Influence of handling at harvest on the softening behaviour of kiwifruit.

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Abstract

The New Zealand Kiwifruit industry in 1991 lost an estimated $54 million due to premature softening of kiwifruit during postharvest storage. The present study sought to determine if premature softening might be associated with the physical damage resulting from handling at harvest.

The influence of physical damage on fruit was investigated on fruit from eleven kiwifruit properties from the Bay of Plenty region in New Zealand. Fruit were harvested and stored at 0°C and 20°C; firmness was destructively assessed. Softening behaviour of fruit sampled immediately after harvest from the vine (no physical damage) were compared with fruit from the same orchard block handled through the normal postharvest handling chain and packed in a packhouse. Analysis of variance and nonlinear regression using two, three and four parameter models were used to help in describing any differences in firmness values for fruit held in cool storage (0°C). The advantages and disadvantages of using analysis of variance and nonlinear regression to describe differences in firmness values between treatments are discussed.

Analysis of variance determined that the packhouse and vine fruit on average were of a similar firmness. Nonlinear three parameter model:

$$\text{Firmness} = a \exp^{-b\,t} + c \quad \text{(starting values: } a = 6,\ b = 0.01 \text{ and } c = 0.5\text{)}$$

where:

- a = difference between initial and final asymptotic firmness
- b = exponent describing rate of decline in firmness
- c = final asymptotic value for fitted firmness

was found to best characterise changing fruit firmness values over time. An analysis of variance was then performed on the resulting parameter values a, b and c which found that vine fruit on average had a slightly faster rate of softening than packhouse fruit. Packhouse fruit were not expected on average to have a similar firmness to vine fruit, as packhouse

fruit were thought to have been exposed to potentially damaging impacts during handling. This may have been due to vine fruit being of a smaller size, position of fruit trays in cool storage or the rewarming of fruit during transportation.

A non-destructive measure of firmness would help to identify the factors leading to premature softening and help to quantify fruit to fruit variability. A second part of this study therefore involved development and evaluation of a non-destructive instrument for measuring kiwifruit firmness (softness meter) compared with a penetrometer and its ability to repeatedly measure an individual fruit's firmness over time.

The non-destructive softness meter characterised fruit firmness by measuring changes in deformation over time. Plots of deformation versus the natural log of time were linear and the gradient of the line was used as the measure of firmness (softness coefficient). Fruit with a range of firmness values were assessed using the softness meter, then penetrometer readings were obtained on the same location of each fruit and the relationship between the two instruments established. Within-fruit variation for both softness coefficients and penetrometer data was strongly related to fruit firmness, with coefficients of variation remaining approximately constant at about 10% for each variable. The softness meter will help to identify how localised treatments applied to fruit affect firmness and help to identify premature softening causes in individual fruit.

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Chapter One

1.0 Introduction

Kiwifruit (*Actinidia deliciosa* cv Hayward; Liang and Ferguson, 1986) in 1991 were New Zealand's sixth largest export earning (New Zealand Kiwifruit Marketing Board (NZKMB), 1991). In 1991 the crop earned $621.5 million with $54 million being lost due to fruit losses (NZKMB, 1991). The principal causes of fruit losses were soft fruit (71.2%), *Botrytis cinerea* (16.0%) and other causes (12.8%) (Hugh King, NZKMB; personal communication, 1992).

A important part of the NZKMB's success in marketing the large volume of kiwifruit produced in this country each year lies in the ability to store the fruit over an extended period before export. This creates opportunities to export fruit in an orderly way over six months to different markets around the world without creating a glut in the few months after harvest time. New Zealand is competing against other kiwifruit-exporting countries from the southern hemisphere and fruit carried over from the previous season in the northern hemisphere. Quality therefore plays an important role in maintaining a premium price and market share for the New Zealand crop: fruit quality must remain high throughout the storage period and during handling through the distribution chain until it reaches the consumer. Fruit quality is rigorously checked on all lines of fruit on a pallet by pallet basis before export.

