pectins, soluble solids, protein N or malic acid (Figure 2.3).

Studies of the physical and biochemical changes during growth and maturation of 'LeConte' pear determined that fruit weight and volume increased whereas specific gravity decreased with the advance of fruit maturation. The fruit colour changed from green to yellow green and the firmness decreased with advancement of maturity. There was an increase in TSS content of the fruit. Sugars increased with later picking date, and a remarkable increase in sugars was recorded in fruit reaching harvest maturity (Mann and Singh, 1985).

According to Watada *et al.* (1984) growth of pears continues through maturation and into the initial part of ripening if the fruit is not detached from the tree. After the climacteric peak, the ripening process is followed by senescence. The point during maturation when pears start to ripen is very important, although it is not distinct, and may vary in date from year to year depending upon a number of factors, including different climatic conditions. Fruit maturity has to be characterised with as much accuracy as possible because proper maturity later assures the best eating quality and pears will be less susceptible to physiological disorders during ripening after coolstorage (Wang, 1982).

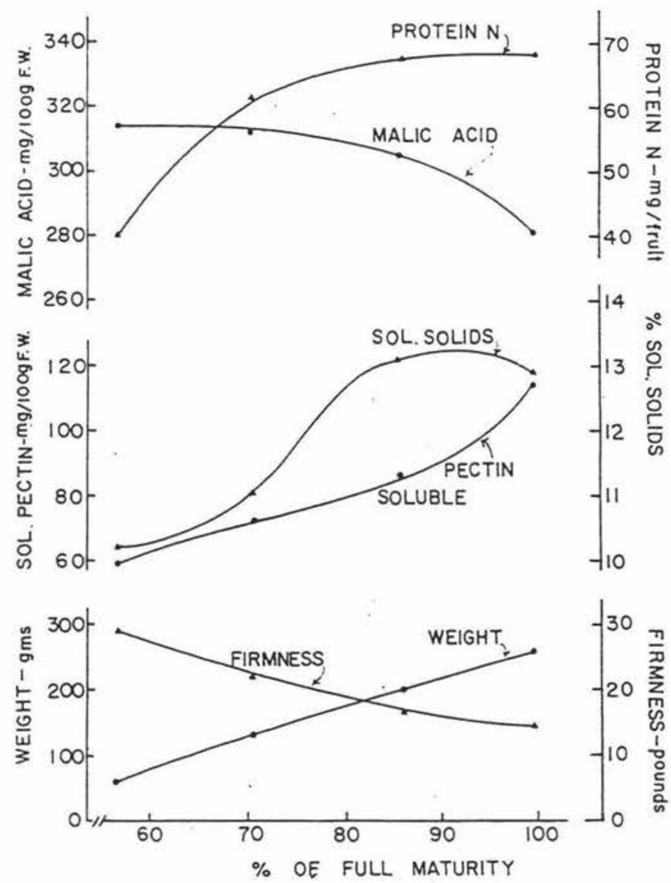


Figure 2. 3 Changes in weight, firmness, and chemical composition during maturation of 'Anjou' pears (Wang *et al.* 1972).

2.1.2 Ripening

Fruit ripening has been defined by Watada *et al.* (1984) as the processes that occur in a fruit from the latter stages of development through the early stages of senescence. These processes are evidenced by changes in composition, colour, texture, and other sensory attributes. Another definition is that ripening is the transformation of the physiologically mature fruit from an unfavourable state for consumption to a favourable state (Westwood, 1993).

Pears are climacteric fruit. Immediately before ripening occurs, fruit respiration rate reaches a pre-climacteric minimum before increasing dramatically to a climacteric peak and subsequently declining. During this rise, changes occur in fruit hormonal balance, especially in ethylene production, and also changes in physical and sensory attributes that are characteristic of the ripening process (Rhodes, 1980; Westwood, 1993). Flavour, texture, and colour are some of the fruit attributes that change during ripening. For example, flavour changes remarkably during this phase. Starch is converted to sugar and sorbitol to fructose, fruit acidity and tannin contents drop. Volatile components that give the characteristic odour and flavour of pears are produced during fruit ripening. Pectins increase, cell walls soften, and cell membranes become leaky. The production of the aromatic components are closely related to the climacteric phase, increasing as respiration increases during the onset of ripening and decreasing during senescence (Jennings, 1967; Hulme and Rhodes, 1971).

Colour changes in the fruit skin during ripening, especially those due to a loss of chlorophyll and an increase in carotenoids, are associated with the transformation of chloroplasts into chromoplasts (Spurr, 1970).

Hulme (1958) summarised information on the sugar content of maturing and ripening pears: fructose, glucose and sucrose make up the bulk of the total sugars, with fructose in excess of glucose, and glucose in excess of sucrose. Xylose, galactose, and sorbitol are also present in pears. The flavour quality of pears was strongly correlated with total soluble solids content. During ripening the TSS content of pears increased and then decreased towards senescence. The impact of sugar on fruit taste appears to be enhanced by the presence of juice within the fruit (Visser *et al.* 1968; Vangdal, 1982)

The texture profile of ripening pears has been studied by Bourne (1980). Attributes like hardness, brittleness, gumminess, chewiness and elasticity run parallel to each other and to firmness recording obtained by a Magness-Taylor penetrometer as the pears ripen. During the ripening period firmness decreased at different rates depending on the variety. Firmness was limiting to the shelf life of pears (Vangdal, 1982).

Temperature during storage and ripening is important to pears. Pears have to be harvested well before they reach the climacteric stage, and placed in coolstorage for a certain period of time that is essential for the development of maximum flavour subsequently during ripening (Wang, 1982). Although pears may colour and soften in coolstorage, they do not ripen normally with fully developed flavour, softness and juice. According to Cleveling and Jennings (1970), a possible explanation for the improved fruit flavour after coolstorage is that an accumulation of unsaturated fatty acids occurs which are esterified and thus volatilised. The ability of pears to ripen depends on the storage temperature and the length of time they have been stored (Richardson and Gerasopoulos, 1994). Each cultivar has a minimum optimum chilling requirement after harvest, though this is strongly maturity dependent (Table 2.1).

Most early-maturing pears do not have a long storage life and break down quickly in coolstorage. However, late-maturing pears usually have a better storage life, and are often termed 'winter pears' in USA. Many of these cultivars such as 'Comice', 'Anjou', 'Bosc', 'Packham's Triumph' and 'Passe Crassane' require a period of coolstorage to develop maximum flavour (Westwood, 1993; Richardson and Gerasopoulos, 1994).

A period of warmer temperature is also important after removal of pears from coolstorage. This allows them to ripen and develop the best eating quality. Most pear cultivars ripen with the highest development of flavour and best texture at 18-21°C. At temperatures higher than 25°C, ripening may not occur (Maxie *et al.* 1974).

Table 2. 1 Chilling requirement (refers to storage in air at -1 to 0°C) of different pear cultivars to obtain optimum eating quality (Richardson and Gerasopoulos, 1994).

Cultivar	Time (days)
Anjou	60
Bartlett*	none
Bosc	15-20
Comice	45
Packham's Triumph	60-70
Seckel	0-20

* early maturing cv.

2.2 Assessment of Maturation and Ripening

Fruit attributes such as firmness, colour, starch pattern and TSS are good indicators for the characterisation of maturation and ripening of pears. The absolute level of such measures for a given state of maturity can vary, depending on various factors such as cultural practices, tree vigour, and climatic conditions. This indicates the need for a different approach when assessing fruit maturity over a range of conditions encountered in any one locality from year to year or between localities in any one year (Kingston, 1993).

The best approach for the characterisation of processes such as maturation and ripening is to follow the weekly changes in several measures and correlate these with tree condition as indicated by leaf analyses, cultural practices, and crop load (Evensen *et al.* 1993).

2.2.1 Firmness

Loss in fruit firmness is one of the physical changes that take place during maturation and ripening. Firmness can be assessed to provide a guide to characterise changes in both these periods. Presently, the most standard method to measure firmness of a pear is a destructive flesh-firmness test that measures the peak force required to penetrate the peeled surface with a 7.9 mm-diameter plunger. The device commonly used for this test for pears, as well as for many other types of fruit, is an Effegi penetrometer. As this technique is destructive it relies on assessing a representative sample of fruit (Abbott *et al.* 1976; Abbott, 1994; Hopkirk *et al.* 1996). The penetrometer is widely used and useful for commercial purposes as a standard firmness measurement. Simple penetrometer recordings of firmness provide a reasonable and straightforward index of pear texture (Vangdal, 1982; Henze, 1995). However, this device punctures the fruit, and thus only a sub-sample, selected to represent all fruit, can be assessed, and it is subject to other disadvantages. Penetrometer readings are often grossly variable among users of the instrument. In addition, the device itself may be a cause of erroneous readings (Harker *et al.* 1996; Lehman-Salada, 1996).

Currently, many research projects seek non-destructive techniques to measure fruit firmness. Amongst these techniques are included acoustic response, force deformation, and optical, vibrational, electrical, or nuclear magnetic resonance (Melschau *et al.* 1981; Delwiche, 1987; Abbott, 1994; Ghafir and Thompson, 1994; Hopkirk *et al.* 1996). A non-destructive test, which does not penetrate the skin or damage the underlying flesh of the fruit, would allow the testing of every individual fruit, and repeated testing of the same fruit, thus providing many advantages for researchers and the industry alike (Watada, 1995; Hopkirk *et al.* 1996).

Whichever method is used to measure firmness, this attribute decreases continuously as pears mature and ripen (Wang, 1982; Mann and Singh, 1985; Eccher Zerbini *et al.* 1996). Different pear varieties have showed different rates of change in firmness during maturation or ripening (Bain, 1961; Vangdal, 1982; Kvåle, 1986; Eccher Zerbini *et al.* 1996). Similarly, different absolute values of firmness provide some indication as to the correct stage for harvesting different cultivars. The recommended ranges of firmness determined from penetrometer values for harvesting different varieties are shown in Table 2.2 (Hansen and Mellenthin, 1979).

Table 2. 2 Recommended ranges of firmness (7.9 mm probe) for harvesting different varieties of pears (converted to N from Hansen and Mellenthin, 1979)

VARIETY	Firmness (N)
Anjou	57.8 - 66.6
Bartlett	66.6 - 84.3
Bosc	62.7 - 71.5
Comice	49.0 - 57.8
Packham's Triumph	57.8 - 66.6

It has been suggested by Bruhn *et al.* (1991) that the fact that pears require further ripening after removal from coolstorage may reduce acceptability of this fruit in the modern market place, where consumers are suggested to want instant satisfaction. Table 2.3 shows that many consumers in a study in the USA were unhappy with pears in stores and the greatest complaint (24%) was that the fruit showed excessive firmness, followed by little flavour (18%; Bruhn *et al.* 1991). Therefore, providing pears at the correct firmness should increase consumers' satisfaction with the product. However, such a development must be balanced against problems for the retailer, with the softening pears having a reduced shelf life, and being more subject to bruising and other forms of mechanical damage.

Table 2. 3 Consumer reasons for dissatisfaction with pears* (Bruhn *et al.* 1991).

Reason for dissatisfaction	%
little flavour	18
too hard	24
too soft	4
mealy	7
never ripens	5
looks bad	5
too expensive	12

*Multiple responses were permitted.

Kappel *et al.* (1995), in developing analytical standards for the sensory attributes of pears, found that there was a linear relationship between perceived firmness and measured firmness in the 1992 and 1993 seasons (Figure 2.4). The slopes of the lines were similar in both years. Optimum firmness for eating was higher than the optimum firmness for preferred juiciness. Ideal firmness for an ideal juiciness rating was 18 to 22 N using an 11.1 mm penetrometer probe.

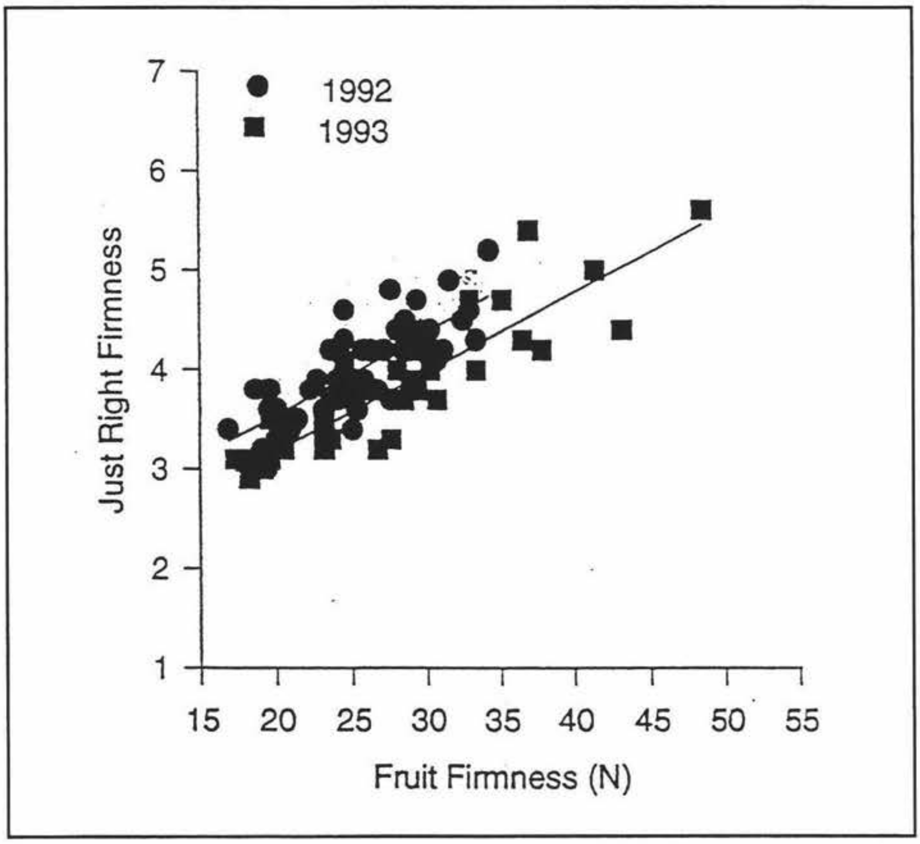


Figure 2. 4 Fruit firmness assessments of pear fruit in 1992 and 1993 for firmness perception (Kappel *et al.* 1995).

Vangdal (1982) working with a number of cultivars, found that pears with firmness between 49 N and 19.6 N were acceptable. Above 49 N the consumer majority rated the pears as too firm and below 19.6 N the pears were too soft. The shelf life of pears is accordingly limited by firmness. From these results, Vangdal defined 'shelf life' as the period of time within which pear firmness decreased from 49 N to 19.6 N. This research showed that pear shelf life could vary with year, and this variation was probably due to climatic conditions. However, the ranking of the cultivars according to the length of shelf life did not change with the year. No significant decrease in shelf life with extended storage was found in this investigation (Table 2.4).

Table 2. 4 Shelf life in days of 5 pear cultivars after storage for different periods at 0°C. Values are averages of 2 years data (Vangdal, 1982)

	Storage period (weeks)		
Cultivar	2	10	15
'Clara Frijs'	11.6	11.0	11.2
'Philip'	8.5	8.3	8.3
'Amanlis'	6.9	6.5	5.7
'Herzogin Elsa'	6.7	6.7	6.5
'Moltke'	4.3	4.4	4.1

It seems evident that firmness combined with another fruit attribute could be adequate for satisfactory indication of fruit maturation. As an example, Evensen *et al.* (1993) working with 'York Imperial' apples, found that firmness and soluble solids content in freshly harvested fruit could be plotted on a graph showing a 'decision line'. If the pre-storage firmness and soluble solids co-ordinates for a given sample were above the decision line, then firmness after storage was predicted to be greater than the target value. Pre-storage flesh firmness and soluble solids content were the best predictors of post-storage firmness (Figure 2.5). According to this research, storage operators could generate decision lines that would be accurate for their own storage conditions by keeping records for two or three years of pre-storage firmness and TSS contents and post-storage firmness of representative samples of fruit.

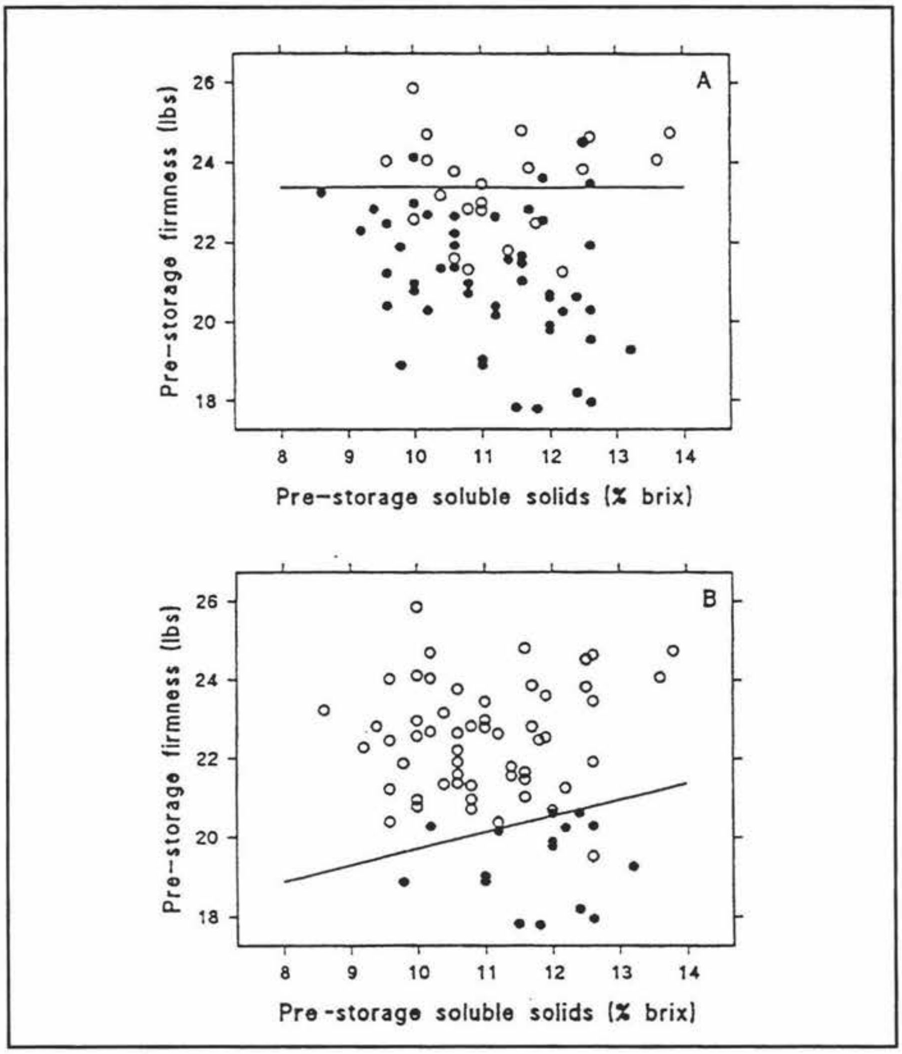


Figure 2. 5 Performance of sliding scales to predict post-storage firmness of 'York Imperial' apples using pre-storage firmness and soluble solids contents. (A) Sliding scale for 6 months storage in air. Decision line: $F_i = -0.23 + (1.31 \times F_t)$. (B) Sliding scale for 9 months of storage in CA. Decision line: $F_i = -3.34 + (1.05 \times F_t) + (0.412 \times S_i)$; where F_i = pre-storage firmness; F_t = post-storage firmness; and S_i = pre-storage soluble solids content (Evensen *et al.* 1993).

Watada (1980) stated that around the middle 1930s, a technique of measuring firmness non-destructively was described. This and other non-destructive methods of determining textural fruit attributes such as firmness, have tremendous potential for use in both research studies and commercial application. Recently several methods of measuring firmness non-destructively have been developed; one example of these is the 'Kiwifirm'. This is a small hand-held device developed by Industrial Research Limited, Auckland. It measures firmness by applying a quantum of energy to the fruit surface through a small, non-penetrating tip, and converts characteristics of the resulting collision using in-built software, displaying a value which has been calibrated to equate to a penetrometer reading when it was used with kiwifruit. It was the simplest device to use, hand held and used without removing fruit from the trays, when it was compared with the 'Softsense', 'Softness Meter' and a 'Massey Twist Tester'. Kiwifirm values were generally well related to penetrometer values when kiwifruit were softer than 15 N, but this relationship was less satisfactory during the period of rapid softening. Rank correlations between penetrometer values and Kiwifirm values were the highest compared with the other devices cited (Hopkirk *et al.* 1996).

2.2.2 Colour

Skin colour is one of the main attributes contributing to pear appearance. The ground colour of pear skin is dependent on the number of pigments present and their amounts. The basic ground colour is due to the presence of chlorophyll (green) and carotenoid (yellow) pigments. The change in ground colour from green to yellow results from the increase in carotenoids and the breakdown of chlorophyll (Hansen, 1955; Mann and Singh, 1985; Bell *et al.* 1996). When fully ripe, the colour of different pear cultivars can vary from dark green to deep yellow depending on relative amounts of chlorophyll and carotenoids. Generally, yellow pears are preferred because this colour is associated with ripeness (Quamme and Gray, 1985).

The red pigmentation that may be present on all or part of the fruit in different intensities is due to the presence of anthocyanins, namely cyanidin-3-galactoside and cyanidin-3-arabinoside, in one or more of the skin layers (Francis, 1970).

Colour change accompanies maturation in pears (Bell *et al.* 1996), therefore it could be used as an attribute to characterise this process. Accurate instruments such as the chromameter, combining electronics and optics elements, permit objective colour measurement. Such a device can complement or replace comparison techniques for colour evaluation, such as colour charts (Francis, 1980; Kingston, 1993). The chromameter will only measure the light reflected from or transmitted through the sample. The instrumental measurement of colour is limited only by the sample presented to the instrument. If the sample is large enough and homogeneous, the approach is simple. Non-uniformity can usually be minimised by taking more readings.

Colour data from the instrument can be represented by different coordinates in space. One is the L value which represents the lightness or darkness. Chroma is the second, it represents the degree of departure from grey toward pure chromatic colour. The third is a function of hue. This relates to the visually perceived redness, yellowness or greenness and can be mathematically calculated by plot of Hunter a vs b. The line joining the a, b plot with the centre makes an angle, theta, with the horizontal axis. This so called 'hue angle' is a measure of hue (Francis, 1980; McGuire, 1992).

2.2.3 Total Soluble Solids

As pears mature, starch is converted to sugars, increasing fruit sweetness and changing fruit taste (Vangdal, 1982; Wang, 1982). Sugar is the major component of total soluble solids and it is easier to measure TSS in extracted juice using a refractometer than to precisely measure sugars (Wills *et al.* 1989).

Soluble solids content tends to increase as pears mature and ripen (Vangdal, 1982; Mann and Singh, 1985; Eccher Zerbini *et al.* 1996), and so it could be useful for characterising the maturation and ripening process.

Soluble solids levels are affected by weather conditions and by the position of the fruit on the tree. Large variation has been found within an orchard and within a tree. Therefore, soluble solids are not considered a useful index of pear maturity when used alone (Hansen and Mellenthin, 1979; Wang, 1982).