Fruit are harvested by hand when the soluble solids (SS) level is at 6.2% or above at 20°C (NZKMB, 1992). Fruit firmness is usually around 8 kilograms force (kgf; Newtons = kgf x 9.81 ms^{-2}) when picked from the vine at the start of the harvesting season in early May. Fruit are harvested into picking bags, then put into wooden field bins to be transported to a packhouse. The NZKMB (1992) recommends that fruit are not dropped more than 30 cm onto a hard surface e.g. into field bins or on grading equipment. At the packhouse fruit are passed over a grader, packed by hand or partly by machine within 96 hours of picking. Fruit are then palletised, force air cooled and placed in coolstore at 0°C within 24 hours of being packed (NZKMB, 1992).

The residual firmness at the time of export must be sufficient to enable it to undergo a further period of transport and handling without becoming excessively soft.

During storage the fruit softens from its original high value at harvest (Fig. 1.1).

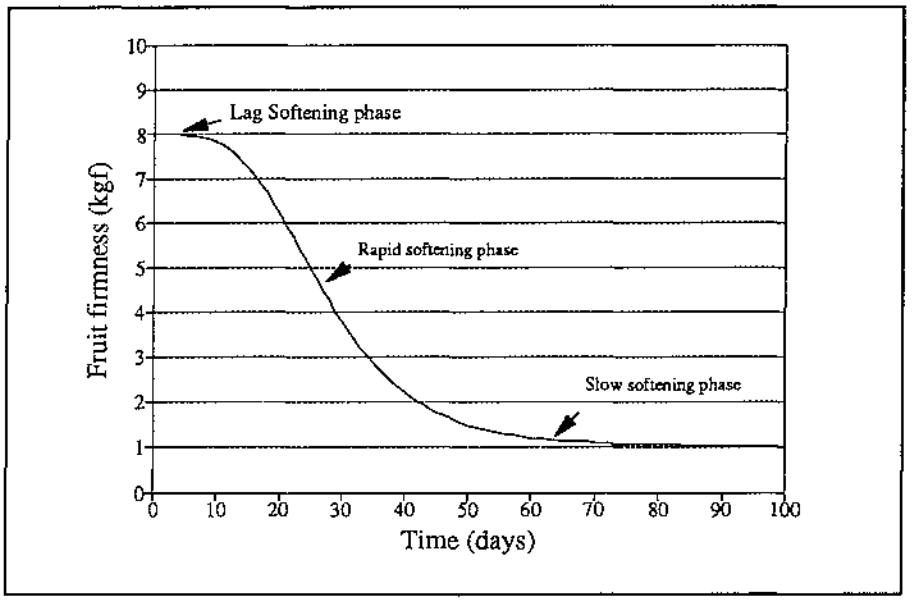


Fig. 1.1 Diagrammatic representation of softening in kiwifruit.

Fruit firmness is therefore used by the NZKMB as a quality criterion in deciding if a line of fruit is accepted or rejected for export. Once fruit has been in a coolstore for longer than 8 weeks from packing it must be condition checked before being exported. Six trays are randomly selected from any one of the corner columns of each pallet. All fruit in each of the six trays are inspected for defects. From each tray the number of soft fruit are recorded as a defect then, following NZKMB guidelines the need for repacking is determined. The average firmness of 20 fruit from a grower's line (randomly selecting four fruit from five trays for a grower by pack date) must be above 1.2 kgf to avoid repacking (NZKMB, 1992).

Fruit described as prematurely soft are rejected for export when their individual firmness (or any area on the fruit surface) is not greater than the export firmness threshold, set by the NZKMB at 1.0 kgf for fruit tested at between 0 and 5°C (NZKMB, 1992). Firmness is very critical 8 weeks after harvest when fruit have softened close to the export

firmness threshold. It is therefore very important to growers that their fruit remains above this level of firmness at least until they have been exported. At present it is not possible for the NZKMB to predict accurately which lines of fruit will have the fastest rate of softening, nor is it possible to assess the likely storage performance of a given line of fruit from its storage behaviour in previous years.

There is, therefore, considerable industry interest in identifying those factors most responsible for influencing fruit firmness. It is thought that mechanical damage resulting in bruising of fruit tissue can cause fruit to soften prematurely (Hopkirk and Finch, 1989). Damage caused by handling at harvest has been associated with the tendency of fruit to develop water-soaked soft patches areas during extended storage (Banks, 1991).

Another problem faced by the industry is the difficulty in accurately assessing firmness of fruit that are close to the export firmness threshold. This is normally done subjectively, by touch, in the condition checking of large numbers of stored fruit. However, an objective, non-destructive method of assessing firmness could be of great value in calibrating an individual's perception of the export firmness threshold or, if rapid enough, in the routine testing of fruit at condition checking.

This thesis examines a number of issues relating to the softening behaviour of kiwifruit. Literature on factors affecting fruit texture and its measurement are reviewed in Chapter 2. In Chapter 3, the potential role of mechanical damage in affecting softening behaviour is examined on fruit stored for an extended period. These same data are used to examine a number of different mathematical approaches to the description of kiwifruit softening behaviour over time. In chapter 4, a non-destructive method for assessing kiwifruit firmness is outlined and compared to the standard method for assessing fruit firmness (the penetrometer; NZKMB, 1992).

Chapter Two

2.0 What is texture?

Fruit and vegetables are covered with one layer of epidermal cells and often several layers of hypodermal cells that constitute the skin which helps protect the underlying tissues from handling damage at harvest. The epidermal layer may be thick or very thin, tender, fuzzy, hard or prickly (Bourne, 1983). The edible parts of fruits are composed predominantly of fleshy parenchyma cells. Mature parenchyma cells are usually 50-500 micrometer (μm) diameter (Bourne, 1983). These cells are usually isodiametric and polyhedral, with individual cells being cemented together by the middle lamella. Small cells with little intercellular spaces form a compact texture while large cells with considerable intercellular space (e.g water melon) form a coarse or spongy texture. Cytoplasmic and vacuolar membranes have the property of differential permeability allowing small molecules such as water to pass through but restricting larger molecules including sugars. Physiological processes within the parenchyma cell enable it to absorb water, thus generating hydrostatic pressure called turgor pressure. This causes the vacuole to enlarge and press tightly against the cell wall imparting turgidity, rigidity, and crispness contributing to the particular quality called "firmness" of the plant tissue.

The membrane is contained by the secondary and primary cell walls (Bourne, 1983). The primary cell wall is made up of cellulose microfibrils that are loosely woven together in an irregular pattern and embedded in an amorphous matrix composed mainly of pectic substances and hemicellulose. The secondary cell wall lies immediately inside the primary cell wall; it consists of cellulose microfibrils embedded in an amorphous matrix of hemicellulose and lignins. The cell wall and middle lamellar layer, which usually constitute only about 1-3% of the weight of fresh fruit but can impart a solid structure to a mixture that is mostly water.

The middle lamella is an amorphous layer external to the primary cell wall that cements individual cells together. The middle lamellar layer consists principally of the calcium salts of polygalacturonic acid that have been partially esterified with methyl

alcohol and are known as the pectic materials. The degree of polymerization and esterification of the polygalacturonide chains, and the amount of cross-linking of adjacent pectin molecules by salt bridge formation, have a profound effect on the physical properties of the middle lamella and the overall textural properties of fruits (Bourne, 1983). The middle lamellae serve as intercellular cement, and their nature largely determines the textural properties of the tissue (Haard, 1976). Disintegration of the middle lamella over time causes "softening" of the tissue.

Edible portions of fruits also contain phloem and xylem cells that conduct nutrients and water. Supporting cells (collenchyma cells) are thick-walled cells that usually take the form of fibres. These supporting and conducting cells form an interconnecting branch network in the fleshy parenchyma tissue. These are heavily lignified but their physical properties and relative scarcity in edible tissue are such that their texture is often not intrusive on the textural sensation. In some commodities these do stand out, such as in fibrous celery, asparagus, and mango. The structural make up of fruit and vegetable texture influences how susceptible tissue is to handling damage and how this will affect the rate of softening of the crop.