2.2.4 Starch Patterns

The maturation of pears is accompanied by changes in the distribution of starch in the flesh of the fruit. Starch accumulates in pears during fruit growth and is hydrolysed to sugar as fruit mature and ripen. Its hydrolysis occurs in the core area first, and tends to progress outwards. The amount of starch present and its distribution can be measured using the starch/iodine reaction (North, 1971; Mann and Singh, 1985; Reid, 1992).

The starch-iodine test on a cut cross section of the fruit has been used more extensively for apples, however it is extremely useful for characterising pear maturation because it shows a consistent and significant change during the maturation period (Wang, 1982). Pears are regarded as ready to be picked when 60 % of the maximum starch content remains. Harvest beyond 60 % can result in fruit being too soft, an increase in storage disorders, and/or a decrease in potential storage period. While this method is easy to apply, the variations from year to year and from one fruit to another are too great to be reliable in some growing areas (North, 1971; Wang, 1982; Stow, 1988).

To maintain consistent weekly evaluations, starch rating is performed by the same person throughout the entire sampling period. Pears are cut through the equator and the surface of one piece is dipped into a shallow dish containing the potassium iodide-iodine solution. A blue-black stain develops as the iodine binds with starch in the pear tissue. Starch content is evaluated by observing the pattern and size of the stain on each pear slice. Each slice is assigned a number according to the starch rating system for that variety. Half values are assigned when necessary (See Appendix A1).

Starch hydrolysis accelerates once fruit are harvested, so the test should be performed as soon as possible after harvest to get a true indication of starch content for fruit characterisation. A distinct change in starch pattern and stain intensity usually occurs about ten days before onset of the climacteric in pears (North, 1971).

2.3 Fruit Softening

As fruits ripen their cell walls undergo dramatic changes in both structure and composition so that they become thinner and less rigid. These changes cause the fruit tissue to soften and fruit texture to change. It is important to understand this process in order to delay or retard the ripening process, maintaining fruit until consumption with good dessert quality. The softening process is an integral part of the ripening of almost all fruits. It has great commercial importance because the postharvest life of fruit is to a large extent limited by increasing softness, which brings with it an increase in physical damage during handling and an increase in disease susceptibility (Huber, 1983).

The softening reactions involve cell wall changes that appear to occur in both the flesh of the fruit and in abscission zones. Cell wall hydrolysing enzymes have featured prominently in studies of the molecular biology of ripening (Brady, 1987).

The softening rate and firmness of fruits during and after coolstorage is dependent on the state of their cell walls. These cell walls include a morphological layer known as the middle lamella, that lies between primary cell walls of adjoining cells and which forms a rather continuous intercellular matrix. The middle lamella is rich in pectic polysaccharides and is believed to be the region of the wall most affected during fruit softening (Redgwell and Harman, 1988).

The cell wall metabolism in the pulp tissue of pears after storage and during ripening has been studied to elucidate the mechanism of texture changes during ripening. In pears textural modifications are most evident during ripening, at which time they may soften quite dramatically. These types of changes are often rapid, and fruit tissues represent attractive systems in which to understand the relationships between the cell wall and the textural properties of tissues and organs (Bartley *et al.* 1982; Knee, 1982a).

The presence of endopolygalacturonase activity in the early stages of softening and the rapid depolymerization of pectin catalysed by this enzyme indicate that it has a role in the softening of pear fruit (Bartley *et al.* 1982). However, the short term inhibitory effects of anoxia on pear softening suggest that a process other than pectin degradation is also involved in pear softening (Knee, 1982b). Pears remain hard during storage at - 1°C but at 18°C soften rapidly and reproducibly. Transfer of whole ripening pears to a nitrogen atmosphere arrested softening, the increase in soluble pectin and the decline in total pectin (Knee, 1982a). Dissolution of the pectic polymers is known to be caused by a number of different enzymes. One in particular, polygalacturonase, has been extensively studied. Rapid softening has been associated with a rise in activity of polygalacturonase that accounts for the decline in the viscosity of the fruit pectin. This enzyme could also account for the solubilisation of pectin in pears, but not in apples (Bartley *et al.* 1982). Anoxia inhibited the synthesis of wall degrading enzymes necessary to the softening process. Additional factors are involved in the textural changes that occur in the early stages of ripening (Knee, 1982b).

All the changes in cell walls during the softening process are affected by various kinds of factors both pre and/or postharvest, and by maturity at harvest, these being reviewed below.

2.3.1 Preharvest Factors

2.3.1.1 Genetic Make-up

It is known from some fruits, such as apple and nectarine, that a small change in the genetic make-up of the fruit can cause wide variation in the rate of fruit softening (MacRae *et al.* 1990). Different pear cultivars soften in different ways and they have different limits of coolstorage life (Vangdal, 1982; Wang, 1988).

2.3.1.2 Climate

Preharvest climatic conditions can affect the softening process of fruits. Abnormally cool temperatures during the 4-5 weeks before harvest were shown to be a major element promoting premature ripening in 'Bartlett' pears. Fruit of this cultivar exposed to cool temperatures developed accelerated rates of softening, yellowing, and ripening. A factor such as climate is difficult to control, but an understanding of how postharvest quality is influenced by this factor should aid in predicting the postharvest behaviour of fruit and help in planning an orderly marketing programme (Wang *et al.* 1971).

2.3.1.3 Fruit Position on Tree

The light microclimate within fruit trees plays an important role in the production of maximum yields of high-quality fruit. Kappel (1989) reported that shade reduced 'Bartlett' pear fruit size and influenced fruit quality. Firmness of green mature fruit was significantly increased by the shading treatments. Mean fruit weight and TSS of mature fruit were significantly reduced by shading treatments. The author suggested that the increased firmness and reduced soluble solids content of the mature fruit indicated that shading delayed the maturity of pears. This would account for a portion of the within tree variation in fruit maturity that can occur in pear trees. The total sugar content and soluble solids content of ripened fruit were also reduced by shading (Figure 2.6).

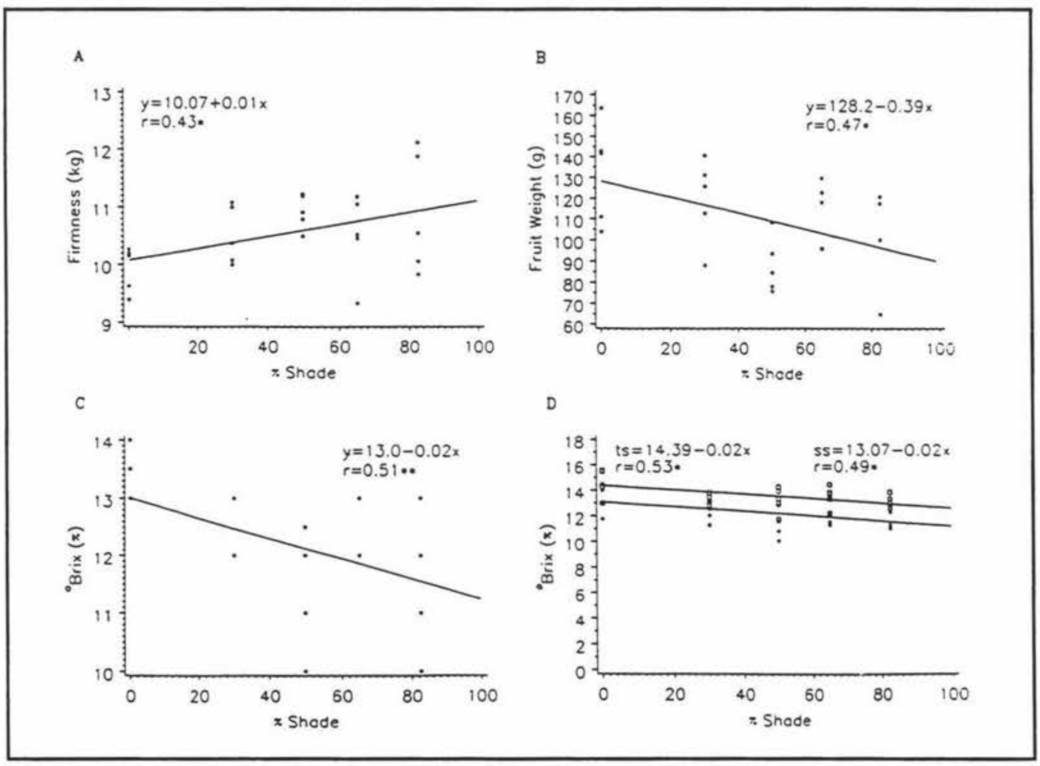


Figure 2. 6 Response of (**A**) fruit firmness, (**B**) fruit weight, and (**C**) soluble solids concentration of green mature 'Bartlett' pear fruit, and (**D**) total sugars (top line) and soluble solids content (bottom line) of ripened 'Bartlett' pear fruit to various shade treatments. For r, * and ** indicate significance at the 5% and 1% levels, respectively (Kappel, 1989).

Ramos *et al.* (1994) studied the relationship between position in the tree canopy and fruit size, maturity and quality of 'Bartlett' pears. Evaluation of the fruit from various locations in the tree indicated that fruit associated with the shaded spurs in the lower inside part of the canopy were significantly smaller than fruit on the outer part of the canopy or top of the tree. The interior shaded fruit were significantly greener in colour and had lower soluble solids content and higher titratable acidity. Fruit firmness was not influenced by canopy position (Table 2.5).

Table 2. 5 Effect of canopy position on specific leaf weight, fruit size and maturity. Values with the same letter are not significantly different by Duncan's multiple range test, P≥0.05 (Ramos *et al.* 1994).

Light Exposure	SLW (mg/cm^2)	Wt/Fr (g)	Colour (CIEa*)	S.S.C. (%)	T.A. (%)	Firm. (N)
Highly Exposed (SLW 11-14)	12.34 a	155 a	-17.7 a	11.0 a	0.23 c	80 a
Intermediate (SLW 9-11)	10.36 b	155 a	-17.8 a	10.6 a	0.25 b	77 a
Highly Shaded (SLW 6-9)	7.50 c	125 b	-18.7 b	9.0 b	0.27 a	78 a

Variation among microsites within a 'Comice' pear tree has been shown to affect fruit N concentrations and may contribute to intracanopy variability in fruit size and quality. It has been shown that specific leaf weight (SLW) and N per unit leaf area increase with available light and that SLW is highly indicative of the level of natural light exposure within tree canopies (Sanchez *et al.* 1991).

2.3.1.4 Calcium

Fruit calcium content is another factor that can influence fruit softening. This nutrient has received considerable attention in horticultural products because of its relationship to physiological disorders and for its other desirable effects such as extended storage life and increased firmness. Ca is an important constituent of cell walls and membranes. It also plays an important role in protecting the cell from toxins and can slow the aging process (Vang-Petersen, 1980; Ferguson and Drobak, 1988).

Low Ca fruits soften faster during and following storage, they may develop low-temperature disorders, or more rots. There is a positive role of Ca in prolonging storage life of pears. High levels of Ca in pear fruit are associated with slow cell degeneration, and slower ripening and senescent breakdown (Eksteen *et al.* 1986; Van-Zyl and Wagner, 1986).

High calcium concentrations are found in the middle lamella of the cell wall, at the exterior surface of the plasma membrane, in the endoplasmic reticulum and in the vacuole (Vang-Petersen, 1980). In the middle lamella Ca is bound to the R.COO group of the polygalacturonic acids (pectin) in a readily exchangeable form. Ca bound as pectate in the middle lamella is essential for the strengthening of cell walls of plant tissues. The degradation of pectates is mediated by polygalacturonase, which is drastically inhibited by high Ca concentrations. In Ca-deficient tissue, some enzymatic activity is increased causing typical symptoms, the disintegration of cell walls and the collapse of the affected tissues (Vang-Petersen, 1980).

2.3.2 Maturity at Harvest

Maturity at harvest is a factor that influences fruit softening. Proper maturity for picking is especially important because it assures the best eating quality and also because a pear with full maturity is less susceptible to physiological disorders and retains better capacity for ripening after long storage. Unlike some other fruits, the full flavour of a pear can only be developed after adequate ripening (Mellenthin and Wang, 1974; Chen and Mellenthin, 1982; Eccher Zerbini *et al.* 1993).

Harvesting fruit at the proper stage of maturity is an important management tool that the industry has at its disposal to optimise fruit storability and postharvest quality in the market place. Storability is known to be highly dependent on fruit maturity at harvest (Kvåle, 1986; Reid, 1992; Eccher Zerbini *et al.* 1996). Monitoring the maturity status of fruit, and using this to determine average maturity level at harvest, therefore, provides the orchardist with the capacity to manage the storability of the harvested fruit (Wang, 1982; Watada, 1995).

Growers often attempt to harvest their fruit too early so as to take advantage of market conditions, however they are reducing fruit quality, because fruit fail to develop full colour, aroma and flavour. Over-mature fruits, on the other hand, are prone to excessive ripening and are more susceptible to bruising, senescent breakdown, and decay during storage (Beaudry *et al.* 1993).

The influence of maturity at different harvest dates on ripening physiology was studied in 'La France' pears. As harvest date was delayed and ripening temperature was raised, the number of days from harvest to full ripeness became shorter. Pear quality was reduced more rapidly in early-harvested fruit ripened at 20°C than in late-harvested fruit ripened at either 15°C or 10°C. As harvest was delayed, total sugar content became higher and starch content was lower at harvest. The maximum content of soluble pectin was reduced during ripening as harvest date was delayed (Kitamura, 1987).

The effect of different degrees of maturity on quality during ripening of 'Conference' and 'Comice' pears has been studied by Eccher Zerbini *et al.* (1993). Although at harvest the starch content and firmness were not different between harvest times, differences in quality became evident after ripening; mature fruit of both cultivars had better sensory quality but were more prone to decay. The rate of softening was different, within the same cultivar, for fruit of different maturity (Eccher Zerbini *et al.* 1993).

Recently, softening of both 'Comice' and 'Bosc' pears has been shown to be affected by harvest date. Early-harvested fruit required longer periods of storage than late-harvested fruit before they reached full ripening potential. The differences in results were related to cultivar, but effect of harvest date was related with wide maturity ranges associated with prolonged periods of bloom (Elgar *et al.* 1997).

2.3.3 Postharvest Factors

2.3.3.1 Storage Temperature

Storage conditions after harvest are very important for pears. Certain winter pears require a period of chilling before normal ripening takes place at room temperature. Fruit stored at the optimum storage temperature of -1.1°C are actually undergoing the essential chilling treatment (Hansen and Mellenthin, 1979). The degree of pear maturity at harvest influences the period that fruit need to be in coolstorage to develop capacity for ripening. Late-harvested 'Anjou' pears at a flesh firmness of 58 to 53 N (measured with a 7.9 mm tip) ripened with fair to good quality following 30 days storage at -1.1°C, while the same cultivar harvested at optimum flesh firmness of 62 to 60 N required 60 days of postharvest chilling to ripen with good quality. Late-harvested 'Bosc' pears at flesh firmness of 58 to 53 N required less than 7 days chilling at -1.1°C to develop the ripening capacity while 'Bosc' pears harvested with flesh firmness of 63 to 60 N were capable of ripening after 10 days chilling (Chen and Mellenthin, 1982).

Controlled atmospheres (especially high CO_2 and low O_2), low temperature, and calcium chloride treatments have been successfully used in controlling the rate of pear ripening and softening. Low-oxygen storage reduces the respiration rate and ethylene production of pears. Generally, the reduction of respiration rate and ethylene production of fresh pears have been assumed to be the main reasons for the beneficial effect of reduced O_2 and/or elevated CO_2 (Wills *et al.* 1989). It is evident from the data shown in table 2.6, that pears in 3% O_2 storage were firmer than those stored in air. On removal from storage, internal ethylene levels were found to be slightly higher in 3% O_2 stored fruits compared to those stored in air, but over the first hours at 20°C the internal ethylene in the former fruit rose significantly, and rapid softening and ripening occurred in pears stored in low-oxygen atmosphere. As with the ethylene, the internal CO_2 evolution on removal from low oxygen storage, was a function of length of storage period. A more pronounced increase in internal carbon dioxide levels was detected during the first hours at 20°C in the more mature fruits. Internal CO_2 levels rose followed the increase in internal ethylene concentration. The maturation of pears cool stored in air during 4, 5 or 6 weeks was enough to induce an immediate rise in endogenous CO_2 levels when transferred to 20°C. Merodio and De la Plaza (1989) suggested that these results make it possible, by following the changes especially in the internal ethylene concentration during the first hours at 20°C, to estimate the physiological maturity of fruit held in coolstorage.

Table 2. 6 Firmness (N) of pears during coolstorage at 0°C, either in 3% O_2 or in air, and during ripening at 20°C (Merodio and De la Plaza, 1989).

Treatment ($\%O_2$) $\%CO_2$	Storage time (weeks)	Two	Two	Six	Six
	Days at 20°C	0	0	2	6
(3) 0		47 ± 1.96	34 ± 0.69	16 ± 1.86	8 ± 0.49
(21) 0		42 ± 1.57	14 ± 0.98	10 ± 0.69	9 ± 0.9

In the investigations reported by Topping (1978), the freezing points of 'Bartlett' pears were found to fall between -3°C and -0.8°C and were closely related to the dissolved solids levels. Soluble solids of 11% corresponded to a freezing point of -1.9°C or lower. Small increments in temperature above the freezing point of the fruit had an effect on its storage life. From these data the author concluded that pears that contain less than 11% of soluble solids in the juice should be stored at higher temperature than normally is recommended (-1°C).

Maintaining 'Bartlett' pears in a storage temperature of -1°C was effective in extending their storage life by 40% and 70% over temperatures of 0°C and 1°C, respectively (Table 2.7). In the same research, Porrit (1964) studied changes in firmness of 'Anjou' pears during storage at various temperatures. Firmness changed at a fairly uniform rate at temperatures of 0°C to 4°C and therefore was a useful means of evaluating the condition of the fruit. From these studies it was estimated that storage at -1.1°C increased the life of 'Anjou' pears by 35% and 125% over that at 0°C and 1.1°C, respectively.

Table 2. 7 Influence of temperature on storage life of 'Bartlett' pears (Porrit, 1964).

Storage temp. (°C)	Time for colour change (days)	Max. useful storage life (days*)	Time until ripe or failure to ripen normally (days)
21	7		10
16	9		13
10	13		18
4	23	20	24
2	30	40	56
1	45	70	85
0	55	85	100
-1	115	120	140
-2	100	100	112

*Maximum period fruit could be held in storage and still ripen normally.

A strong relationship has been found by Downs *et al.* (1989) between the accumulated heat units (AHU) experienced between harvest and storage, and fruit softening and yellowing after storage of 'Packhams Triumph' pears. Fruit exposed to low AHU had greater visual and eating appeal and lost less fresh weight during storage and in the shelf period. Fruit that had begun ripening before storage had a greater incidence of core flush and senescent breakdown disorders when assessed 16 weeks after harvest. This research suggested that there was benefit in cooling pears to storage temperature as soon as possible after harvest (Downs *et al.* 1989).

According to this literature review, considerable information is available on the biology and biochemistry of pears, and for some cultivars on some aspects of its preharvest and postharvest behaviour. Nevertheless, a complete characterisation of maturation on the tree, during coolstorage and ripening of 'Comice' pears has not been available. It is important to consider the many preharvest factors which influence postharvest fruit quality, and fruit softening behaviour. In this research the effects have been studied of such preharvest factors, for example harvest date, position on the tree and crop load, on post-storage behaviour of 'Comice' pear. In this study, correlations between harvest data and post-storage data on the same fruit using non-destructive assessments have been made. The overall purpose of this work was to identify ways to reduce fruit quality variability in the market place and allow increased profit from the pear export crop.

3. Characterisation of maturation and ripening of 'Doyenne du Comice' pears.

3.1 Introduction

The concept that consumers have about what constitutes a high-quality pear results from the assessment of several external and internal attributes. Customers purchasing fruit must choose it on the basis of its external appearance. External attributes such as size and colour, therefore, strongly influence purchase decisions. However a final judgement cannot be made until internal factors such as flavour, firmness and total soluble solids (TSS) are experienced when the fruit is eaten (Quamme and Gray, 1985). If they like the fruit, consumers continue to purchase fruit from the seller and are willing to pay good prices for the product (Kingston, 1993). Fruit of consistently high quality win consumer favour and realise top prices. Therefore, it is important to have fruit of uniformly high quality in a box or bin presented for sale.

Variation in firmness, rate of softening, colour and TSS after storage causes problems in the marketing of 'Doyenne du Comice' pears (*Pyrus communis* L.). Some of these problems might be reduced if maturity variation could be detected in the orchard or on the grading line. In the current work, maturation and ripening of 'Comice' pears were characterised using both non-destructive and destructive assessments before harvest, at harvest, and during and after coolstorage. These characterisations should permit associations between fruit attributes before or at harvest and subsequent softening behaviour to be identified. Such information could be used to make predictions that could reduce variability in fruit quality in the market place.

Decreasing fruit firmness as maturity approaches is well documented in pear (Bain, 1961; Wang *et al.* 1972; Mann and Singh, 1985; Wrolstad *et al.* 1991; Eccher Zerbini *et al.* 1996). Eccher Zerbini *et al.* (1996) reported that in 'Comice' pears the rate of change in flesh firmness changed significantly before they reached commercial maturity. The continued decrease in fruit firmness in pears reaching maturity may be attributed to dissolution of insoluble pectin fractions into soluble pectins in the cell sap and in the middle lamella (Bain, 1961).

Wang (1982) found flesh firmness one of the most satisfactory ways to characterise pear maturation. This approach is also used by storage operators and researchers for monitoring pear response to storage conditions. However, the rate of change in fruit firmness may vary between seasons and in relation to other maturity indices. Such inconsistencies, and the large influence of outside factors on the level of fruit firmness, indicate that this attribute has to be used in conjunction with measurements of other fruit attributes to give a good indication of progress in the processes of 'Comice' maturation and ripening.

Recommended levels of firmness at harvest have been developed for each pear cultivar to ensure acceptability to the consumer after storage. A range of acceptable firmness levels allows for fluctuations between seasons (Wang, 1982). Additional variation has to be permitted if firmness is measured destructively by penetrometer because penetrometer readings can vary with the operator (Hopkirk *et al.* 1996; Harker *et al.* 1996; Lehman-Salada, 1996). Penetrometer readings can also be affected by variation in properties with depth into the fruit because a skin slice must be removed which may vary in thickness depending on the cutting method and the softness of the fruit (Davie *et al.* 1996). Use of the penetrometer punctures the fruit, and thus only a sub-sample from the population can be tested. Non-destructive and non-damaging tests could potentially allow testing of every individual fruit, and repeat testing of the same fruit. They would also provide useful tools for characterising patterns of firmness change with time (Hopkirk *et al.* 1996; Macnish *et al.* 1997), providing advantages for research and the industry alike.

The Kiwifirm (Hopkirk *et al.* 1996) and softness meter (Davie *et al.* 1996) are non-destructive testers of fruit firmness, though neither has been developed for commercial use at this point. In this work, these devices were compared with the penetrometer for their ability to characterise softening behaviour of pears in the context of both maturation on the tree and ripening after harvest. Other fruit attributes, such as size, colour, TSS and starch index were also measured in this work, to characterise maturation and ripening during the same periods.

3.2 Materials and Methods

3.2.1 Experimental Material

Ten similar 'Comice' trees (Fig. 3.1) on quince BA29 rootstocks grown at the Fruit Crops Unit (Block P3) of Massey University in Palmerston North, were used in the study. Trees were 4 years old and 3.5 m tall and were trained as central leader pyramids.

3.2.1.1 1996 Experiment

A 20 fruit sample consisting of 2 fruit per tree harvested randomly from the same 10 trees was gathered every 3 or 5 days, starting 23 days before commercial harvest (5 samples), at harvest (1 sample), and from coolstorage weekly for 60 days after harvest (8 samples). Two groups of samples (7 and 8 samples), were evaluated after coolstorage at 0°C for 4 or 9 weeks respectively, every two days at 20°C, to characterise softening behaviour after coolstorage.

3.2.1.2 1997 Experiment

A 20 fruit sample consisting of 2 fruit per tree harvested randomly from the same 10 trees was gathered every 3 days, starting 15 days before commercial harvest (5 samples), at harvest (1 sample), and from coolstorage weekly for 49 days after harvest (7 samples). Of a group of 6 samples, 1 was evaluated, after coolstorage at 0°C for 7 weeks, every two days at 20°C, to characterise softening behaviour after coolstorage.

Details of harvesting dates are shown in Table 3.1.

A

B

Figure 3. 1 Views of A) the block of 'Comice' pear trees and B) an individual 'Comice' pear tree used in the experiments described herein at the Fruit Crops Unit, Massey University, Palmerston North.

Table 3. 1 Commercial and experimental harvesting dates for 'Comice' pears at Fruit Crops Unit, Massey University in the 1996 and 1997 seasons.

Season	*Experimental harvest date*	*Commercial harvest interval*	
		Opening	*Closing*
1996	18 March	11 March	26 March
1997	12 March	5 March	22 March

3.2.2 Measurements

For all samples on which both non-destructive and destructive tests were carried out, all measurements were made on the same day. All fruit were evaluated after equilibration for 20 h at 20°C.

3.2.2.1 Fruit Size

Fruit size was characterised by fruit length, diameters, and weight in 1996, and by fruit weight in 1997.

Each fruit was weighed using a Mettler balance (model PM6100; Mettler Instrument AG, CH-8606, Greifensee, Zürich, Switzerland) to the nearest 0.1 g.

Length of each fruit was measured using a Mitutoyo digital calliper (Mitutoyo Corporation, Japan). Two diameters on the equator of each fruit were similarly measured, one from the blushed (red) to the shaded (yellow) side of the fruit, and the other at 90° to this.

3.2.2.2 Firmness

Firmness was assessed by Kiwifirm (Fig. 3.2A) and penetrometer (Fig. 3.3A) in 1996 and by Kiwifirm, penetrometer, texture analyser (Fig. 3.3B) and softness meter (Fig. 3.2B) in 1997. For all firmness measurements, care was taken to avoid areas of sunburn, bruising or russeting on the skin as these can give abnormal readings. Fruit firmness was measured non-destructively with the Kiwifirm

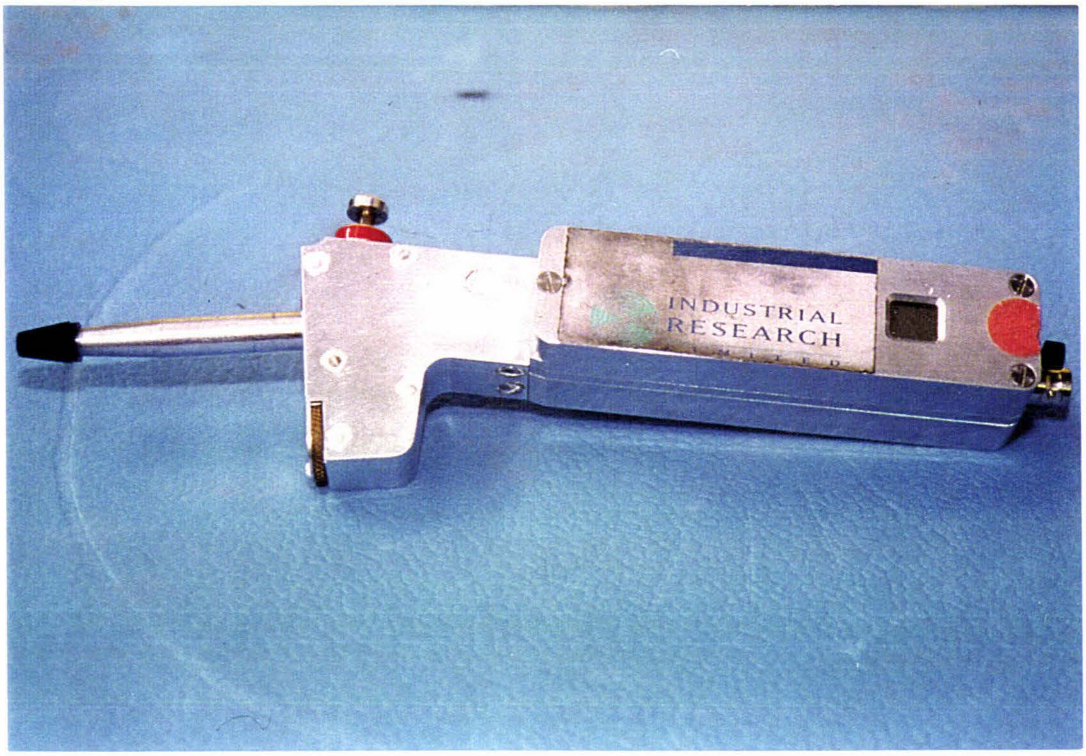
(Industrial Research Limited, Auckland, New Zealand). Both blushed and shaded sides of each fruit were tested. Measurements on both sides of each fruit were recorded separately. Fruit firmness was also measured non-destructively with the 'Softness meter' during and after coolstorage. As described by Davie *et al.* (1996), the 'Softness meter' had a micrometer that was pre-set to zero at the initial location of the fruit surface and measured displacement of the fruit surface after application of a 100 g weight. Measurements were taken slightly before any contact with the fruit surface by pressing a button which transferred three micrometer readings per second to a computer data acquisition system for 5 s. Data used excluded all negative readings (before contact with the fruit surface) and the first three positive readings. Raw data were converted to softness coefficients as described by Davie *et al.* (1996).

Fruit firmness was measured destructively on both sides of each pear after removing a 1 mm thick slice of skin/outer cortex, using a press-mounted Effegi penetrometer (model FT 327; 48011, Alfonsine, Italy) with a 7.9 mm diameter probe. The penetrometer was pre-calibrated using a 3 decimal point top loading balance (model FM 460 Mettler-Delta range; Mettler Instrument AG, CH-8606, Greifensee, Zürich, Switzerland). Both blushed and shaded sides of each fruit were tested, and measurements were recorded separately. Penetrometer values in kgf were converted to Newtons (N) by multiplying values by 9.807 (Soule, 1985).

In the 1997 season, firmness readings were also made on peeled surfaces of both sides of each pear using a 'Texture Analyser' (model TA-XT2; Stable Micro Systems) with a 7.9 mm diameter penetrometer probe. Both blushed and shaded sides of each fruit were tested.

Previous publications have reported penetrometer data for pears obtained using either 7.9 mm or 11.1 mm probes (Kappel *et al.* 1995). In order to be able to compare these data with those from the present study, the relationship between data obtained using both sizes of tips was developed using the 'Texture Analyser'. A group of 11 samples of 5 pears each was held at 20°C. One sample was evaluated every two days to obtain a wide range of firmness values. Both blushed and shaded sides of each fruit were tested.

A



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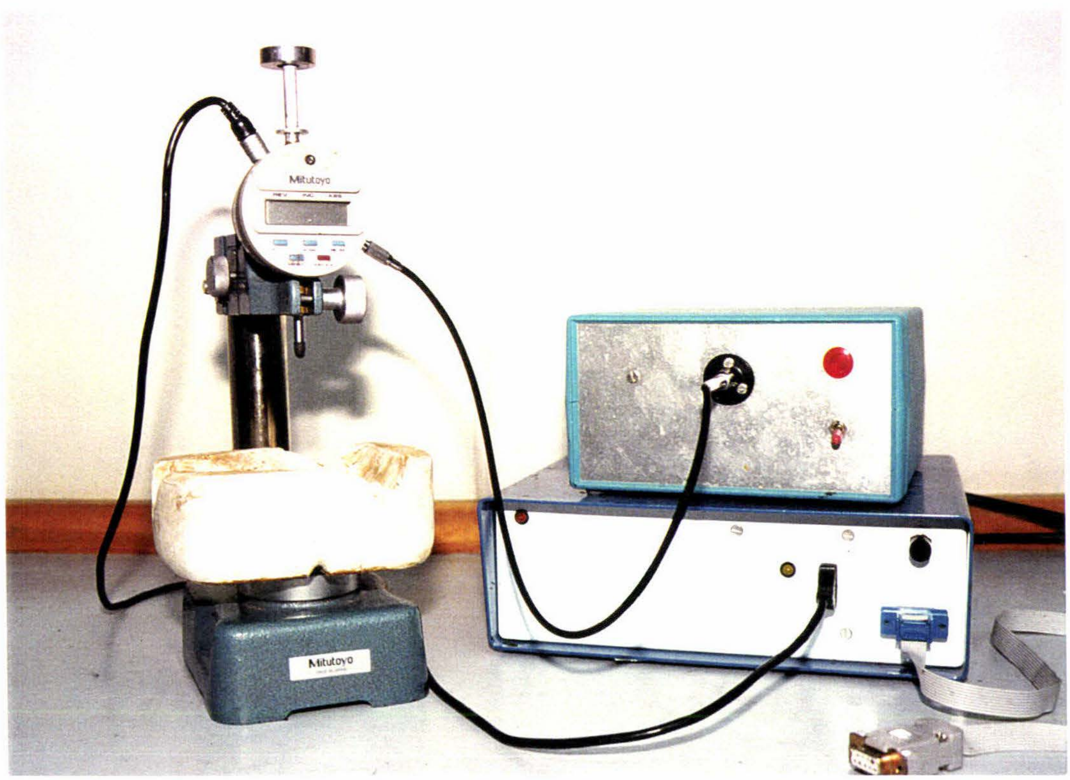
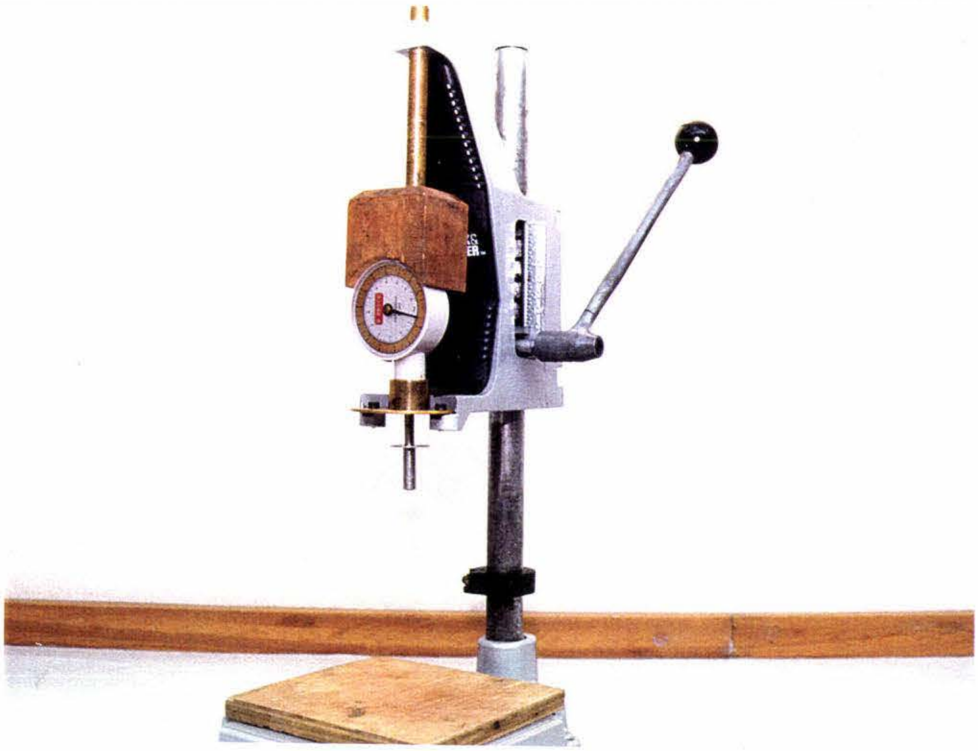


Figure 3. 2 A) the 'Kiwifirm' and B) the 'Softness meter' as used in the experiments described herein.

A



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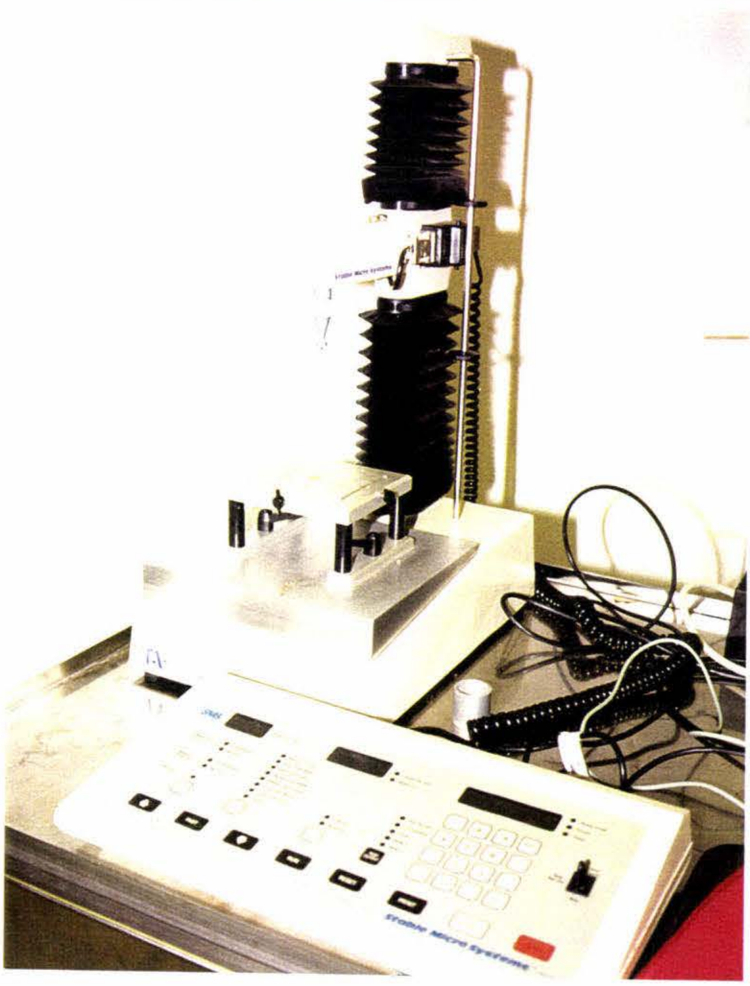

Figure 3. 3 A) the press-mounted penetrometer and B) the texture analyser as used in the experiments described herein.

3.2.2.3 Skin Colour

Skin colour was measured at two opposite points on the equator of each fruit, these points being midway between the blushed and shaded sides. Care was taken to avoid russet or marked areas of the skin. Instrumental colour measurement was carried out using a portable chromameter (model CR-200; Minolta Camera Co. Ltd., Osaka, Japan) equipped with a 10 mm diameter aperture on the measuring head. This was calibrated to a green standard plate ($Y = 29.9$ $\chi = 0.273$ $\gamma = 0.369$) with viewing geometry d/0. Results were recorded as L (Lightness), C (Chroma), and H (Hue angle; McGuire, 1992).

3.2.2.4 Total Soluble Solids

Values for TSS (°Brix) were determined using an Atago (model N-20; Atago Co., Ltd., Tokio, Japan) hand-held refractometer after mixing a drop of juice from each of the two penetrometer wound sites.

3.2.2.5 Starch Index

Each pear was transversely cut at the equator and one half was placed, cut surface down, for 2 minutes in a solution of potassium iodide (1% w/v) and iodine (0.25% w/v). The resulting pattern on the cut surface was scored on a scale from 0 to 6 where 0 indicated the least and 6 the most starch to sugar conversion (see Appendix A1).

Assessments of flesh firmness by penetrometer, and starch pattern index were made following the specifications for 'Comice' from ENZA Fruit New Zealand - International (see Appendix A2).

3.2.3 Statistical Analyses

Curves were fitted using the PROC NLIN procedure of the SAS system (SAS, 1990).

3.3 Results

Data from 1996 and 1997 generally were very similar, unless data for both years are presented.

3.3.1 Fruit Size

Fruit size increased with the advancement of the growing season (Figs. 3.4A-C) and decreased gradually in coolstorage and during ripening. Fruit growth rate and size at harvest maturity were similar in both seasons. Pears reached a given weight later in 1996 (18 March) than in 1997 (12 March; data not shown). However, the blossom date had differed by 3 days (full bloom was on 15 Oct. and 12 Oct., respectively).

There was no clear relationship between fruit size and the other maturation attributes measured. Length, diameter and weight increased significantly between harvest dates when they were analysed by univariate analysis. Diameter was the attribute that better characterised fruit size considering different harvest dates when data were analysed with canonical discriminant analysis.

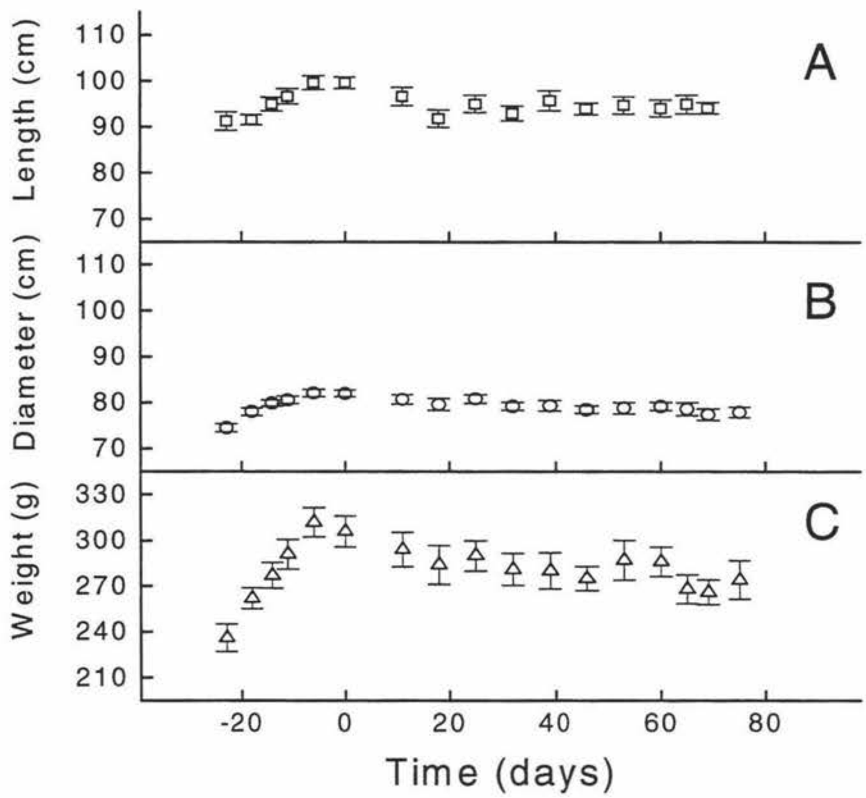

Figure 3. 4 Changes with time, relative to commercial harvest date (day 0), in A) length, B) diameter, and C) weight of 'Comice' pears in 1996. Commercial harvest date was 18 March 1996. Fruit were taken from coolstorage 9 weeks after harvest (day 63).

3.3.2 Firmness

Fruit firmness decreased continuously with time during maturation and ripening, but only slightly during coolstorage (Figs. 3.5A,B and 3.6A-D). Kiwifirm was able to measure firmness on softer fruit than the other devices.

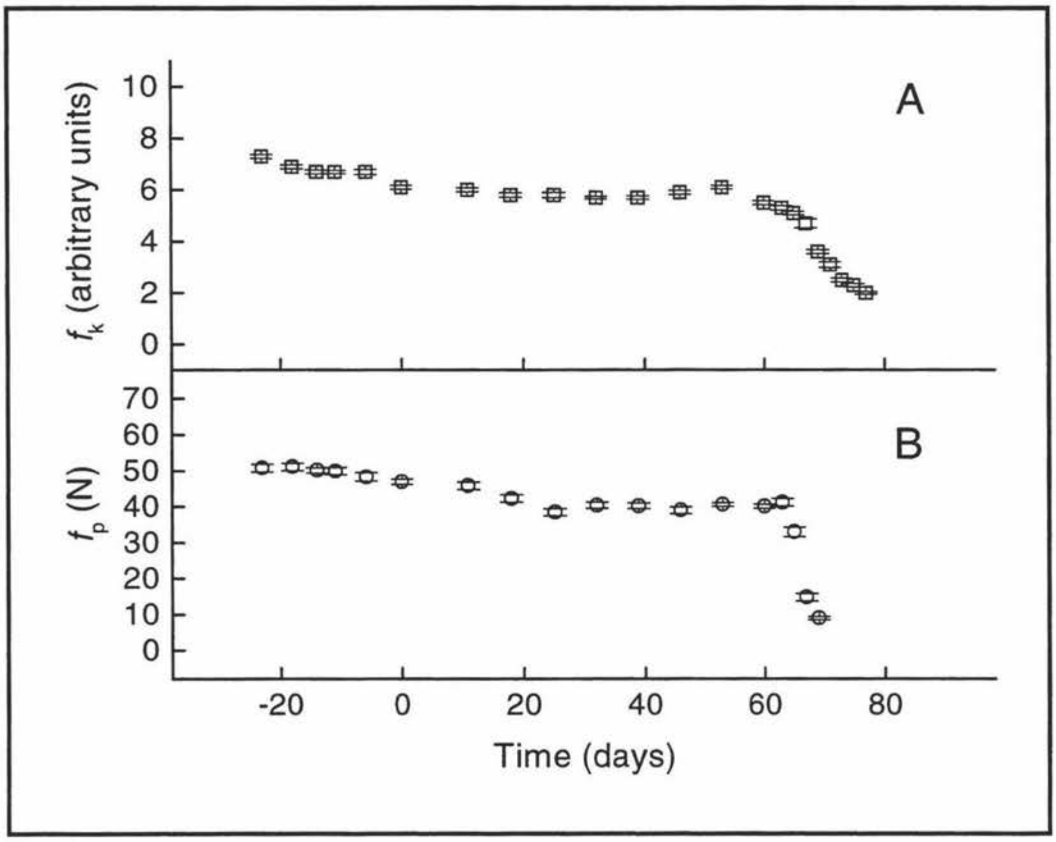

Figure 3. 5 Changes with time, relative to commercial harvest date (day 0) in firmness at 20°C of 'Comice' pears in 1996, assessed A) by Kiwifirm (f_k) and B) by penetrometer (f_p) before harvest, during storage at 0°C and during ripening after 9 weeks of coolstorage. Data represent averages for samples of 20 fruit. Bars indicate ± standard error of the mean. Penetrometer readings after 69 days were too low to be recorded. Commercial harvest date was 18 March 1996. Fruit were taken from coolstorage 9 weeks after harvest (day 63).