2.1 Ontogenetic development

2.1.1 Normal pattern of preharvest fruit development

Pratt and Reid (1974) described kiwifruit growth as being made up of five phases (Table 2.1). It appears that fruit volume reaches a maximum 21 to 23 weeks after anthesis which corresponds with horticultural maturity. Ethylene is produced in trace amounts throughout the life of the fruit but only low concentrations are present within the fruit tissue (e.g. < 0.1 $\mu l.l^{-1}$; Pratt and Reid, 1974). It is after period V that harvesting and handling of the fruit takes place, as fruit are then mature enough to ripen in coolstorage but still have a high initial firmness (10 to 8 kgf) and a long storage potential at 0°C.

Table 2.1 Different growth phases associated with kiwifruit development (based on Pratt and Reid, 1974).

Phase	Weeks	Growth changes
Period I	0 to 9 weeks	initial rapid growth, seeds reaching full size
Period II	9 to 12 weeks	slow growth, seeds harden and start to colour, first very large response to ethylene
Period III	12 to 17 weeks	rapid growth, seeds become dark brown, respiratory response to ethylene increases
Period IV	17 to 21 weeks	very little growth, seeds dark brown, softening starts, soluble solids start to increase, respiratory response to ethylene rises to a maximum and then decreases
Period V	21 to 23 weeks	smaller growth increases to approximately final fruit size, fruit matures, seeds become dark brown and free in tissue. Respiratory peak induced by ethylene treatments are reduced to about the same magnitude as the endogenously induced peaks, initial respiration of untreated fruit drops to a basal level which persists for the rest of the season.

2.1.2 Preharvest changes in fruit composition

Very young fruit have a high starch content and the content of soluble solids and sugars is low and constant (Pratt and Reid, 1974). In early April there is an initial rise in soluble solids. Harvested fruit continue to increase in soluble solids, as the residual starch is converted to sugar. Okuse and Ryugo (1981) found that total carbohydrate content increased rapidly with fruit growth as a kiwifruit developed. Green immature fruit were rich in glucose but the level decreased while starch accumulated rapidly late in the season. As starch hydrolysis began, glucose level increased rapidly, attaining nearly 10% on a dry weight basis by harvest. Fructose increased gradually from the youngest stage of fruit

development until harvest. Continued accumulation of dry matter by the fruit while starch was hydrolysing was reflected by an increase in total soluble solids. This accumulation indicates that photosynthates were still being imported until the fruit was harvested.

2.1.3 Physiological processes associated with textural change

Changes in the chemical nature of the pectic materials are the primary cause of changes that occur in the textural properties of horticultural products (Van Buren, 1979). As a fruit ripens, chain length of the pectin polymers decreases, forming water soluble pectin, and the structure becomes increasingly soft (Bourne, 1983). MacRae *et al.* (1990) proposed that softening of kiwifruit is partly due to enzymatic degradation and solubilization of the pectic substances. Pectic substances have been shown to solubilize during ripening in kiwifruit after harvest. During the early phase of fruit softening (10 to 1.5-2 kgf) large amounts of pectin are solubilised in the cell wall, allowing pectins previously insoluble in the cell wall to become water soluble. Redgwell *et al.* (1991) proposed that cell wall breakdown in kiwifruit may be due to solubilization and depolymerisation of polyuronide, and the release of galactose from the pectic polymers. This appeared to be a non random process in kiwifruit *in vivo*, occurring to varying degrees in different pectic fractions. Changes to the primary structure of the pectic polysaccharides, although accompanied by other ripening-associated phenomena, such as starch hydrolysis and the de-esterification of polyuronides, are not in synchrony with them. This may indicate that starch hydrolysis occurs independently of fruit softening. At harvest the outer pericarp is thought to contain the pectic polymers identified as consisting of a backbone of 4-linked galacturonic acid interrupted by 2-, and 2,4-linked rhamnose sugar found in plant glycosides. Factors that promote the pectin bonds between cell walls might enable a kiwifruit to better withstand handling influences that may otherwise induce more rapid enzymic breakdown of the middle lamella and cause softening of the overall fruit texture.