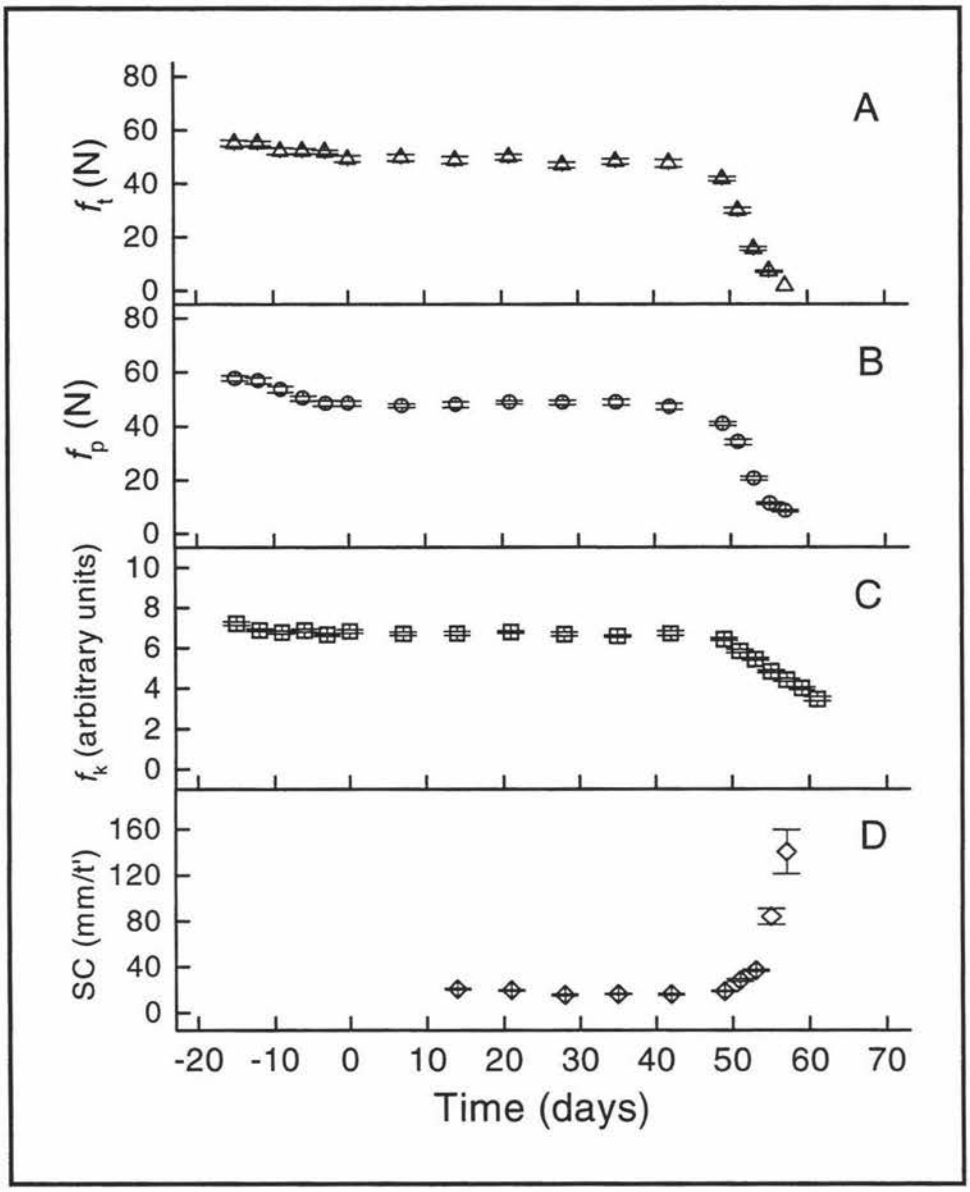

Figure 3. 6 Changes with time, relative to commercial harvest date (day 0), in firmness at 20°C of 'Comice' pears in 1997, assessed by A) texture analyser (f_t), B) penetrometer (f_p), C) Kiwifirm (f_k) and D) softness meter (SC) before harvest, during storage at 0°C and during ripening after 7 weeks of coolstorage. Data represent averages for samples of 20 fruit. t' = ln (time in s). Bars indicate ± standard error of the mean. Texture analyser, penetrometer and softness meter readings after 58 days were too low to be recorded. Commercial harvest was 12 March 1997. Fruit were taken from coolstorage 7 weeks after harvest (day 49).

Firmness measured in 1996 with both Kiwifirm and penetrometer before harvest (Fig. 3.5A,B) had a linear, declining relationship with time (t):

$f_k = 6.05\ (\pm 0.05) - 0.05\ (\pm 0.01)\ t,\ r^2 = 0.99;$

$f_p = 47.28\ (\pm 0.44) - 0.19\ (\pm 0.03)\ t,\ r^2 = 0.95.$

The relationship between Kiwifirm and penetrometer was different depending on the period considered. Visually, it is clear that there was some systematic deviation from linearity in this relationship, with the slope being steeper at low than at high penetrometer values (Fig. 3.7).

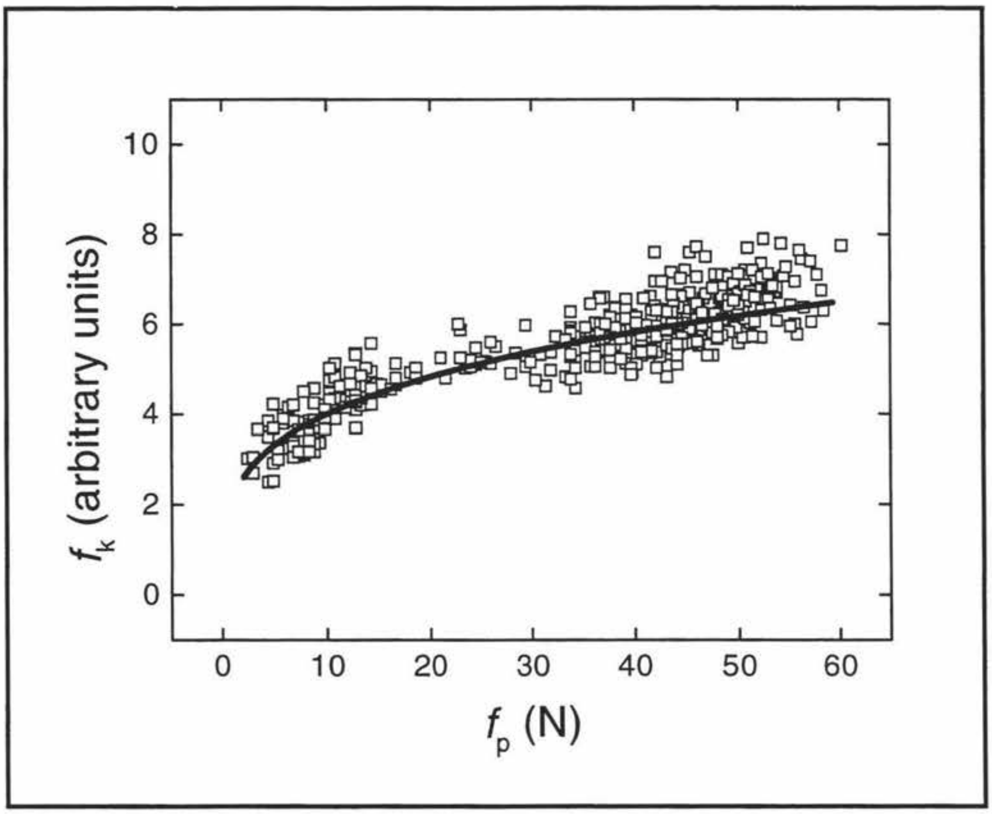

Figure 3. 7 Relationship between firmness of 'Comice' pears measured by Kiwifirm (f_k) and by penetrometer (f_p) on 29 samples of 20 fruit measured from before harvest until ripening in 1996. $f_k = 2.15\, f_p^{\ 0.27}$.

The relationship between penetrometer readings obtained by press-mounted penetrometer and by texture analyser was largely linear and positive in 1997, though there was some evidence for a curve in the relationship at low firmness levels

(Fig. 3.8A). The relationships between firmness measured by Kiwifirm and measured by penetrometer or texture analyser showed a similar tendency to that found in 1996 (Figs. 3.8B and C, Fig. 3.7).

Firmness measured by softness meter was hyperbolically and negatively related to firmness measured by penetrometer, texture analyser or Kiwifirm (Figs. 3.8D-F respectively).

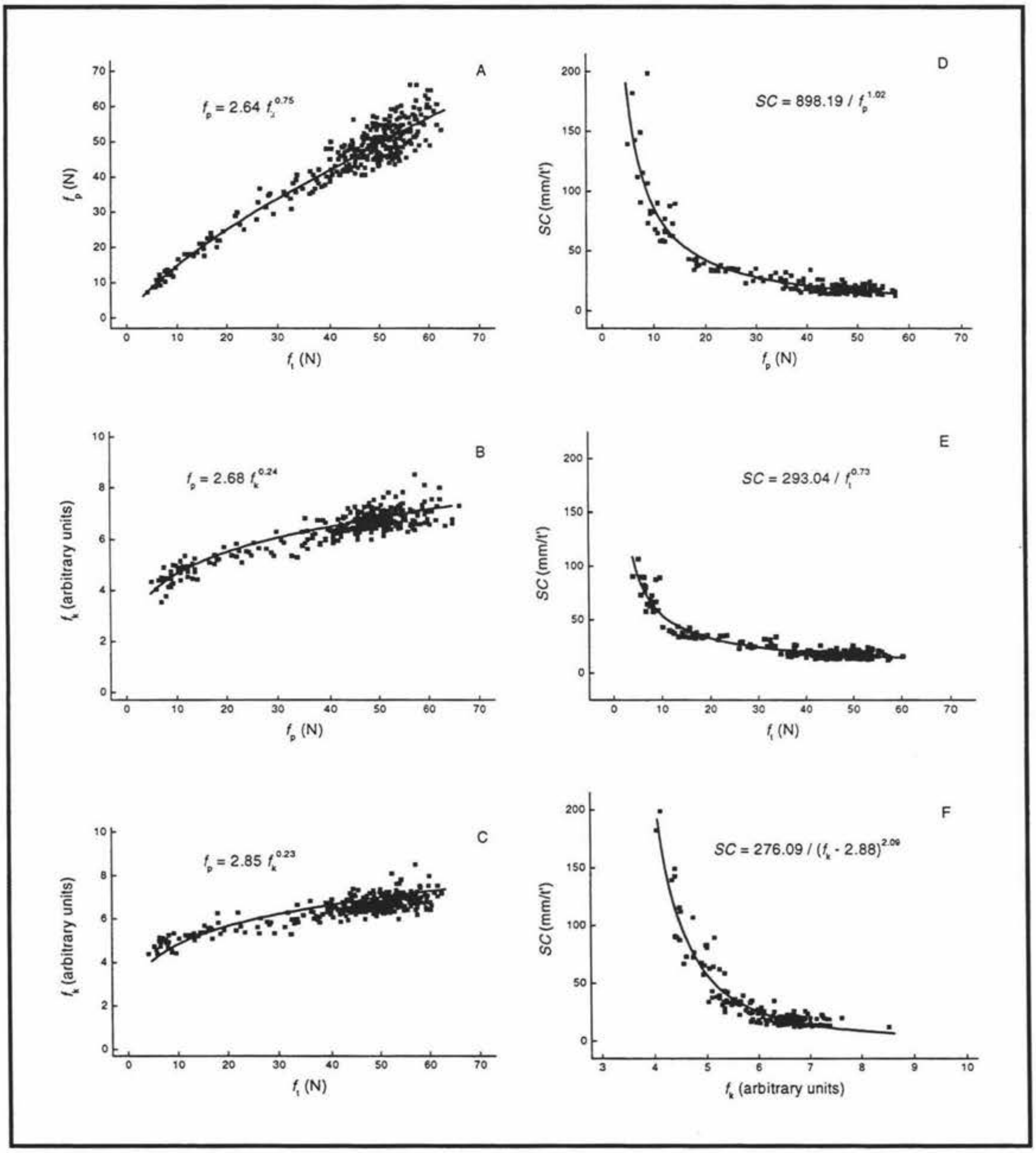

Figure 3. 8 Relationship between firmness measured by different devices in 1997 (f_p = by penetrometer, f_t = by texture analyser, f_k = by Kiwifirm) where N = Newtons and SC = softness coefficient (mm/t') and t'=ln(time in s).

The relationship between firmness measured with 7.9 mm and 11.1 mm diameter probes on the texture analyser was curvilinear (Fig. 3.9). The 11.1 mm probe showed greater standard error of the mean than the 7.9 mm probe (Table 3.2). On firmer pears firmness readings with a 7.9 mm tip showed less variation than those obtained using an 11.1 mm tip (Fig. 3.9).

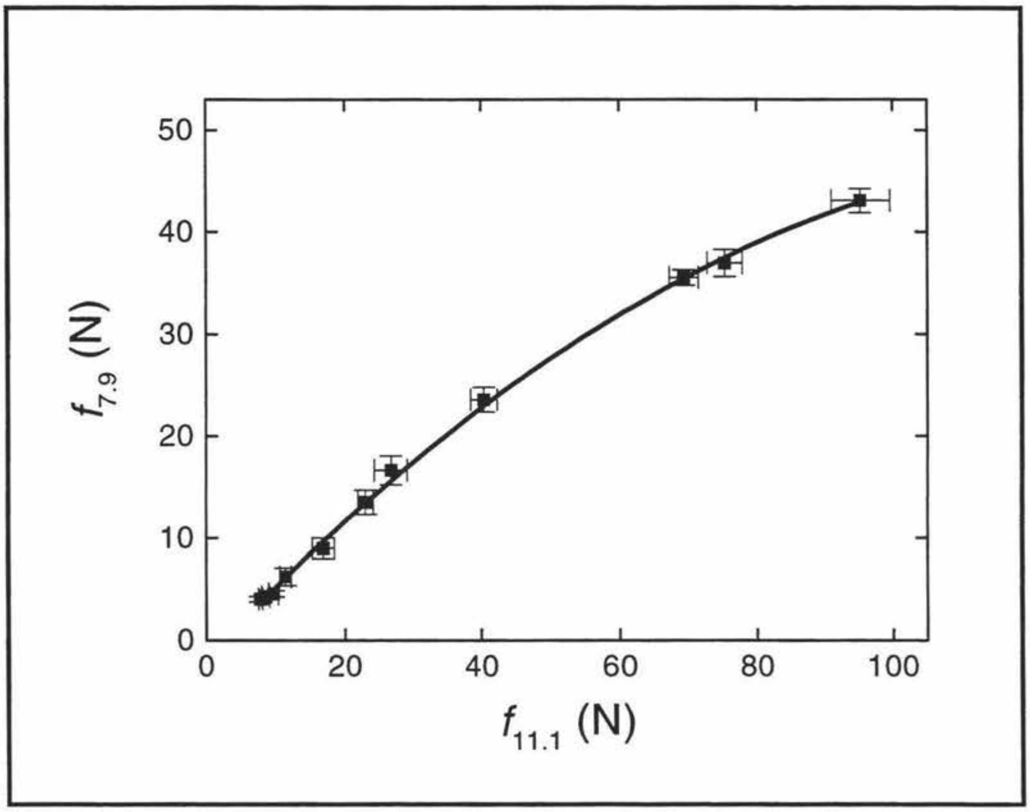

Figure 3. 9 Relationship between firmness determined with 7.9 mm and 11.1 mm probes used in a texture analyser, assessing firmness of 'Comice' pears in 1997; $R^2 = 0.99$, $f_{7.9} = 0.637\ (\pm 0.032)\ f_{11.1} - 0.0019\ (\pm 0.0004)\ (f_{11.1})^2$. Data represent averages of two measures on each pear for samples of 5 pears. Bars indicate ± standard error of the mean for each variable.

Table 3. 2 Firmness mean, standard error, coefficient of variation and minimum and maximum values for both 7.9 mm and 11.1 mm probes measured with a texture analyser on the same fruit samples in 1997 (n = 55).

Probe (mm)	Firmness Mean (N)	Standard error (mean)	Coefficient of Variation (mean)	Minimum Value (N)	Maximum Value (N)
7.9	18.0	± 1.26	21.07	3.1	48.8
11.1	34.9	± 2.30	18.56	6.0	120.1

3.3.3 Skin Colour

Lightness increased only slightly during the preharvest phase and during coolstorage, but increased significantly during ripening (Fig. 3.10A). Chroma remained approximately constant throughout (Fig. 3.10B). Hue angle decreased slightly before harvest and during coolstorage, but decreased substantially during ripening (Fig. 3.10C), corresponding to a change in colour from green-yellow to yellow.

In 1996, hue angle decreased in fruit kept for 4 or 9 weeks in coolstorage (Fig. 3.11). Fruit were more yellow after 9 weeks than after 4 weeks in coolstorage. However, hue angle decreased similarly and rapidly for both lots of fruit during ripening at 20°C after removal from storage.

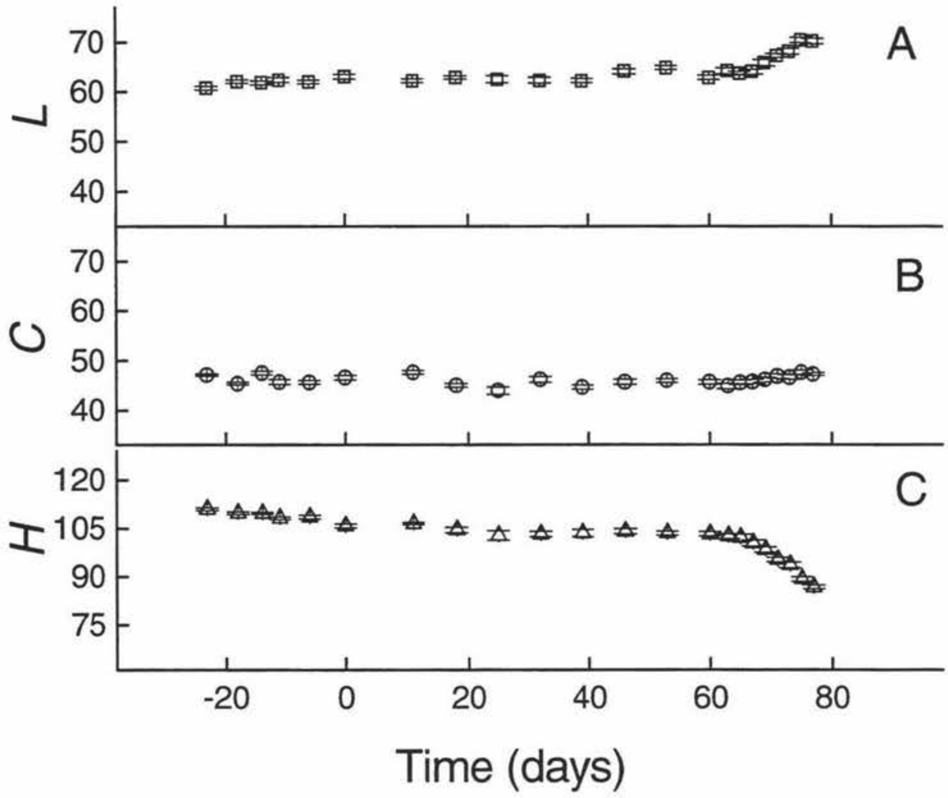

Figure 3. 10 Changes with time, relative to commercial harvest date (day 0), in A) lightness, B) chroma and C) hue angle of 'Comice' pears in 1996. Data represent averages for samples of 20 fruit. Bars indicate ± standard error of the mean. Commercial harvest was 18 March 1996. Fruit were taken from coolstorage 9 weeks after harvest (day 63).

Colour varied between seasons. Fruit from the same trees were more yellow (lower hue angle) at commercial harvest in 1997 than in 1996 and were more yellow after 7 weeks in coolstorage than fruit from 1996 season kept 4 or 9 weeks in coolstorage. Hue angle decreased to a similar final value during ripening in both seasons (Fig. 3.11).

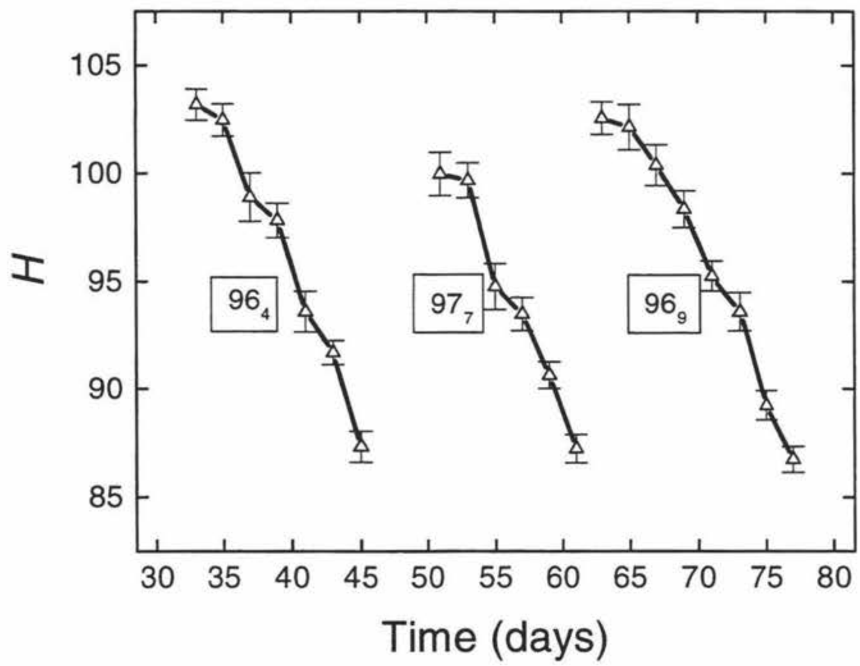

Figure 3. 11 Changes with time, relative to commercial harvest (day 0), in hue angle of 'Comice' pears at 20°C, after removal from 4 or 9 weeks at 0°C, in 1996 (96_4, 96_9) and after 7 weeks at 0°C in 1997 (97_7). Data represent averages for samples of 20 fruit. Bars indicate ± standard error of the mean. Commercial harvest dates were 18 March 1996, and 12 March 1997.

3.3.4 Total Soluble Solids

TSS showed a continuous increase in 'Comice' pears until ripening (Fig. 3.12A). Pears reached similar TSS values one week earlier (at commercial harvest) in 1997 than in 1996. Pears were harvested with about 15 °Brix in both seasons. TSS increased by approximately 1 °Brix from harvest to the end of ripening.

3.3.5 Starch Index

The starch index increased similarly in both seasons, with a value of 2 at commercial harvest during both seasons, continuing to develop, and reaching the score 5 or 5.5, in coolstorage (Fig. 3.12B). The index reached the full score of 6 during ripening.

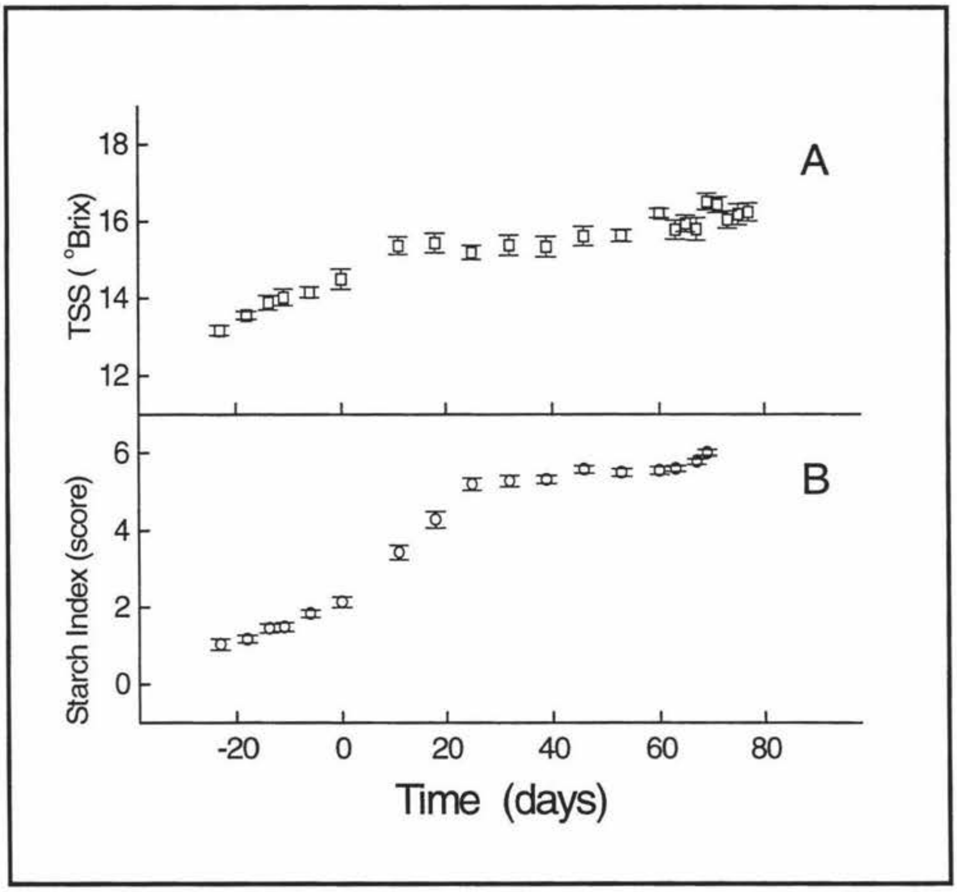

Figure 3. 12 Changes with time, relative to commercial harvest date (day 0), in A) TSS and B) starch index of 'Comice' pears in 1996. Data represent averages for samples of 20 fruit. Bars indicate ± standard error of the mean. Commercial harvest date was 18 March 1996. Fruit were taken from coolstorage 9 weeks after harvest (day 63).

3.4 Discussion

The processes of softening, growth, colour change and conversion of starch to sugars were analysed in 'Comice' pears during maturation and ripening. The morphological and physiological changes occurring during these stages followed similar patterns in the two seasons although the rate and magnitude of these changes varied from season to season, in common with observations by previous workers (Bain, 1961; Eccher Zerbini, 1996). Fruit took around 150 days after full bloom (dafb) to obtain harvest maturity during both the 1996 and 1997 seasons.

In this discussion, the processes of softening, and the influences of the technique of its measurement, and the other processes analysed are evaluated for their potential to provide useful characterisation of maturation and ripening in 'Comice' pears.

3.4.1 Softening

The decrease in flesh firmness before commercial harvest shows that the induction of softening in 'Comice' occurred before harvest. This has been established in previous studies (Wang *et al.* 1972; Mann and Singh, 1985; Eccher Zerbini *et al.* 1996). As firmness measured by Kiwifirm and by penetrometer before harvest decreased linearly with time, this should be a useful way to characterise pear maturation.

Kiwifirm was easier to use and firmness measured with this device was more straightforward than with the other devices. Variability of the data produced by Kiwifirm was less than that produced by penetrometer due, perhaps, to the reduction in potential for operator bias (Hopkirk *et al.* 1996; Harker *et al.* 1996; Lehman-Salada, 1996). However, the relative scale of difference indicated by the Kiwifirm was less than that measured by penetrometer, over penetrometer values from approximately 60 to 20 N Kiwifirm values varied only between 6 and 5 arbitrary units (Fig. 3.7). Kiwifirm was calibrated for use on kiwifruit, and it should be possible to recalibrate it for higher firmness levels. Below 20 N the relationship between penetrometer and Kiwifirm changed, with 20 to 5 N corresponding to about 5 to 3 arbitrary Kiwifirm units respectively. There is evidence in this changed relationship, and also in the fact that it was possible to measure softer fruit with Kiwifirm (see Figs. 3.2 A and B), suggesting that at lower firmness levels the skin makes an increased contribution to the Kiwifirm readings. This suggests that the contribution of the skin to Kiwifirm readings means that this device does not measure exactly the same "firmness" as the penetrometer. However, the relatively high f_k values obtained on soft fruit indicate that Kiwifirm may have potential for defining eating ripeness in 'Comice'.

Kiwifirm could also be useful for detecting changes in firmness occurring before harvest due to changes in external factors that can affect harvest date and subsequent fruit quality. Kiwifirm readings prior to harvest measured on the same fruit on the tree (data not presented) showed a strong linear relationship with time. Firmness is affected by temperature (Bourne, 1982); therefore measurements on the tree should preferably be made in the early morning, avoiding temperature variation as much as possible.

In general, it is believed that greater confidence in the results can be expected if the same sample is repeatedly tested rather than a different sample each time. For this reason, with Kiwifirm, harvest date could be predicted with more confidence than with penetrometer, because the same fruit are always measured and so it can better characterise maturation. Evaluation of fruit firmness non-destructively with the Kiwifirm could also be a good strategy for detecting texture changes in lots of fruit in coolstorage. Marketing decisions could be changed depending on the texture of the fruit in coolstorage, and Kiwifirm can detect such differences.

Fruit deformation measured non-destructively with a softness meter also characterised ripening of 'Comice' pears, causing negligible damage to the fruit. Figures 3.5 D-F reflect the inverse relationship between values obtained using the softness meter and the penetrometer, demonstrating that firmer fruit is less readily deformed and vice-versa, as has previously been found for kiwifruit (Davie *et al.* 1996). In a very immature pear, no deformation would be expected and as a consequence this fruit would have a softness meter reading close to zero. Conversely, a soft fruit would display a higher softness meter reading due to a high rate of deformation under load. The increase of the standard error of the softness coefficients on soft fruit provided further evidence of variability in softening behaviour after coolstorage. Thus characterisation of firmness during ripening would be more difficult with a softness meter than with Kiwifirm or penetrometer. The major disadvantage of the softness meter is the time required to make measurements, which would make it unsuitable for use in the field.

The curvilinear relationship presented between fruit firmness measured with the texture analyser and with the penetrometer (Fig. 3.8A) may be explained by the fact that the texture analyser gave firmness readings on softer fruit than the penetrometer, which may be an aspect of operator effect. The major disadvantages of the texture analyser are its higher cost and its unsuitability for use in the field.

3.4.2 Comparison of Flesh Firmness measured by Different Diameter Penetrometer Tips

The yield point force as a function of tip diameter can be expressed by the following equation (Bourne, 1980):

$$f_D = K_c \frac{\pi}{4} D^2 + K_s . \pi D \qquad [1]$$

where f_D = yield point force

K_c = compression coefficient of the fruit

K_s = shear coefficient of the fruit

D = diameter of the tip

If we call $K_1 = K_c\,(\pi/4)$, and $K_2 = K_s.\pi$, the equation will be as follows:

$$f_D = K_1 D^2 + K_2 D \qquad [2]$$

From this equation it is possible to calculate K_1 as:

$$K_1 = \frac{f_D - K_2 D}{D^2} \qquad [3]$$

Since;

$$K_1 = \frac{f_{7.9} - 7.9K_2}{7.9^2} = \frac{f_{11.1} - 11.1K_2}{11.1^2} \qquad [4]$$

then K_2 can be calculated as:

$$K_2 = \frac{11.1^2 f_{7.9} - 7.9^2 f_{11.1}}{280.61} \qquad [5]$$

Substituting in this equation values for $f_{7.9}$ using the fitted equation for Fig. 3.9, $f_{7.9} = 0.637\ (\pm\ 0.032) f_{11.1} - 0.0019\ (\pm\ 0.0004)\ (f_{11.1})^2$, it should be possible to calculate K_c and K_s for any value of $f_{11.1}$ in 'Comice' pears.

$$K_c = K_1 \frac{4}{\pi} \quad \text{and} \quad K_s = \frac{K_2}{\pi} \qquad [6]$$

The compression coefficient (K_c) of 'Comice' pears decreased hyperbolically with time (Fig. 3.13A), with the steep decrease with time that occurred when fruit were firm declining throughout the softening process. For very firm fruit, the shear coefficient (K_s) was initially negative, increasing to become maximally positive by the time fruit had softened to about 35 N ($f_{7.9}$), subsequently declining to close to zero as fruit became very soft (Fig. 3.13B). Compression comprised the majority of the peak force required to puncture the fruit throughout the most of the ripening process (Fig. 3.13C), though it became less than half of the total firmness when fruit were between 10 and 20 N ($f_{7.9}$). Clearly, the apparently negative contribution of shear to total peak penetration force is an artefact resulting from a breakdown in the theoretical characterisation of the relationship presented by Bourne (1980) between the two measures of firmness obtained with the different probe tips. The absolute quantification of the contributions of compression and shear forces to total peak penetration force at different stages of ripening will require further work with additional diameters of probe tip. Nevertheless, these data provide an indication that the relative contributions of compression and shear change substantially as the fruit soften, perhaps accounting for some aspects of perceived textural change of 'Comice' pears during the ripening process.

The similar coefficient of variation for the 7.9 mm and the 11.1 mm tip indicates that both can be used for measuring firmness in 'Comice' pears. However, use of the 11.1 mm tip should enable measurements of firmness of pears that are too soft to measure with the 7.9 mm tip. The function relating firmness readings obtained with the two tips should enable interconversion of data between the two in such situations.

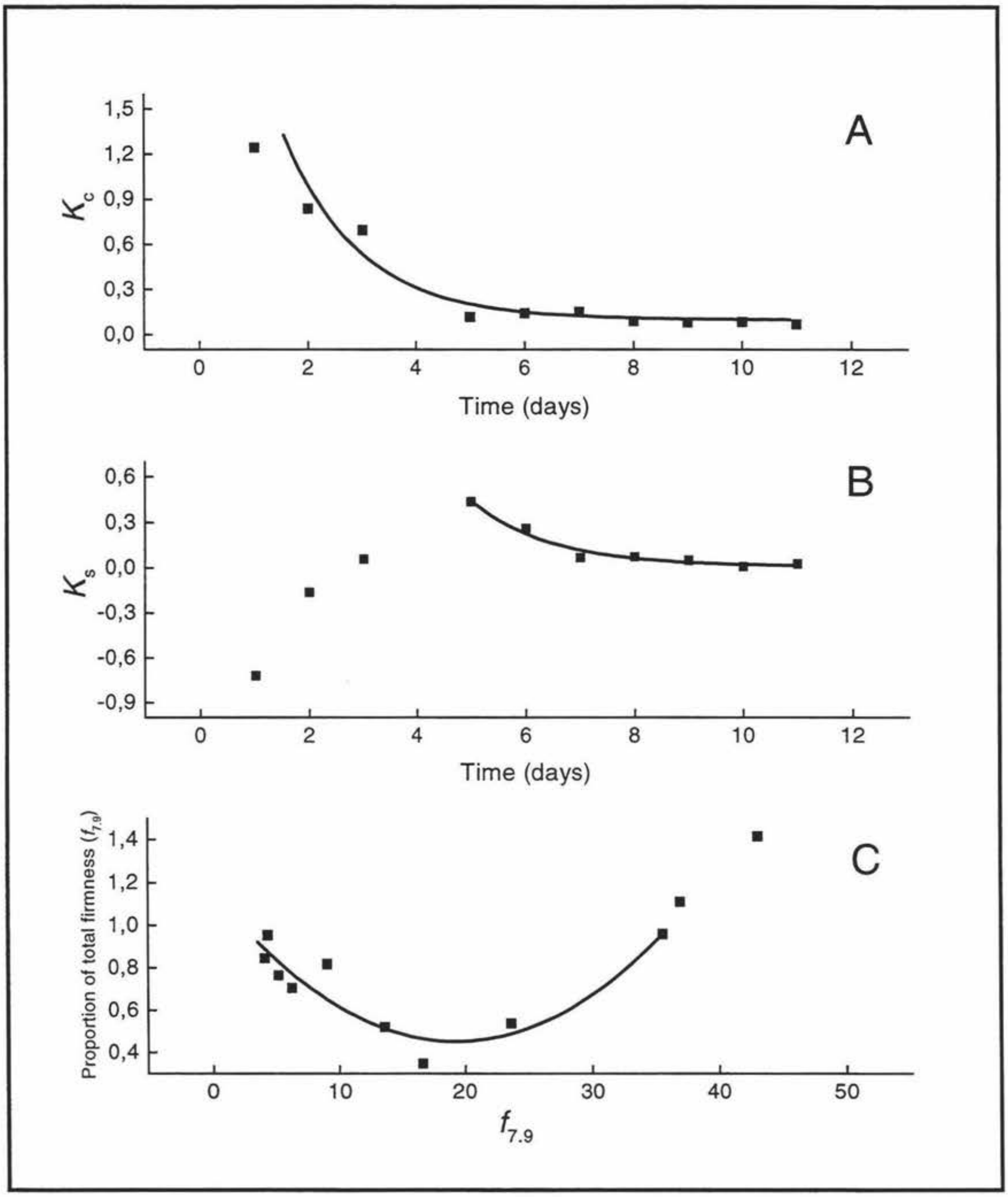

Figure 3. 13 Changes in A) compression coefficient ($K_c = 0.099 + 3.689 \times 0.491^t$) with time; shear coefficient ($K_s = 0.0092 + 14.701 \times 0.495^t$) with time; and C) proportion made up by compression of total peak force (Proportion $f_{7.9} = 1.154 - 0.073 f_{7.9} + 0.0019 (f_{7.9})^2$) in firmness of 'Comice' pears ripening at 20°C obtained with the 7.9 mm diameter penetrometer tip (1997 data).

3.4.3 Other Processes Analysed

3.4.3.1 Growth

The lack of a clear relationship between fruit size and the other attributes assessed suggests that fruit size attributes alone are not good indicators of fruit maturity because big fruit may still be commercially immature.

The high variability presented by size attributes was in large part due to these measurements having been made on samples. Length and weight presented higher variability than diameter, suggesting that the latter attribute may be a more reliable indicator of progress in the process of 'Comice' growth. Diameter and length could be measured on the same fruit on the tree before harvest, reducing their variability and better characterising growth at this stage. The considerable growth of the pears during the final 3 weeks before harvest indicates that early harvested fruit would be appreciably smaller.

3.4.3.2 Skin Colour Changes

There was a strong positive relationship between hue angle and flesh firmness during the whole period of study. This suggests that hue angle may be a good attribute to provide an indication of progress in the processes of 'Comice' maturation and ripening.

When fruit was removed from coolstorage in 1997 it was more yellow (lower hue angle) than in 1996. Eccher Zerbini *et al.* (1996) also found variation in colour after storage in different seasons. Climate or other orchard conditions may have had different effects on pear colour in the different seasons. Fruit reached the same colour 8 days earlier in 1997 than in 1996 (Fig. 3.11).

3.4.3.3 TSS and Starch Index

The TSS values increased prior to harvest in 1996 but this increment was smaller in 1997 (data not shown). The influences of weather conditions and location on tree, make it inadvisable to use TSS as the only guide to characterise maturation of pears (Wang, 1982; Kingston, 1993). In future work, TSS measurement may be another non-destructive technique. An instrument used by Dull *et al.* (1992), based on near infrared (NIR) reflectance techniques was capable of determining non-destructively the percent soluble solids in whole honeydew melons. With such a device it may be possible to characterise TSS on the tree, and continue to do so during coolstorage and ripening on the same fruit.

Starch index increased slowly until harvest (Fig 3.12B) consistent with the increase in TSS, but as starch index increased from 1 to 2, the increase in TSS was bigger than when starch index changed from 4 to 5. Assuming a direct proportionality of TSS values and sugar content, it would seem that the starch index is not linearly related to starch content in 'Comice' pears.

In summary, the evidence shows how well firmness measured by Kiwifirm, and hue angle, decreased linearly in unison during maturation before harvest and again during ripening. With this kind of behaviour, firmness and hue angle would be good techniques to characterise the maturation and ripening processes of 'Comice' pears.

Kiwifirm enabled measurements of firmness in fruit that were too soft to measure by penetrometer. With some further development, it appears that Kiwifirm could provide a useful tool to characterise pear firmness and as a maturity test for pears.

A function has been developed that allows interconversion of values obtained with 7.9 mm and 11.1 mm penetrometer tips.

4. Influence of Harvest Date and Crop Load on the Storage Behaviour of 'Doyenne du Comice' pears

4.1 Introduction

Variation in fruit quality after storage causes problems in the marketing of 'Doyenne du Comice' pears. Some of these problems may be caused by preharvest factors such as crop load, which may affect correct harvest date. The storage life of pears is influenced by growing conditions (Vaz and Richardson, 1985), climate (Wang, 1982) and harvest date (Elgar *et al.* 1997). Harvest date, through its effects on fruit maturity, influences the quality of fruit after storage. Pear maturity at harvest can affect both its condition after coolstorage, and subsequent changes (Avelar, 1984; Eccher Zerbini *et al.* 1996; Elgar *et al.* 1997). Critical questions to be answered are how much of the variation in quality can be accounted for by the variation in maturity, and how this influences consumer response to pears.

As quality is the highest priority for marketing pears, these require an optimal harvest date and period of coolstorage to allow normal ripening and to obtain good dessert quality. When optimal, these factors allow subsequent satisfactory development of flavour, flesh firmness, and colour during ripening. Early picked pears may lack the ability to ripen properly, resulting in poor quality. Late harvested pears will be more predisposed to CO_2 damage, rot and internal breakdown (Stow, 1988; Elgar *et al.* 1997).

The harvest date may be adjusted for year-to-year variation based on observations of bloom date, fruit size, colour development, starch rating, firmness and the climatic conditions (Rizzolo *et al.* 1989; Kingston, 1993). Recently, softening of both 'Comice' and 'Bosc' pears has been shown by Elgar *et al.* (1997) to be affected by harvest date. According to this research, early-harvested fruit required longer periods of storage than late-harvested fruit before they reached full ripening potential. The differences in results were related to cultivar, but effect of harvest date on subsequent ripening was related to wide maturity ranges associated with prolonged periods of bloom (Elgar *et al.* 1997).

Factors such as crop load could also influence fruit quality after coolstorage. The aim of this section is to study the influence of harvest date and crop load on fruit quality of 'Doyenne du Comice' pears after storage.

4.2 Materials and Methods

4.2.1 Experimental Material

Eighteen similar 'Comice' trees on quince BA29 rootstocks grown at the Fruit Crops Unit of Massey University in Palmerston North, were used in the study. Trees were 4 years old and 3 m tall and were trained as central leader pyramids. They were randomly allocated to 6 blocks of 3 trees each. One of three crop load (main plot) treatments was applied to each tree in the 6 blocks.

Crop Loads
Low (L) - 50 to 90 fruit/tree
Medium (M) - 90 to 130 " "
High (H) - 130 to 170 " "

On each of the 1, 11 and 21 March 1996 sequential harvests (split plot) of 12 fruit per tree selected randomly (total 216 fruit) were made. These harvests will be referred to as harvests 1, 2 and 3 respectively. After each harvest, all fruit were transferred to single layer boxes with polyliners, and stored at 0°C in air for 6 weeks. On each harvest day a pre-storage set of reference assessments was made on a further sample of 20 fruit. These were harvested randomly from the different regions on the trees, and after 20 h equilibration at 20°C were assessed as described below for the post-storage assessments.

The main commercial harvest day was 18 March 1996, as determined by ENZA Fruit - New Zealand (International) requirements for this variety (See Appendix A3).

4.2.2 Measurements

All fruit samples were subjected to both non-destructive and destructive assessment techniques after 6 weeks in coolstorage (11 April, 21 April and 1 May respectively). All fruit were evaluated after equilibration for 20 h at 20°C, and measurements were completed during a single day for each batch of fruit.

4.2.2.1 Fruit Size

Each fruit was weighed using a Mettler balance (model PM6100; Mettler Instrument AG, CH-8606, Greinfensee - Zürich, Switzerland) to the nearest 0.1 g.

Length of fruit was measured using a Mitutoyo digital calliper (Mitutoyo Corporation, Japan). Two diameters on the equator of each fruit were similarly measured , one from the blushed (red) to the shaded (yellow) side of the fruit, and the other at 90° to this.

4.2.2.2 Firmness

For all firmness readings, care was taken to avoid areas of sunburn, bruising or russeting on the skin as these can give abnormal readings.

Fruit firmness was measured non-destructively with the 'Kiwifirm' (Industrial Research Limited, Auckland, New Zealand). Two measurements on both blushed and shaded sides of each fruit were recorded separately.

Fruit firmness was measured destructively on both sides of each pear after removing a 1 mm thick slice of skin/outer cortex using a press-mounted Effegi penetrometer (model FT 327; 48011, Alfonsine, Italy) with a 7.9 mm diameter probe. It was calibrated using a 3 decimal point top loading balance (model FM 460 Mettler-Delta range). Both blushed and shaded sides of each fruit were tested, and measurements were recorded separately. Penetrometer values in kgf were converted to Newtons (N) by multiplying values by 9.807 (Soule, 1985).

4.2.2.3 Skin Colour

Skin colour was measured at two opposite points on the equator of each fruit, each midway between the blushed and shaded sides. Care was taken to avoid russet or marked areas of the skin. Colour measurements were made with a portable chromameter (model CR-200; Minolta Camera Co. Ltd., Osaka, Japan) equipped with a 10 mm diameter aperture on the measuring head. This was calibrated to a green standard plate ($Y = 29.9$ $\chi = 0.273$ $\gamma = 0.369$). Results were recorded as L (Lightness), C (Chroma), and H (Hue angle; McGuire, 1992).

4.2.2.4 Total Soluble Solids

Values for TSS (°Brix) were determined using a hand-held refractometer (Atago, model N-20, Atago Co., Ltd., Tokyo, Japan) after mixing a drop of juice from each of the two penetrometer wound sites in the pear.

4.2.2.5 Starch Index

Each pear was transversely cut at the equator and one half was placed, cut surface down, for 2 minutes in a solution of potassium iodide (1% w/v) and iodine (0.25% w/v). The resulting pattern on the cut surface was scored on a scale from 0 (least) to 6 (most) starch to sugar conversion (See Appendix A1).

Assessments of flesh firmness by penetrometer, and starch pattern index were made following the specifications for 'Comice' from ENZA Fruit New Zealand - (International; see Appendix A2).

4.2.3 Statistical Analyses

Analyses of variance of fruit maturity data were performed using the PROC GLM procedure of the SAS system (SAS 1990; Steel *et al.* 1997).

4.3 Results

The variation in harvest date resulted in variation of maturity attributes of the fruit at harvest (Table 4.1). Weight, density, TSS and starch index continued increasing between harvests 1 and 3. Firmness measured both by Kiwifirm and penetrometer decreased from harvest 1 to harvest 3. Hue angle decreased with harvest date, as skin colour became less green (Table 4.1). Lightness and chroma did not change between harvests 1 and 3 (data not shown). These results generally were maintained after 6 weeks of coolstorage (Table 4.2B).