There is also a decrease in the size of another group of cell wall polymers called hemicelluloses (MacRae *et al.*, 1990). These are polysaccharides that are tightly bound to the cellulose fibres in the fruit wall, and are thought to assist in maintaining the integrity of the cell wall. During the latter phase of softening most pectins have been solubilized,

but degradation of soluble pectins to smaller polymers continues. Pectin esterase and polygalacturonase have been shown to be present in kiwifruit during ripening. Polygalacturonase is involved in degradation of the middle lamella of the cell wall. Soda *et al.* (1986) reported that polygalacturonase plays a role in the solubilization of pectic substances and in textural changes involved in kiwifruit ripening. It appeared to be absent in unripe fruit but was detectable in rapidly ripening fruit.

2.2 Factors affecting fruit texture

2.2.1 Time

MacRae *et al.* (1989) demonstrated that kiwifruit lose firmness progressively with time after harvest. The softening pattern depended upon fruit maturity at harvest. Kiwifruit that were not fully mature (21 weeks from anthesis) had a lag phase in their softening curve (Fig 1.1). The lag phase was steadily reduced over time. Decreases in flesh firmness occur rapidly from 8-10 kgf to 2 kgf (MacRae *et al.* 1990). From 1.5-2 kgf flesh firmness decreases at a much slower rate therefore a biphasic softening pattern for kiwifruit has been proposed based on the first rapid then reduced decrease in fruit firmness (Arpaia, 1980; cited in Arpaia *et al.* 1987). Handling influences at harvest may promote a more rapid drop in fruit firmness and so reduce the time it would take for fruit to reach 1.0 kgf.

There can be wide variation in the time at which ripening occurs in fruit which were set and harvested at the same time and which might be expected to be physiologically alike (Pratt and Reid, 1974). Lallu *et al.* (1989) harvested fruit from the same orchard block over two seasons and applied the same treatments to fruit, but the time taken for fruit to reach 1.0 kgf differed by two weeks between years. There were also differences between fruit within a given harvest. Variability in softening behaviour of individual fruit is one of the main problems in the commercial storage of kiwifruit since the sub-standard fruit have to be weeded out. It could be that handling at harvest is adding to the variation between individual rates of fruit softening. On a commercial level there is a difference between the mean softening rates of kiwifruit from different orchards in the same region (Crisosto *et al.*, 1984).

Arpaia *et al.* (1987) showed that the initial stages of softening in both air and CA storage may be influenced as much by starch hydrolysis and consequent cell turgor changes as by solublization of the cell wall components. Hatfield and Knee (1988) proposed that apple firmness was influenced by cell turgor, with loss of water from fruit leading to better maintenance of cell cohesion during ripening. As fruit matured the cell walls lost their rigidity and under the influence of cell turgidity the cell became more spherical in nature. This led to an increase in the size of intercellular spaces between cells. They implied that the average area of contact between cells was reduced, whereas in high weight-loss fruit the cell contact was maintained due to the air spaces not increasing. The findings by Apraia *et al.* (1987) and Hatfield and Knee (1988) indicate that in kiwifruit a similar process of starch and cell cohesion could occur whereby starch hydrolysis may increase cell turgor, so reducing cell cohesion and producing a reduction in fruit firmness.

2.2.2 Direct temperature effects

Coolstorage at 0°C is the main practice used to delay the reduction in softening of fruit firmness below the export cutoff firmness of 1.0 kgf (NZKMB, 1992). Low temperature storage causes physiological changes associated with fruit softening to progress more slowly leading to a significant reduction in ripening (Wright and Heatherbell, 1967).