Table 4. 1 Attributes of 'Comice' pears at harvest for three picking dates in 1996. Values are the averages of samples of 20 fruit. Lg = length; Dia = diameter; Wg = weight; F_k = firmness measured by Kiwifirm ([1] arbitrary units); F_p = firmness measured by penetrometer; TSS = total soluble solids; SI = starch index; H = hue angle.

Harvest Date	Lg (cm)	Dia (cm)	Wg (g)	F_k (au)[1]	F_p (N)	TSS (°Brix)	SI (score)	H (°)
1-Mar	91.5	78.0	262	6.9	51	13.6	1.7	109.8
11-Mar	99.6	82.0	306	6.8	48	13.9	1.8	108.5
21-Mar	99.6	82.1	312	6.1	47	14.5	2.1	105.8
SED (n=20)	1.30	0.80	8.95	0.09	0.99	0.18	0.11	0.51
ANOVA p =	***	***	***	***	*	**	***	***

ns, *, **, *** not significant, significant at 0.05≥P>0.01, 0.01≥P>0.001, and 0.001≥P respectively.

With respect to crop load, firmness measured after coolstorage by penetrometer declined significantly with increasing crop load, while firmness measured with the Kiwifirm showed no difference between crop load treatments (Table 4.2A). Similarly, levels of TSS after coolstorage declined with increase in crop load but there were no residual effects of harvest date at this time on this attribute.

After coolstorage there were no remaining effects of either harvest date or crop load on starch index or hue angle (Table 4.2A and B).

Table 4. 2 Effects of A) crop load and B) harvest date on quality attributes of 'Comice' pears after 6 weeks in coolstorage in 1996. Abbreviations as in Table 4.1.

Source	Level	Lg (cm)	Dia (cm)	Wg (g)	F_k (au)[1]	F_p (N)	TSS (°Brix)	SI (score)	H (°)
A Crop Load	High	93.4	78.7	268	6.00	39.2	15.0	5.5	104.4
	Medium	91.7	77.9	255	6.22	39.6	15.4	5.6	102.9
	Low	94.1	78.8	271	6.02	42.6	15.6	5.6	106.2
ANOVA p =		ns	ns	ns	ns	*	*	ns	ns
B Harvest Date	1	90.6	76.5	244	6.2	43.0	15.4	5.6	106.9
	2	93.6	79.0	269	6.1	38.8	15.3	5.5	103.5
	3	94.9	79.9	281	5.9	39.6	15.3	5.7	103.0
ANOVA p =		***	***	***	***	**	ns	ns	ns
SED (n = 18)		0.58	0.36	3.55	0.021	0.67	0.22	0.06	2.09

ns, *, **, *** not significant, significant at 0.05≥P>0.01, 0.01≥P>0.001, and 0.001≥P respectively.

There was a significant interaction between harvest date and crop load on fruit firmness after coolstorage when this was measured by Kiwifirm (Fig 4.1). Fruit firmness decreased more rapidly with harvest date in fruit from trees with low and medium crop loads, than in fruit from high crop load trees, which appeared to be less mature.

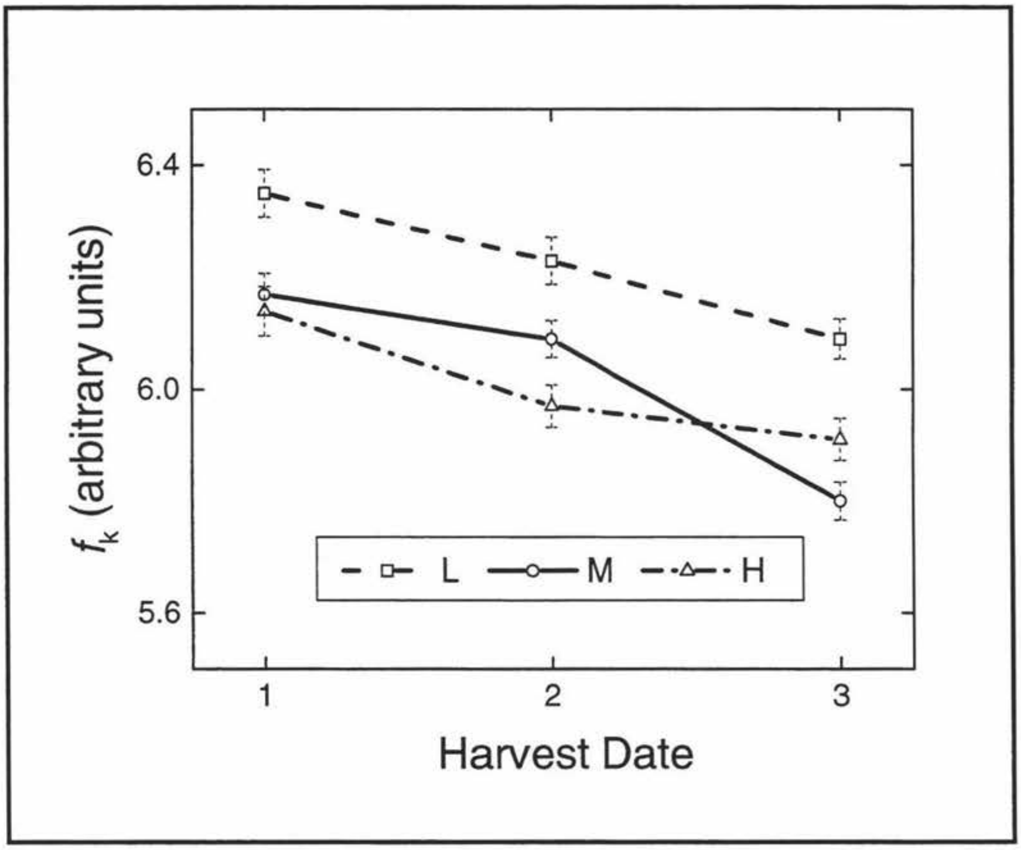

Figure 4. 1 Effects of harvest date (1 = 1 Mar, 2 = 11 Mar and 3 = 21 Mar) and crop load (L = low, M = medium and H = high) in 1996 on 'Comice' firmness after 6 weeks in coolstorage measured by Kiwifirm. Bars indicate ± standard error of the mean.

4.4 Discussion

Influences of Harvest Date on Fruit Maturity at Harvest

Harvest date influenced 'Comice' maturity assessed at harvest. Harvest 1 appeared to be a very early harvest date that gave fruit small in size and immature according to the other maturity attributes. Fruit size was increasing considerably between harvests 1 and 2, while the other attributes were not changing much between these harvests. Fruit from harvest 3 had the standard attributes recommended for commercial harvest by ENZA Fruit - New Zealand (International) to New Zealand growers.

In this study fruit firmness declined rapidly before harvest, and the differences between harvest date in fruit firmness (Table 4.1) suggested that the softening process started before commercial harvest.

Differences in skin colour (hue angle) at harvest suggested that the process of chlorophyll degradation appeared to commence between harvests 2 and 3, when some slight skin degreening and yellowing occurred. Skin colour changes during fruit maturation have often been associated with the action of ethylene (Chen *et al.* 1993) though the lack of change in other maturity attributes over the same period indicates that rapid ripening had not been initiated in these fruit. Differences in hue angle at harvest may persist after coolstorage and cause differences in skin colour in the market place.

Influences of Harvest Date on Fruit Quality Attributes After Coolstorage

The differences shown in firmness suggested that fruit from harvests 2 and 3 behaved differently in terms of softening during coolstorage. The general reduction in fruit firmness observed with later harvest in this study has been noted in other pear research (Boonyakiat *et al.* 1987; Eccher Zerbini *et al.* 1993; Eccher Zerbini *et al.* 1996).

This study suggests that the rate of ripening differed in fruit of different maturities. In further work, it would be important to consider the relationship between maturity at different harvest dates and subsequent ripening behaviour of 'Comice' pears over the range of growing conditions in New Zealand. Another matter for further research would be the assessment of ripening behaviour of fruit from different harvest dates using the non-destructive devices for measuring colour and firmness.

It is suggested that this kind of work has to be complemented by evaluation by taste panel. A taste panel could compare stored fruit from various harvest dates, evaluating how organoleptic properties change with harvest date.

Influences of Crop Load on Fruit Quality Attributes After Coolstorage

The general absence of crop load effects on fruit size in the present study could be a consequence of the fact that the levels of crop load were not sufficiently different, or other production factors, such as environmental conditions, orchard management, etc., may have influenced the results.

Results for TSS and colour showed that light crop was associated with advanced fruit maturity, suggesting that reduced carbohydrate availability on more heavily laden trees had retarded fruit maturity. This is supported by Francesconi *et al.* (1996) and Ferguson and Watkins (1992) who worked with apples and found that light crop load was correlated with advanced fruit maturity.

Bloom date may be another factor that influenced maturity of fruit at harvest and after coolstorage. The experimental 'Comice' trees had an extended bloom period. The length of the growing season of individual fruit on a tree could contribute to the variation in fruit maturity within the canopy. Thus tree factors which influence the timing of fruit set as well as harvest date will perhaps have an influence on the maturity of fruit at harvest and its quality after coolstorage.

In summary, early harvest was associated with smaller fruit size, more green colour, lower TSS and starch index. At the same time (before harvest), there was a corresponding decline in firmness. In general, interactions between harvest date and crop load did not influence fruit quality after coolstorage, but these factors had separate effects on fruit maturity at this stage. However, this research suggests that in further work studying crop load effects on fruit quality after coolstorage, wider differences between crop load treatments should be used. Fruit quality after storage may be influenced by other factors, such as climatic conditions or orchard management, that have to be considered when a practical decision of when to harvest 'Comice' pears has to be taken.

The usefulness of maturity indicators depends on the extent to which they contribute to the prediction of fruit quality after storage. A further implication of this work is that sources of variation in fruit quality need to be identified and controlled so that fruit of consistent quality can be produced. The study suggests that 'Comice' pears should be harvested over a short period of time when fruit reach optimum maturity in order to decrease fruit quality variability at the market place due to differences in maturity at harvest.

5. Effect of Fruit Position and Crop Load on Fruit quality of 'Doyenne du Comice' pears

5.1 Introduction

Variation among microsites within the tree canopy has been shown to affect nutrient concentrations such as N and may contribute to intracanopy effects on fruit size and quality (Sanchez *et al.* 1991). Ramos *et al.* (1994) showed that with increasing shade 'Bartlett' pear fruit were smaller and greener with lower TSS and higher titratable acidity, though fruit firmness was not influenced by fruit position in the canopy. Light appears to be of primary importance, affecting fruit size positively (Barrit *et al.* 1987; Kappel, 1989). The low potential for photosynthesis in shaded parts of the tree may account for the reduced supply of carbohydrates to fruit in these areas (Kappel, 1989). However shading may also affect the sink strength of these fruit.

The work of Rossi *et al.* (1984) supported the proposition that light availability within the canopy could be one of the factors that affect fruit maturity. They studied the availability of photosynthetically active radiation (P.A.R.) in hedgerow trained pear tree canopies. This work concluded that the availability of P.A.R. in pear orchards gradually decreased moving downwards to the ground and horizontally towards the inside part of the trees, even though the sun's rays could penetrate the foliage. It was noted in this study that reduction of the available radiant energy within the canopy could reach about 50 % of that existing above the tree top.

Other research on apples, for example Morgan *et al.* (1984) and Tustin *et al.* (1988), showed that light related well with fruit size, TSS, and red colour development. However, Volz *et al.* (1995) working with 'Royal Gala' found that irradiance had minimal direct influence on fruit maturity and quality attributes.

Variation in fruit quality after storage causes problems in the market place of 'Doyenne du Comice' pears. Some of these problems may arise in the orchard, linked to maturity at harvest, position within the tree canopy and crop load on the tree

(Ramos *et al.* 1994; Volz *et al.* 1995). There have been virtually no published studies relating factors such as fruit position and crop load to fruit size and quality at harvest and after coolstorage in 'Comice' pear, but these variables may influence fruit shelf life.

Preharvest factors such as crop load and fruit position on the tree could also influence fruit quality at harvest, and this could result after coolstorage in different fruit softening behaviour. The aims of this work were to characterise the nature and degree of within-tree and between tree variability in harvest maturity, storage and final ripening behaviour of 'Doyenne du Comice' pear, and to evaluate the potential for predicting storage behaviour of this cultivar from characterisation of fruit attributes made at harvest.

5.2 Materials and Methods

5.2.1 1996 Experiment

Eighteen similar 'Comice' trees on quince BA29 rootstocks grown at the Fruit Crops Unit of Massey University in Palmerston North, were used in the study. Trees were 4 years old and 3.5 m tall and were trained as central leader pyramids. A split plot design was used where trees were randomly allocated to 6 blocks of 3 trees each. One of three crop load treatments was applied to each tree in the 6 blocks (Table 5.1A). Within each tree, all fruit on the trees were sampled from 8 regions (3 factors at each of 2 levels in factorial combination, Table 5.1B). Fruit were identified by labelling with a marker pen to show their source, i.e. tree and region.

Immediately after harvest, all sampled fruit were evaluated using non-destructive maturity assessments. Half of the fruit from each treatment were evaluated also using destructive maturity assessments. The other half was held in the Fruit Crops Unit coolstorage at 0°C for a period of 8 weeks. These fruit were again assessed using both non-destructive and destructive methods after removal from coolstorage.

Table 5. 1 Treatment structure for the 1996 experiment

A	***Crop Loads* (main plot)**
L	= Low - 50 to 90 fruit/tree
M	= Medium - 90 to 130 " "
H	= High - 130 to 170 " "

B	***Regions of the tree* (split plot)**		
		Levels	
	Vertical	Top	Bottom
Factors	Compass	North	South
	Horizontal	Inside	Outside

The bottom part of the tree was defined as below 1.8 m height. The outside part of the tree was defined as the outer 60 cm of the canopy.

The following tree and fruit attributes were measured (a) at harvest and (b) after coolstorage:

- total fruit number and yield per tree (a)
- weight (a, b)
- hue angle, lightness and chroma (a, b)
- firmness measured with a Kiwifirm (a, b)
- firmness measured with a penetrometer (a, b)
- TSS (a, b)
- starch index (a)

5.2.2 1997 Experiment

Ten similar 'Comice' trees selected from the eighteen trees that were used in 1996 were used in the study. Trees were 5 years old and 4 m tall. A split plot design was used where trees were randomly allocated to 5 blocks of 2 trees each. One of two crop load treatments was applied to each tree in the 5 blocks (Table 5.2). Within each tree (main plot), 5 fruit were sampled from the same 8 regions as in the 1996 season (3 factors at each of 2 levels in factorial combination, Table 5.1B).

Table 5. 2 Crop loads used in the 1997 experiment.

Crop Loads		
L = Low	-	50 to 110 fruit/tree
H = High	-	110 to 170 " "

Immediately after harvest, fruit were evaluated using non-destructive maturity assessments and then placed in the Fruit Crops Unit coolstore at 0°C. Fruit were again assessed with non-destructive and destructive methods after a period of 7 weeks in coolstorage.

The following tree and fruit attributes were measured (a) at harvest and (b) after coolstorage:

- total fruit number and yield per tree (a)
- weight (a, b)
- hue angle, lightness and chroma (a, b)
- firmness measured with a Kiwifirm (a, b)
- firmness measured with a penetrometer (b)
- TSS (b)

5.2.3 Measurements

For each sample on which both non-destructive and destructive tests were made such measurements were made on the same day. All fruit were evaluated after equilibration for 20 h at 20°C.

Harvest dates in the 1996 and 1997 seasons are shown in table 5.3.

Table 5. 3 Commercial and experimental harvesting dates for 'Comice' pears at the Fruit Crops Unit, Massey University in the 1996 and 1997 seasons.

Season	Experimental harvest date	Commercial harvest interval	
		Opening	Closing
1996	18 March	11 March	26 March
1997	12 March	5 March	22 March

5.2.3.1 Fruit Size

Each fruit was weighed using a Mettler balance (model PM6100; Mettler Instrument AG, CH-8606, Greifensee - Zürich, Switzerland) to the nearest 0.1 g.

Length of each fruit was measured using a Mitutoyo digital calliper (Mitutoyo Corporation, Japan). Two diameters on the equator of each fruit were similarly measured , one from the blushed (red) to the shaded (yellow) side of the fruit, and the other at 90° to this.

5.2.3.2 Firmness

For all firmness readings, care was taken to avoid areas of sunburn, bruising or russeting on the skin as these can give abnormal readings.

Fruit firmness was measured non-destructively with the 'Kiwifirm' (Industrial Research Limited, Auckland, New Zealand). Both blushed and shaded sides of each fruit were tested. Measurements on both sides of each fruit were recorded separately.

Fruit firmness was measured destructively on both sides of each pear, after removing a 1 mm thick slice of skin/outer cortex, using a press-mounted Effegi penetrometer (model FT 327; 48011 Alfonsine, Italy) with a 7.9 mm diameter probe. It was pre-calibrated using a 3 decimal point top loading Mettler balance (model FM 460 Delta range; Mettler Instrument AG, CH-8606, Greifensee - Zürich, Switzerland). Both blushed and shaded sides of each fruit were tested, and measurements were recorded separately. Penetrometer values in kgf were converted to Newtons (N) by multiplying values by 9.807 (Soule, 1985).

5.2.3.3 Skin Colour

Skin colour was measured at two opposite points on the equator of each fruit, these points being midway between the blushed and shaded sides. Care was taken to avoid russet or marked areas of the skin. Instrumental colour measurement was carried out using a portable chromameter (model CR-200; Minolta Camera Co. Ltd., Osaka, Japan) equipped with a 10 mm diameter aperture on the measuring head. This was calibrated to a green standard plate ($Y = 29.9$ $\chi = 0.273$ $\gamma = 0.369$). Results were recorded as L (Lightness), C (Chroma), and H (Hue angle; McGuire, 1992).

5.2.3.4 Total Soluble Solids

Value for TSS (°Brix) were determined using a hand-held refractometer (Atago, model N-20, Atago Co., Ltd., Tokyo, Japan) after mixing a drop of juice from each of the two penetrometer wound sites.

5.2.3.5 Starch Index

Each pear was transversely cut at the equator and one half was placed, cut surface down, for 2 minutes in a solution of potassium iodide (1% w/v) and iodine (0.25% w/v). The resulting pattern on the cut surface was scored on a scale from 0 (least) to 6 (most) starch to sugar conversion (See Appendix A1).

5.2.4 Statistical Analyses

Analyses of variance on both 1996 and 1997 data derived from crop load and vertical position levels (top and bottom) were performed using the PROC GLM procedure of the SAS system (SAS 1990). Data from compass (north and south) and horizontal (inner and outer) position levels for both seasons were similarly but separately analysed.

5.3 Results

5.3.1 1996 Experiment

The different crop load and vertical locations on the tree had some effects on the maturity of 'Comice' pears at harvest (Table 5.4A). There were (non significant) trends for fruit from trees with light crop loads to be heavier, with higher TSS but lower starch index. Such fruit were significantly firmer measured by both Kiwifirm ($P \leq 0.01$) and penetrometer ($P \leq 0.05$) and they had a less green skin colour ($P \leq 0.05$). Overall, despite more yellow skin, fruit from low crop load appeared to be less mature than fruit from high and medium crop loads. After 8 weeks in coolstorage (Table 5.4B) light crop fruit remained firmer, but were less yellow than fruit from more heavily cropping trees. At this stage, fruit from low crop load trees had a slightly higher TSS value.

In considering vertical location effects at harvest (Table 5.4A) there was a trend for fruit from the tree top to be bigger, and significantly ($P \leq 0.01$) less green than fruit from the tree base. Upper fruit were also firmer by Kiwifirm ($P \leq 0.01$), with a slightly lower starch index ($P \leq 0.05$). After coolstorage, the trend for upper fruit to be heavier remained but, otherwise, the only significant effect was that these were marginally less yellow (Table 5.4B).

Table 5. 4 Attributes of 'Comice' pears measured A) at harvest and B) after 8 weeks in coolstorage in 1996, considering crop load and vertical location on the tree. Lg = length; Dia = diameter; Wg = weight; F_k = firmness measured by Kiwifirm ([1] arbitrary units); F_p = firmness measured by penetrometer; TSS = total soluble solids; SI = starch index; H = hue angle.

A **Source**	**Level**	**Lg** (cm)	**Dia** (cm)	**Wg** (g)	F_k (au)[1]	F_p (N)	**TSS** (°Brix)	**SI** (score)	**H** (°)
Crop Load	High	93.8	80.0	283	5.74	42.3	14.4	2.3	105.4
	Medium	92.6	79.4	276	5.71	40.8	14.7	2.5	106.1
	Low	94.9	80.6	295	6.09	45.1	15.1	2.0	103.5
SED (n = 12)		1.34	0.82	10.61	0.094	1.15	0.30	0.22	0.74
ANOVA p =		ns	ns	ns	**	*	ns	ns	*
Vertical	Bottom	94.3	79.2	275	5.76	43.0	14.7	2.3	106.4
	Top	93.3	80.8	293	5.94	42.5	14.8	2.2	103.5
SED (n = 18)		1.15	0.76	9.76	0.039	1.12	0.15	0.03	0.47
ANOVA p =		ns	ns	ns	**	ns	ns	*	**

B **Source**	**Level**	**Wg** (cm)	F_k (au)[1]	F_p (N)	**TSS** (°Brix)	**H** (°)
Crop Load	High	272	5.16	38.9	15.5	100.0
	Medium	261	5.28	38.7	15.6	97.8
	Low	276	5.54	42.7	16.0	102.2
SED (n = 12)		6.68	0.050	0.07	0.19	0.73
ANOVA p =		ns	***	**	*	*
Vertical	Bottom	262	5.24	39.4	15.6	100.3
	Top	279	5.29	39.0	15.6	97.9
SED (n = 18)		5.78	0.046	0.06	0.11	0.61
ANOVA p =		ns	ns	ns	ns	*

ns, *, **, *** not significant, significant at 0.05≥P>0.01, 0.01≥P>0.001, and 0.001≥P respectively.

Horizontal and compass locational effects were analysed separately, and are shown in Table 5.5A,B. Fruit from the inner parts of the trees were firmer and more green than fruit from the outer parts of the trees at harvest. These differences were not maintained after coolstorage. Fruit from the north side of the trees were heavier, firmer and had higher TSS levels at harvest than fruit from the south side of the trees. Fruit from the north side of the trees were heavier than fruit from the south side of the trees after coolstorage (Table 5.5B).

Table 5. 5 Attributes of 'Comice' pears assessed A) at harvest, B) after 8 weeks in coolstorage in 1996, considering the horizontal and the compass locations on the tree. Abbreviations as in Table 5.4.

A Source	Level	Lg (cm)	Dia (cm)	Wg (g)	F_k (au)[1]	F_p (N)	TSS (°Brix)	SI (score)	H (°)
Horizontal	Inside	93.3	79.7	280	5.94	43.9	14.6	2.4	105.4
	Outside	93.7	80.1	282	5.66	41.7	14.7	2.3	103.5
SED (n = 18)		0.75	0.68	8.00	0.027	0.59	0.08	0.04	0.74
ANOVA p =		ns	ns	ns	**	*	ns	ns	*
Compass	North	94.3	80.5	287	5.82	43.5	14.6	2.2	105.3
	South	93.3	79.7	279	5.86	42.6	14.9	2.3	104.3
SED (n = 18)		0.81	0.15	1.84	0.019	0.31	0.08	0.11	0.66
ANOVA p =		ns	**	**	ns	*	*	ns	ns

B Source	Level	Wg (cm)	F_k (au)[1]	F_p (N)	TSS (°Brix)	H (°)
Horizontal	Inside	270	5.34	39.7	15.4	100.1
	Outside	268	5.31	39.1	15.6	99.9
SED (n = 18)		4.98	0.109	0.72	0.25	0.58
ANOVA p =		ns	ns	ns	ns	ns
Compass	North	273	5.22	39.3	15.5	99.7
	South	264	5.32	39.2	15.6	98.9
SED (n = 18)		2.23	0.089	0.81	0.14	0.48
ANOVA p =		*	ns	ns	ns	ns

ns, *, **, *** not significant, significant at 0.05≥P>0.01, 0.01≥P>0.001, and 0.001≥P respectively.

5.3.2 1997 Experiment

The different crop load and locational effects studied at harvest in 1997 had, in general, similar effects on maturity of 'Comice' pears as in 1996. Light crop trees showed a trend for bigger and firmer fruit, which appeared to be less mature than fruit from high load trees at harvest (Table 5.6A). These trends on fruit weight and firmness were maintained after coolstorage and after ripening.

At harvest, fruit from the tree tops were smaller, firmer and less green than fruit from the tree bases. After coolstorage upper fruit remained firmer and less green, and this remained the trend after ripening (Table 5.6B,C).

Table 5. 6 Attributes of 'Comice' pears assessed A) at harvest, B) after 7 weeks in coolstorage and C) at the end of ripening in 1997, considering crop load and vertical locations on the tree. Abbreviations as in Table 5.4.

	Source	Level	Wg (g)	F_k (au[1])	H (°)	TSS (°Brix)
A	**Crop Load**	High	253	6.83	106.5	
		Low	268	7.13	106.1	
	SED (n = 10)		8.44	0.088	0.44	
	ANOVA p =		ns	*	ns	
	Vertical	Bottom	263	6.83	107.3	
		Top	258	7.14	105.3	
	SED (n = 10)		1.30	0.093	0.25	
	ANOVA p =		*	*	**	
B	**Crop Load**	High	243	6.14	101.6	
		Low	260	6.35	101.3	
	SED (n = 10)		8.16	0.088	0.49	
	ANOVA p =		ns	*	ns	
	Vertical	Bottom	253	6.17	102.7	
		Top	250	6.32	100.2	
	SED (n = 10)		1.40	0.044	0.49	
	ANOVA p =		ns	*	**	
C	**Crop Load**	High	234	3.84	90.5	15.8
		Low	249	3.91	89.9	16.5
	SED (n = 10)		7.38	0.082	0.65	0.30
	ANOVA p =		ns	ns	ns	ns
	Vertical	Bottom	244	3.83	90.87	16.2
		Top	239	3.91	89.46	16.2
	SED (n = 10)		2.06	0.047	0.49	0.11
	ANOVA p =		ns	ns	*	ns

ns, *, **, *** not significant, significant at $0.05 \geq P > 0.01$, $0.01 \geq P > 0.001$, and $0.001 \geq P$ respectively.

Horizontal and compass locational effects were analysed separately, and are shown in Table 5.7. Fruit from the outer parts of the trees were heavier and less green than fruit from the inner parts of the trees at harvest. These differences were maintained after coolstorage but, after ripening, only fruit weight remained significantly different. Compass location did not show any significant effects among the attributes measured, although there was a trend throughout for fruit from the north side to be larger (Table 5.7A-C).

Table 5. 7 Attributes of 'Comice' pears assessed A) at harvest, B) after 7 weeks in coolstorage and C) at the end of ripening in 1997, considering the horizontal and the compass locations on the tree. Abbreviations as in Table 5.4.

	Source	Level	Wg (g)	F_k (au[1])	H (°)	TSS (°Brix)
A	**Horizontal**	Inside	248	7.02	106.7	
		Outside	272	6.94	105.9	
	SED (n = 10)		2.18	0.107	0.08	
	ANOVA p =		***	ns	***	
	Compass	North	265	7.04	106.6	
		South	256	6.94	106.1	
	SED (n = 10)		6.51	0.092	0.44	
	ANOVA p =		ns	ns	Ns	
B	**Horizontal**	Inside	240	6.21	102.3	
		Outside	263	6.33	100.7	
	SED (n = 10)		2.09	0.045	0.33	
	ANOVA p =		***	ns	**	
	Compass	North	257	6.21	101.8	
		South	246	6.33	101.1	
	SED (n = 10)		6.80	0.089	0.41	
	ANOVA p =		ns	ns	Ns	
C	**Horizontal**	Inside	230	3.76	90.2	16.0
		Outside	254	3.86	90.1	16.3
	SED (n = 10)		1.88	0.023	0.23	0.06
	ANOVA p =		***	ns	Ns	**
	Compass	North	246	3.83	90.5	16.1
		South	237	3.92	89.8	16.2
	SED (n = 10)		7.10	0.045	0.78	0.13
	ANOVA p =		ns	ns	Ns	ns

ns, *, **, *** not significant, significant at 0.05≥P>0.01, 0.01≥P>0.001, and 0.001≥P respectively.

During ripening, because both hue angle and firmness (measured with Kiwifirm) were recorded on the same individual fruit every two days, it was possible to determine the relationship of this data versus time for the whole batch of fruit (400) assessed. Figure 5.1 shows the linear relationship between firmness measured non-destructively by Kiwifirm and time with an r^2 value of 0.99, while figure 5.2 shows the curvilinear relationship between hue angle and time ($R^2 = 0.99$). The same relationship was analysed (data not shown) comparing firmness for fruit from different vertical locations but there was no significant difference between firmness measured on fruit from the top and the bottom of the trees.

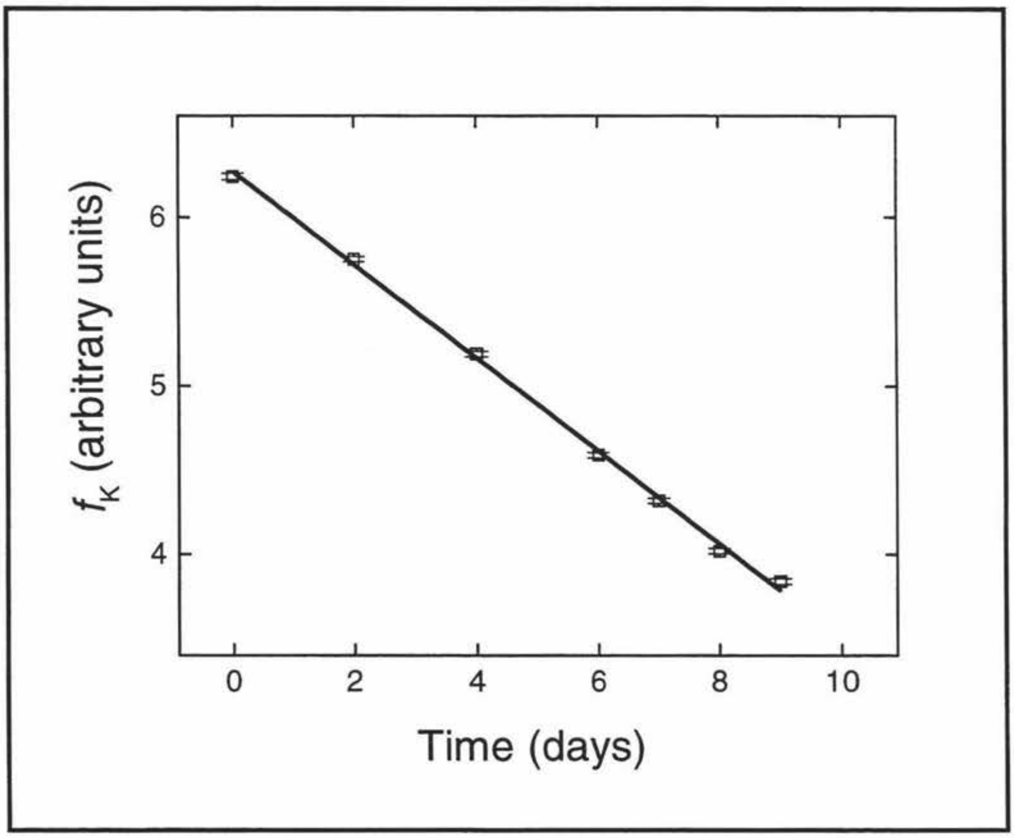

Figure 5. 1 Relationship between firmness measured by Kiwifirm during ripening at 20°C and days after coolstorage. Bars indicate ± standard error of the mean. $f_K = 6.272\ (\pm 0.030)\ -0.276\ (\pm 0.005) \times t$.

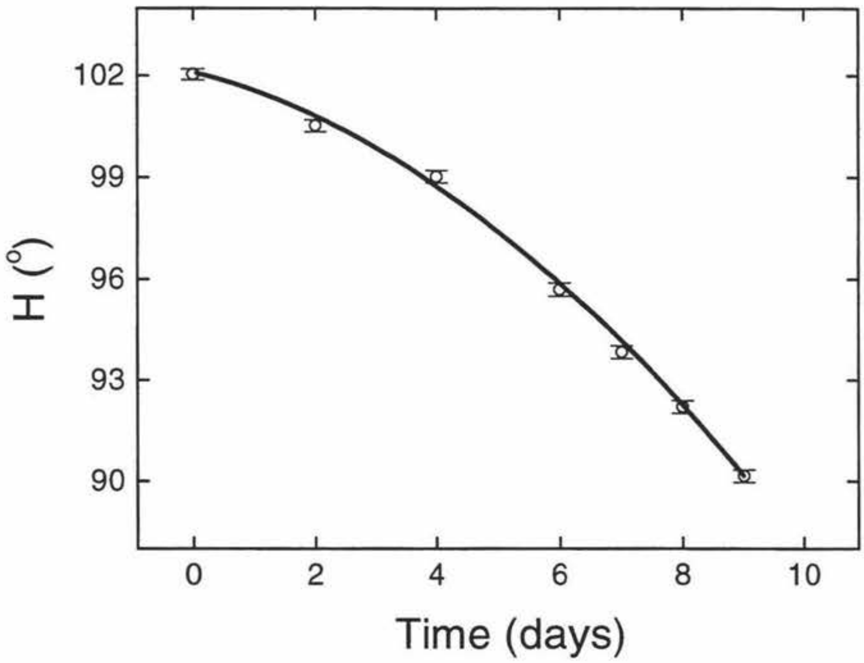

Figure 5. 2 Relationship between hue angle measured during ripening at 20°C and days after coolstorage. Bars indicate ± standard error of the mean. $H = 102.06\ (\pm 0.091) - 0.453\ (\pm 0.046) \times t - 0.0972\ (\pm 0.005) \times t^2$.

It was possible to determine when the fruit reached certain values of ripeness with repeated measurements on the same fruit through the time. Values of Kiwifirm (4.0 au) and of hue angle (95.0 ^{0}) were set as standardised ripeness thresholds (SRT) for firmness and colour change, respectively.

There was a low relationship between days after coolstorage when fruit reached SRT values for firmness ($r^2 = 0.26$) and the initial firmness measured at harvest for the same individual fruit (Fig. 5.3). The wide spread of points around the line means that firmness measured by Kiwifirm is not particularly valuable for predictive purposes.

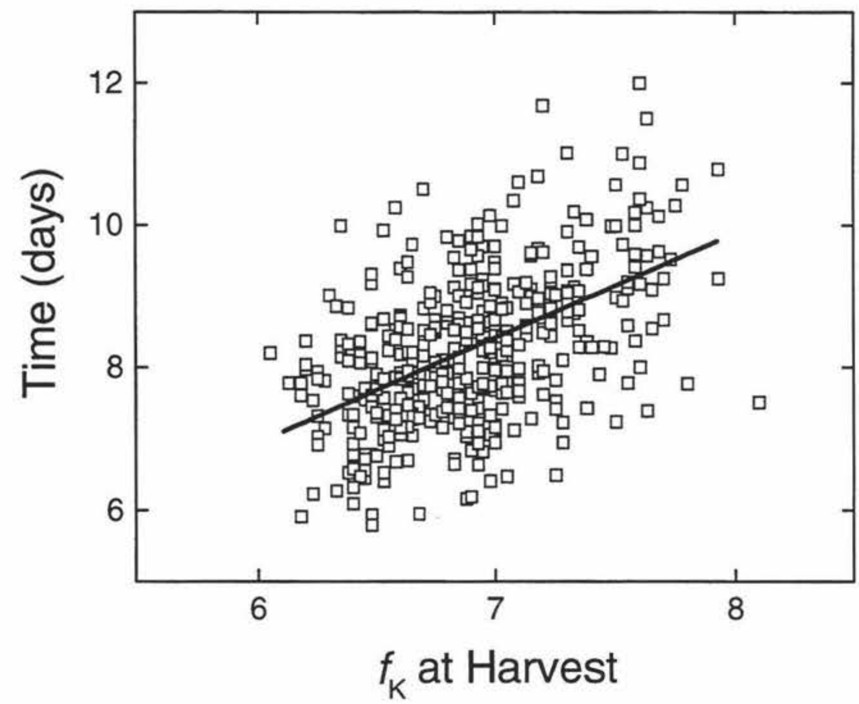

Figure 5. 3 Relationship between days after coolstorage when fruit reached SRT for firmness and firmness measured at harvest by Kiwifirm,

t = -1.857 (±0.85) + 1.468 (±0.12) × f_{Ko}.

There was a stronger relationship between days after coolstorage when fruit reached SRT values for hue angle (r^2 = 0.54) and the initial hue angle measured at harvest for the same individual fruit (Fig. 5.4).

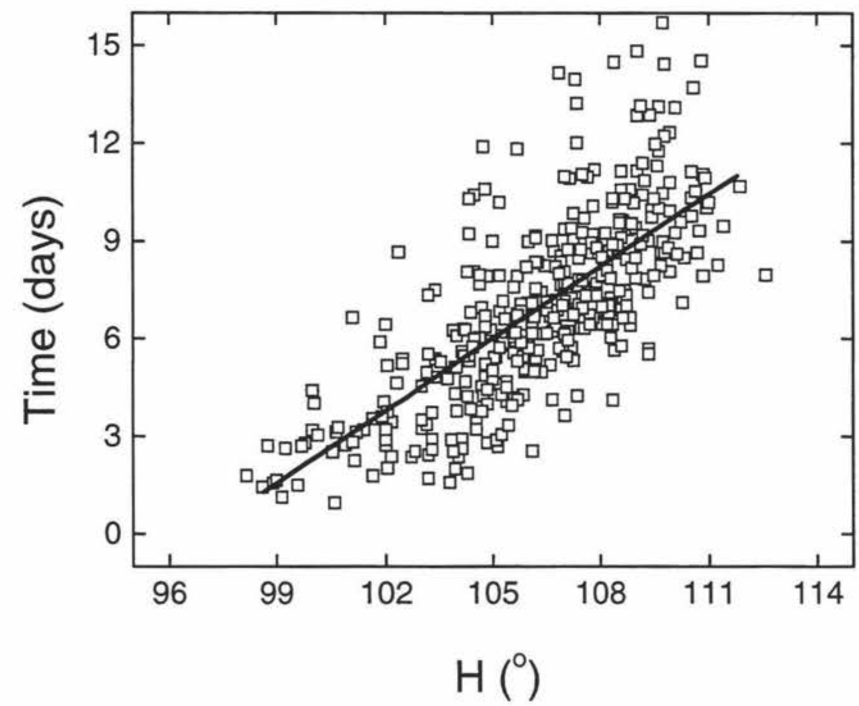

Figure 5. 4 Relationship between days after coolstorage when fruit reached SRT for hue angle and hue angle measured at harvest, $t = -71.696\ (\pm 3.668) + 0.740\ (\pm 0.034) \times H_{(at\ harvest)}$.

The value of r^2 (0.20) for the regression of SRT on the product of initial firmness and initial hue angle was less than that obtained with either variable individually (data not shown).

The regression of time taken for fruit to reach SRT for firmness and harvest hue values had a low r^2 value, and similar results were obtained between the time taken for fruit to reach SRT for hue angle and harvest firmness values (data not shown). Clearly, the low relationships in both analyses show that these two processes are not very strongly related to each other. However, on the basis of the greater coefficient of determination, hue angle seems to be a better attribute to consider for predictive purposes, provided time required to reach SRT for hue is useful in commercial handling of the fruit.

The time after removal from coolstorage when the fruit reached SRT values was compared for each crop load and locational treatment (Table 5.8A-B). The vertical factor was the only one that had any effect on the time that fruit required to reach the SRT. Fruit from the tree top reached Kiwifirm SRT (4 au) approximately 1 day later than fruit from the bottom of the canopy, and fruit from the tree tops reached the hue angle SRT (95.0 ^{0}) 1 day before than fruit from the canopy base (Table 5.8B).

Table 5. 8 Time (days) after removal from coolstorage when fruit reached Kiwifirm and hue angle SRT values in 1997, considering A) crop load and B) vertical location treatments.

	Source	Level	Days (f_K=4 au)	Days (H=95°)
A	**Crop Load**	High	7.9	6.4
		Low	8.3	6.0
	SED (n = 10)		0.276	0.402
	ANOVA p =		ns	ns
B	**Vertical**	Bottom	8.10	6.78
		Top	9.15	5.65
	SED (n = 10)		0.115	0.396
	ANOVA p =		*	*

ns, *, **, *** not significant, significant at 0.05≥P>0.01, 0.01≥P>0.001, and 0.001≥P respectively.

Fruit firmness measured 7 days after removal from coolstorage differed depending on crop load and vertical location (Table 5.9A,B). The results showed that fruit from trees with high crop loads presented lower Kiwifirm readings compared with fruit from trees with low crop load (Table 5.9A) and fruit from the top part of the trees reached higher Kiwifirm readings than fruit from the trees bases (Table 5.9B).

Hue angle measured 7 days after coolstorage was different in response to vertical location on the tree (Table 5.9B). Fruit from the top part of the trees were more yellow compared with fruit from the bottom part of the trees.

Table 5. 9 Kiwifirm and hue angle values reached 7 days after removal of 'Comice' pears from coolstorage in 1997, considering A) crop load and B) vertical location treatments.

	Source	Level	f_K	H (°)
A	**Crop Load**	High	4.23	94.0
		Low	4.61	93.4
	SED (n = 10)		0.072	0.556
	ANOVA p =		*	ns
B	**Vertical**	Bottom	4.01	94.5
		Top	4.46	91.9
	SED (n = 10)		0.033	0.530
	ANOVA p =		**	*

ns, *, **, *** not significant, significant at 0.05≥P>0.01, 0.01≥P>0.001, and 0.001≥P respectively.

5.4 Discussion

Fruit maturity at harvest and during ripening after coolstorage appears to be influenced by crop load and locational factors within the canopy. This maturity variation may be explained by differences in fruit exposure to sunlight within the tree canopy. Other researchers have shown that light appears to have great effects on fruit quality (Barrit, 1987; Kappel, 1989), affecting fruit size, firmness, TSS levels and skin colour. Changes in firmness were related to position on the tree, showing that more exposed fruit were firmer than those less exposed. This suggests that sunlight influenced fruit skin texture, making the skin thicker, and so firmness was higher when measured non-destructively by Kiwifirm through the skin. This effect of the sunlight on the skin was expressed also during ripening, fruit from the top part of the trees reached a Kiwifirm reading of 4 arbitrary units later than basal fruit but their colour (hue angle) changed to yellow before fruit from the bottom part. It appears that exposure affects differentially the processes of softening and colour change.

The variation in TSS levels of fruit between outside and inside the trees may be explained by the low potential for photosynthesis in shaded parts of the tree. Pears located inside the tree and heavily shaded had the lowest TSS levels (Table 5.7). This may have been due to a reduced supply of carbohydrates to fruit in these regions. However, shading may also have affected the sink strength of these fruit.

Further work will be necessary to define exactly the SRT values from the consumers point of view; taste panels could help in this. Even with the preliminary approach adopted here, it appears that the differences in days required to reach SRT values by fruit from different vertical locations on the trees, as found in this study, may explain some of the maturity variability found in the market place.

Usually, high crop load retards fruit maturity, due to reduced carbohydrate availability to the fruit (Francesconi *et al.* 1996). The effect of crop load in this study was not the same in both seasons, this may be because the differences between the crop loads compared were not large enough for the 'Comice' pears to show clear maturity differences. The differing softening behaviour of 'Comice' pear in response to crop load may be explained by differences in fruit nutrient composition due to differing nutrient availability within the tree (Sanchez *et al.* 1991).

From the relationship found between harvest firmness measured by Kiwifirm and the time after coolstorage pears required to reach 4 arbitrary units, it is possible to deduce that firmer fruit at harvest take longer to ripen after coolstorage (Fig. 5.1). The process of colour change appeared to vary in fruit from different parts of the tree, and fruit that was greener at harvest reached the hue angle SRT value later than fruit that were less green at harvest (Fig. 5.2). The regression analysis results suggest that hue angle may be an attribute to measure at harvest that can be related with fruit softening behaviour after coolstorage. It would be interesting to segregate batches of fruit according to colour at harvest to see wether this would reduce variability in fruit maturity in the market.

In summary, fruit location on tree and crop load appear to affect fruit maturity and fruit quality at harvest and after coolstorage. Fruit from the tree top appear to be more mature than fruit from other parts of the tree. For these reasons, selective picking may improve the uniformity of fruit quality. However further work, across several seasons and different production areas, is required before firm recommendations can be made.

Some differences were found in the softening behaviour of fruit from different regions within the tree canopy. Fruit from the top or bottom part of the tree or from high or low crop load required different amounts of time to reach the SRT values used in this study. Further work is required to define the SRT values useful for comparing softening behaviour of 'Comice' pear. Packing fruit together, which have similar softening behaviour, could reduce maturity variation in the market place.

6. General Discussion

This investigation confirms that the variation in fruit quality after coolstorage is partly due to crop load, location on the tree and fruit maturity at harvest (Fig. 6.1). Thus, it is important to consider these factors in determining fruit management at harvest in order to decrease fruit variability in the market place. It is suggested that as maturity at harvest plays an important role determining the postharvest behaviour of fruit, it should be characterised as accurately as possible and in a way that such harvest data can be correlated with fruit behaviour during and after coolstorage. Maturity assessments at harvest would be a good tool to generate a 'Maturity Index' and a 'Storage Index' that may be related to each other and could predict fruit quality after coolstorage. These indices should be linearly related with time in order to establish an optimum value defining when to harvest the fruit to predict good post-storage quality.

Fruit softening and skin colour changes were the processes that changed more consistently and linearly through maturation and ripening. These relationships help to relate data collected at harvest or on a grading line with the softening behaviour of the fruit. The collection of data on the grading line could be possible by adapting a device that can measure fruit attributes non destructively. With these kinds of strategies it could be possible to separate batches of fruit that will have different softening behaviour, or reach standardised eating points at different times, reducing the variability in maturity that fruit have in the market place, which sometimes costs a lot of money and effort in the industry. This study indicates that there is a good possibility of distinguishing at harvest batches of fruit with different storage potential based on fruit attributes such as firmness and skin colour measured at harvest.

Seasonal factors such as weather and labour, and varying stages of colour development generally make it unfeasible to pick all fruit at ideal maturity. For this reason, the record of orchard data from previous seasons is valuable. This can give a reference to the pre- and postharvest conditions of the fruit in earlier years and what its subsequent behaviour was during that season. Knowledge of the storage potential of the fruit would permit segregation of fruit having different potentials.

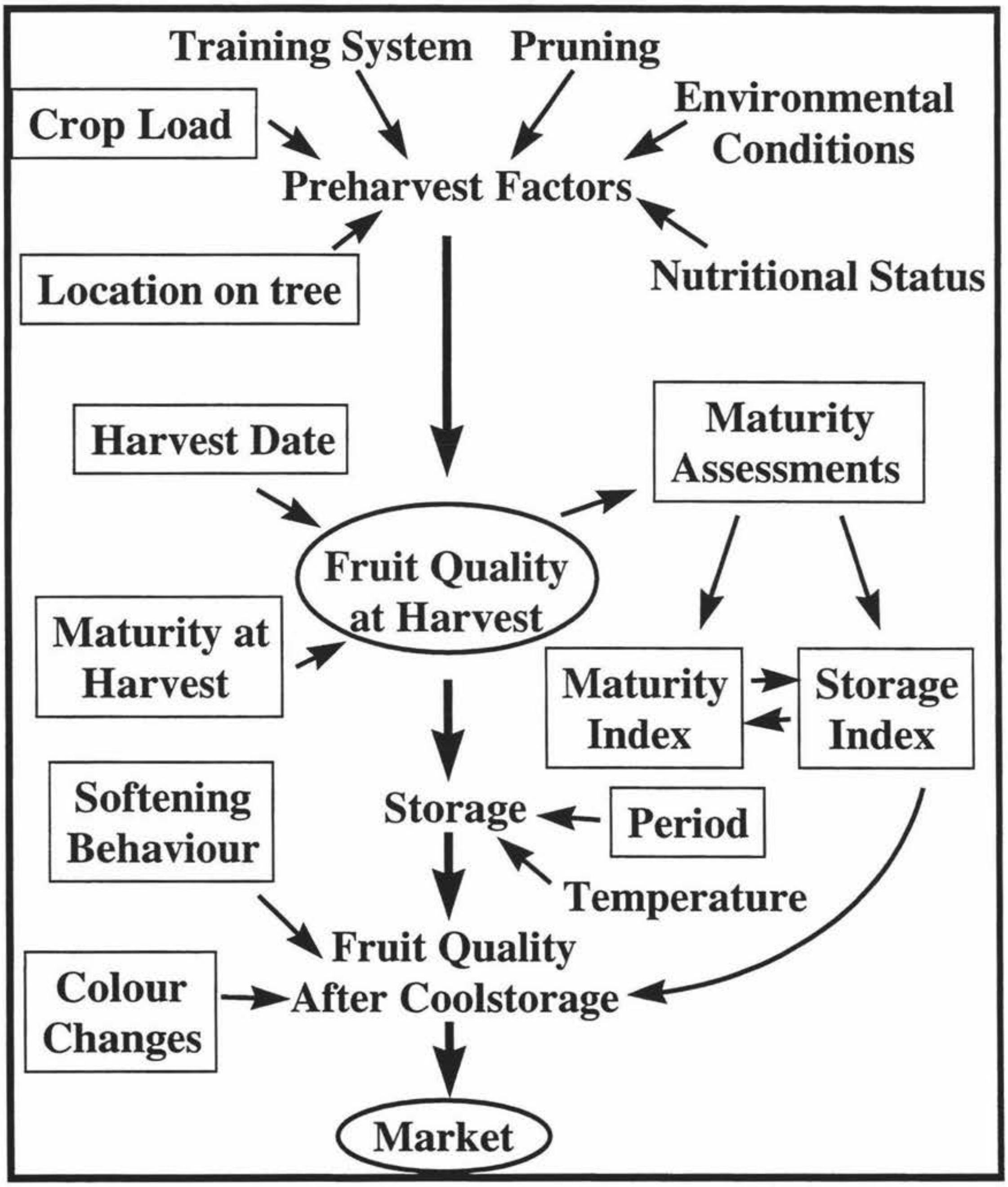

Figure 6. 1 Schematic diagram of the preharvest and postharvest factors and processes that affect fruit quality attributes. Those involved in the current study are enclosed in boxes.

Further work is necessary, but this preliminary study suggests selective picking to allow for maturity variation in fruit on the 'Comice' trees within an orchard could be valuable. For example, considering location on the trees, fruit from the top of the tree canopy appeared to be significantly more mature earlier than fruit from the canopy base. Similarly, fruit from the outside were more mature than those from inner parts of the trees. These results appear to indicate a relation between fruit quality and light availability according to location in the canopy of 'Comice' pear trees. Where the levels of light were low, fruit maturity was delayed. Such fruit might be harvested later when they reach similar firmness to fully exposed fruit. Some practices such as summer pruning that can increase light penetration into the tree canopy, can be suggested to reduce fruit variability within the tree by allowing more uniform light availability.

In New Zealand, a pear maturity programme has been developed as a tool to aid orchardists, field and pack-house workers, storage operators, horticulture agents, and researchers in managing fruit maturity and storability. However, 'Comice' pears are grown in areas within New Zealand with considerable differences in climate, soil type, and cultural practices that can result in a wide variance in maturation and ripening behaviour between growing regions. This variability in postharvest behaviour affects fruit in the market, decreasing perceived quality and acceptance when nowadays excellent appearance and eating quality of pears must be provided if they are to satisfy consumers. Thus, optimisation of fruit quality through a maturity programme for each pear region needs to be one of the goals of New Zealand 'Comice' pear production. Within this maturity programme, crop load and harvest date need to be defined precisely for each pear area according to the season's conditions.

Clearly further studies are required to assess other preharvest factors that could affect storage behaviour of 'Comice' pears. Knowledge of variation in fruit maturity and quality within pear trees would enable growers to define different zones on the tree and apply selective picking, and to refine certain tree management practices to produce uniform and optimum fruit quality for the export market, and so increase their profit.

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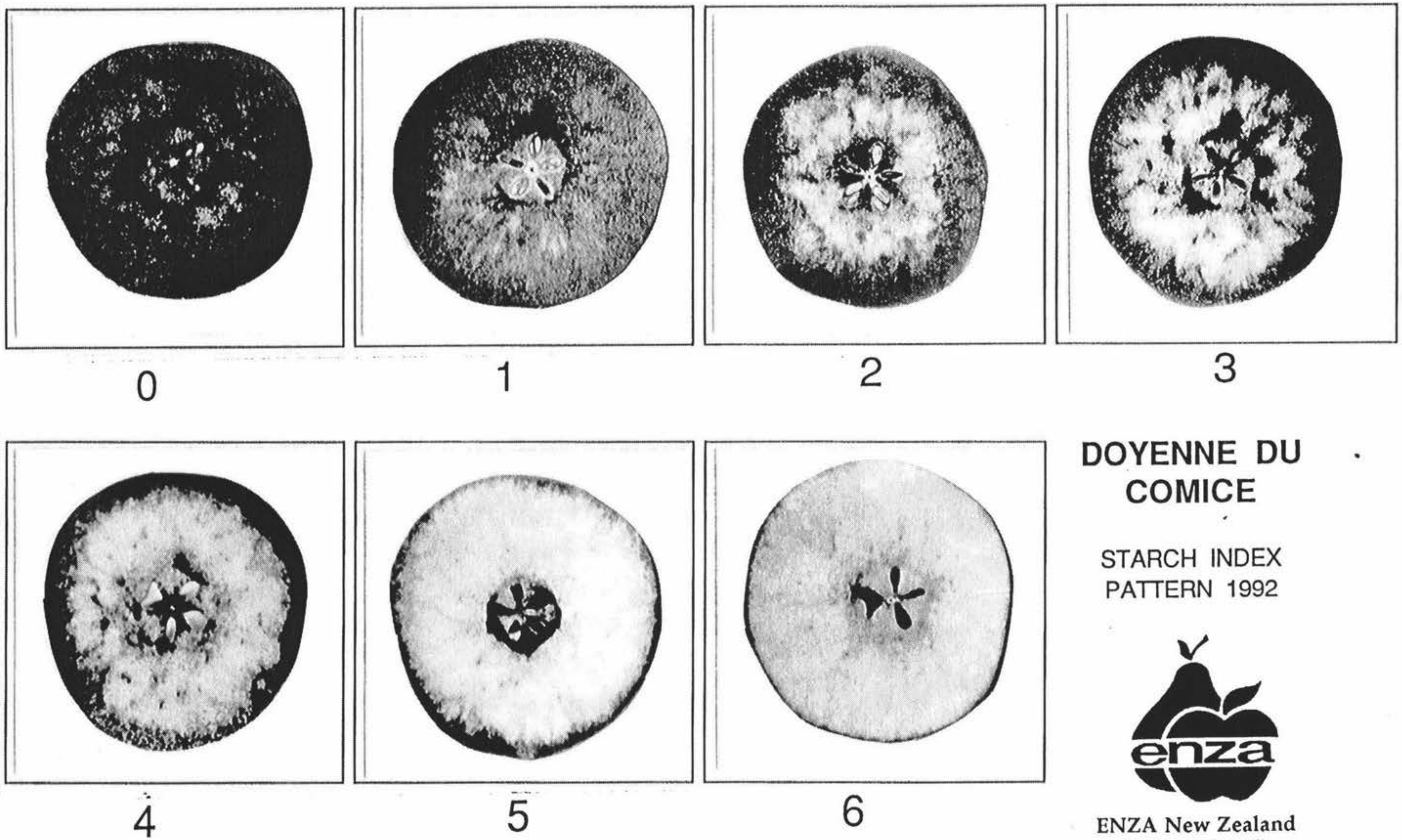

DOYENNE DU COMICE

STARCH INDEX
PATTERN 1992

ENZA New Zealand
(International)

Appendix A2

ENZA New Zealand (International)

Pipmark

January 1995 TECHNICAL BULLETIN

Doyenne du Comice

MATURITY AND QUALITY HARVEST GUIDE

The information in this bulletin provides some practical advice and parameters for harvesting Doyenne du Comice.

INTRODUCTION

With Doyenne du Comice, as with most perishable commodities, optimum quality is a compromise between a number of factors. For Comice, fruit size, cosmetic appearance, storage potential, eating qualities, and market opportunity, are the main issues.

The parameters, values, and procedures recommended to use for harvest are different from some off-shore industries and maybe different to historical parameters used on your orchard or in your district.

Assessment of research and a range of data from the last six years, mainly in the Hawke's Bay and Nelson areas, has led to the following recommendations. To date they have produced a high percentage of juicy, sweet, fine textured, tasty fruit, whether eaten firm or softer, after storage at -0.5°C.

In the past it has been observed that in some years, and/or some districts and orchards, problems have occurred which may have been compounded by applying off-shore industry harvesting parameters.

In addition, although the data is largely anecdotal, scuffing and marking of fruit during the harvest, packing, and distribution processes can be affected by maturity and quality at harvest. Therefore some potential exists to minimise these problems by the correct timing of harvest.

Further research is aimed at better defining these relationships.

MATURITY & QUALITY PARAMETERS

1. For Orchard Use

Starch Pattern Index (SPI)

This parameter, used more extensively for apples, is however extremely useful for Doyenne du Comice, showing a consistent and significant change during the maturation period.

To date in New Zealand this has proven to be a more reliable indicator of the optimum harvest period, avoiding the pitfalls sometimes found with flesh firmness.

Recommendation:

Open at 2.5 Close at 5.0

Caution:

Harvesting at less than 2.5 results in reduced flavour characteristics, but the fruit will still ripen if harvested above 1.5.

Harvest beyond 5.0 can result in fruit being too soft, an increase in storage disorders, and/or a decrease in potential storage length.

Flesh Firmness (FF)

This has been a traditional parameter of maturity and can be considered another key indicator like the SPI. However, on occasions, subject to season and location, it does not give as complete a picture of maturity and so must be considered in conjunction with other parameters.

It has been demonstrated that fruit that is too immature (inadequate flavour or ripening following storage), or fruit that is too soft after storage, can occur if relying on flesh firmness only.

Accordingly, the harvest window for optimum quality can be short (2.5 weeks) with the relatively narrow range of values recommended.

Recommendation:

Open at 5.5 kg-f Close at 4.3 kg-f

Caution: 5.39 4.21

Harvesting less than 4.3 kg-f tends to result in increased marking and scuffing and softer fruit after storage.

Soluble Solids (SS)

Given the low level of acidity in Doyenne du Comice, much of the flavour component and eating quality is associated with adequate soluble solids (sweetness).

At harvest, soluble solids levels should be greater than 11.5%, and should be regarded as a secondary parameter. That is, do not delay harvest waiting for soluble solids to increase if all the crop cannot be harvested within the SPI and FF levels specified.

Recommendation:

Harvest >11.5%

2. Other Parameters

Ethylene Production Rate

This is useful to determine the end of harvest, which is indicated by a significant increase in the rate of ethylene production.

This measurement usually requires laboratory analysis and taking larger fruit numbers. It enables a better decision to be made about when to stop harvest. This is especially so when the SPI or FF appears not to change even though the harvest period is lengthening.

Fruit Weight

A simple measure, which can be useful to indicate increase in average size. Thus, fruit weight, when taken in conjunction with other parameters, can help maximise packout.

Caution:

Fruit weight is very dependent on the sampling procedure.

Background Colour

This is not a good or consistent indicator of maturity or quality and should not be used as a harvest criteria.

Titratable Acidity

A laboratory type analysis is required.

It can be useful when considered in association with soluble solids. However it is not generally seen as a useful harvest parameter.

FIELD PROCEDURES

1. Sampling

To give a more reliable estimation of the state of the crop, a 20 fruit sample per block is recommended. A 10 fruit minimum is an option, however the errors associated with any results are greater. Trees selected for sampling must be scattered through the block and representative of the majority of the trees in the block.

Weekly sampling is generally sufficient to track any maturity and quality movement, but more frequent sampling may be of use, especially if in a period of rapid movement. It is not necessary to re-visit the same 20 trees, however there is someadvantage in doing so in which case trees should be marked.

The fruit should be removed from random locations within the tree, i.e. from inner and outer, upper and lower and at different points of the compass.

Fruit size and cosmetic quality must be within the specifications and grade standards that apply to the grade(s) or market(s) in question.

Note: Caution needs to be exercised if your sample is not representative of the range of the fruit on the tree. That is, maturity and quality may be over or under estimated, especially if the sample is all one type of fruit or from similar locations.

2. Measurement Details

Starch Pattern Index (SPI):

This measurement relies on the simple fact that starch will stain blue/black in the presence of iodine and potassium iodide. It is the pattern that is of particular interest when determining the SPI, rather than the darkness or intensity of the blue/black colour.

Conversely the clear yellow/white pattern indicates regions of nil or low starch levels.

Procedure

1) Cut fruit in two as near as possible to the equator. (Following flesh firmness determinations - see later)
2) Place stalk end(s) in shallow dish (plastic or glass recommended) containing the iodine/potassium iodide solution.
3) Leave in the solution for approximately two minutes.
4) Remove fruit carefully (avoid "washing" cut surface in the solution) and place upside down on a Friday tray.
5) Leave for a further two minutes before comparing it with the Doyenne du Comice SPI chart. When reading, record the SPI number that is closest to the fruit pattern in question rather than estimating half or quarter units. Across a sample of 20 these differences have little impact.
6) Dispose of the iodine/potassium iodide solution carefully. Do not add back to the stock bottle!
7) Average the results for your SPI value.

Iodine/Potassium Iodide Solution

This is a 0.25 percent w/v iodine and 1.0 percent w/v potassium iodide solution. It is available from ENZA Technical Support Laboratories or your local chemist. Store in a cool, dark, ventilated location at all times.

Caution: Care should be exercised at all times when handling the solution. Avoid contact with and breathing of vapours.

Flesh Firmness (FF):

This measurement is expressed in kilograms - force Kg-f (alternative units are pounds force, or Newtons).

FF is determined using a penetrometer of which there are mechanical and electronic types available from a number of manufacturers. A widely used model in a number of countries and industries, including the pipfruit industry, is the Effegi Fruit Pressure Tester, model FT327. This model is available from a number of horticultural and scientific suppliers in New Zealand.

Note: Two plunger diameters are used in pipfruit; a 7.9mm (5/16) plunger tip for European pears (also kiwifruit and stone fruit), and a 11.1mm (7/16) plunger tip for apples and Asian pears.

Typically the penetrometer is hand held and forced into the fruit following the removal of a small area of skin.

Results obtained are extremely operator dependent, and differences of over one Kg-f are possible from the same sample.

Despite this, it is possible, with good operator discipline and procedure, to obtain reasonably consistent measurements within a season.

For this reason we recommend the penetrometer be mounted on a rack and pinion drill stand (a direct lever action type induces greater operator variation).

Procedure

1) With a sharp knife or mounted paring blade, remove a disk of skin and flesh on opposite sides of the fruit at the equator, sufficient to allow the plunger entry without touching the skin. Avoid removing a large disk and exposing the deeper tissue.
2) Firmly hold the fruit (a cradle to reduce roll is recommended). Insert the plunger at a steady speed and force to the inscribed circle on the plunger tip.

   Typically this takes just under one second.
3) Read the value and record.
4) Re-zero penetrometer, and repeat procedure for the other side of the fruit and both sides of remaining fruit.

   Note: save the fruit for SPI and SS measurement.
5) Average all 40 values recorded.
6) Clean the penetrometer with fresh water after use and avoid juice or water entering the plunger barrel.

   Annual calibration through your ENZA Technical Support Laboratory is recommended.

Soluble Solids: (SS)

A hand held refractometer is the only significant equipment required to undertake this determination, which is measured in units of % Brix.

There are a number of manufacturers, and types of refractometers. We recommend the adjustable type with a 0-20 % scale which will allow you to re-zero your refractometer, as it can be affected by different ambient and sample temperatures.

Procedure:

1) Zero your refractometer with distilled or de-ionised water. This water should be at the temperature of your juice sample for a more accurate reading. Place water drop or drops on prism, holding the prism at the level.
2. Replace the cover and read. Adjust to zero (0) using adjustment screw or wheel.
3. Wipe prism dry with a soft tissue.
4. A juice sample can be measured from each side of each fruit by expressing a small amount of juice on to the refractometer from the penetrometer plunge site. Wipe the prism dry between readings, with soft tissue.
5. The results are then averaged for your SS value.

Alternatively for each fruit express a small amount of juice from each plunge site into a small beaker. When all fruit have been sampled mix the solution well and read on the refractometer. Clean the prism, place another drop on and read to confirm the original reading. The average is your SS value.

3. Results

It is strongly recommended that results are kept in a readily utilisable and user friendly form for reference in the season and in subsequent years. Results transferred each week, to a simple graph as shown below, have proven to be the most useful format.

This visual presentation gives immediate assessment of any significant differences in the rate of change as well as readily identifying the absolute cut-off values mentioned for each parameter.

It can be worth while to keep all raw results as a means of determining relative variation between sampled fruit from week to week and season to season.

For further advice, recommendations or information please contact your ENZA Technical Support Laboratory or your Product Development Technician.

ACKNOWLEDGEMENTS

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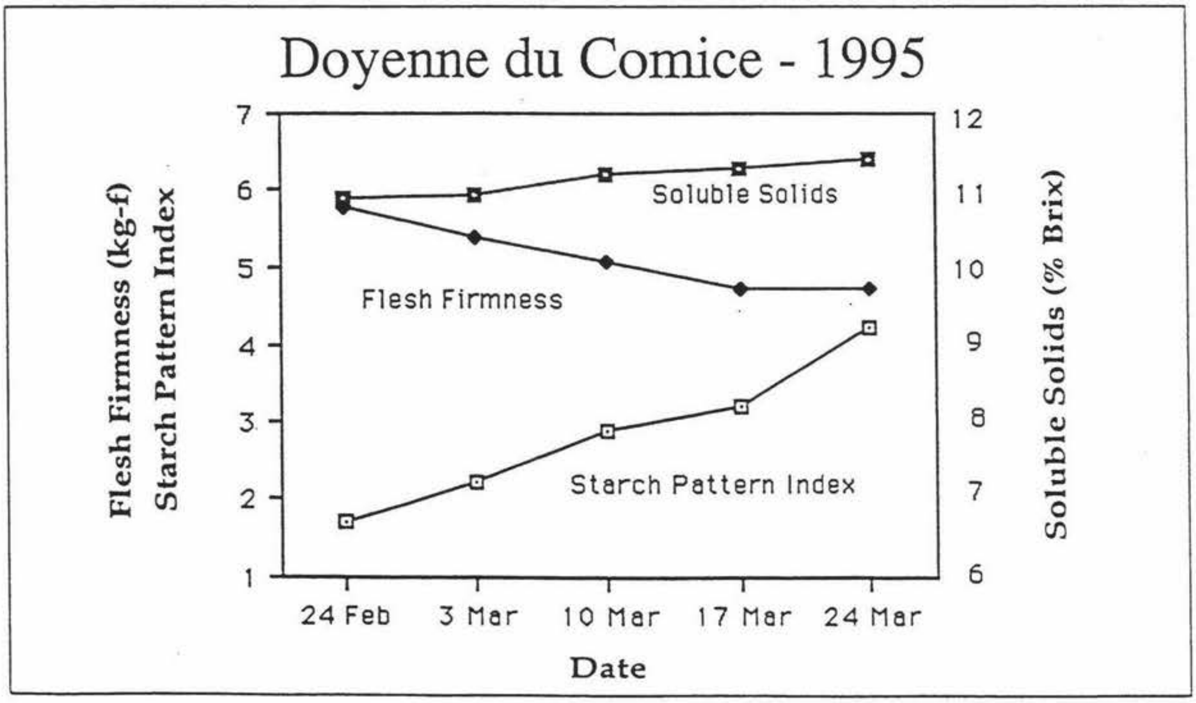

Issued by the New Zealand Apple and Pear Marketing Board, PO Box 3328, Wellington.

Appendix A3

Values of fruit attributes required for harvest of 'Comice' pears. ENZA Fruit - New Zealand (International).

DOYENNE DU COMICE

PARAMETERS	PARAMETER GUIDELINES AND RANGES		KEY	HARVEST or PACKING COMMENT
	O D	C D		
Flesh Firmness	6.2 - 5.5	5.5 - 4.5	Yes	No harvest below 4.1. Ideal range 6.2 - 5.0
Soluble Solids	11.0 - 13.0	12.5 - 15.0	No	
Starch Pattern Index	2.0 - 2.6	4.5 - 5.0	Yes	Not recommended to harvest less than 1.5. Ideal range 2.5 - 4.0.
Titratable Acidity	4.5 - 3.7	3.7 - 2.8	No	Less than 3.5 not recommended.

Comments:

Failure to apply correct coolchain promptly will jeopardise post storage fruit quality regardless of harvesting parameters.

Harvest beyond SPI 5.0 can result in fruit being too soft post storage even if FF was within acceptable range.

Flesh firmness below 4.1 is not recommended as fruit tends to scuff easily and too soft post storage.

It is not recommended that harvest period not be delayed once SPI has reached 2.5 and/or flesh firmness at 5.5kg-f. Complete harvest in shorter time as possible; typically this would be within 17 days.