The temperature at which fruit are tested can affect their physical properties and thus any numerical value of an objective firmness measurement. An investigation by Bourne (1982a) on a range of commodities involved measuring their firmness with different firmness instruments over a range of temperatures. Firmness decreased with increasing temperature for most commodities and for every type of firmness measurement, with the relationship being linear for most commodities. Firmness-temperature (FT) coefficients (percentage change in firmness per degree temperature increase over the temperature range studied) varied widely. They varied from commodity to commodity, from cultivar to cultivar within the same commodity, from one test principle to another on the same commodity, on the same commodity during storage and from year to year. Most commodities had a FT coefficient of between -0.1% and -1% per °C. Large differences in a commodity temperature could therefore result in very detectable differences in firmness

for some crops. The greater the FT coefficient the smaller the temperature change needed to detect a temperature effect.

Banks *et al.* (1991) have examined the differences in firmness for kiwifruit 0°C and 20°C from 6 growers at a range of firmness levels. For fruit with an average firmness close to the export threshold firmness level (1.2 kgf), there was 0.7 kgf change in firmness for fruit at the different temperatures (Fig. 2.1).

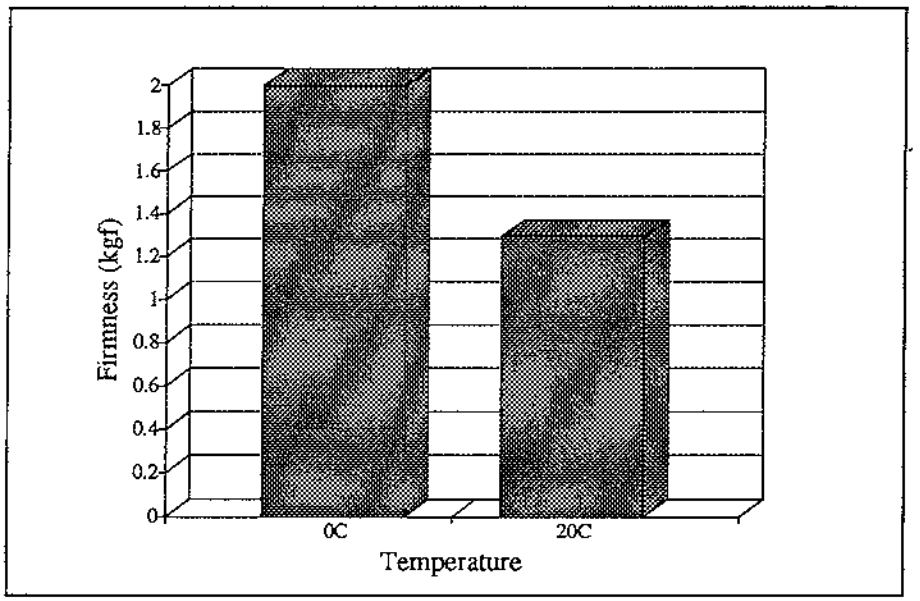


Fig. 2.1 Differences in fruit firmness at 20°C and 0°C in otherwise identical fruit.

Banks *et al.* (1991) data was used to calculate FT coefficients from fruit at different mean firmness values. FT coefficient varied with fruit firmness (Fig. 2.2). The overall mean FT coefficient in this study was -0.7% change in firmness for every degree change in temperature. This coefficient is larger than the values for most other raw fruits and vegetables reported by Bourne (1982a), which shows how much temperature influences firmness in kiwifruit. It is still to be clearly determined if the temperature-firmness relationship for kiwifruit is linear. If it is then warming of fruit by a few degrees would only have a small influence on their firmness. Nevertheless, these preliminary observations make clear the need to identify fruit temperature at the time of testing when making statements about fruit firmness. However, most investigations of kiwifruit softening behaviour have been carried out on fruit which have been allowed to equilibrate to room

temperature overnight before firmness was measured (Pyke, 1991). Estimates of time taken to reach the export threshold in research studies could therefore be seriously underestimated by identifying the time taken for fruit to reach the same firmness value if they are allowed

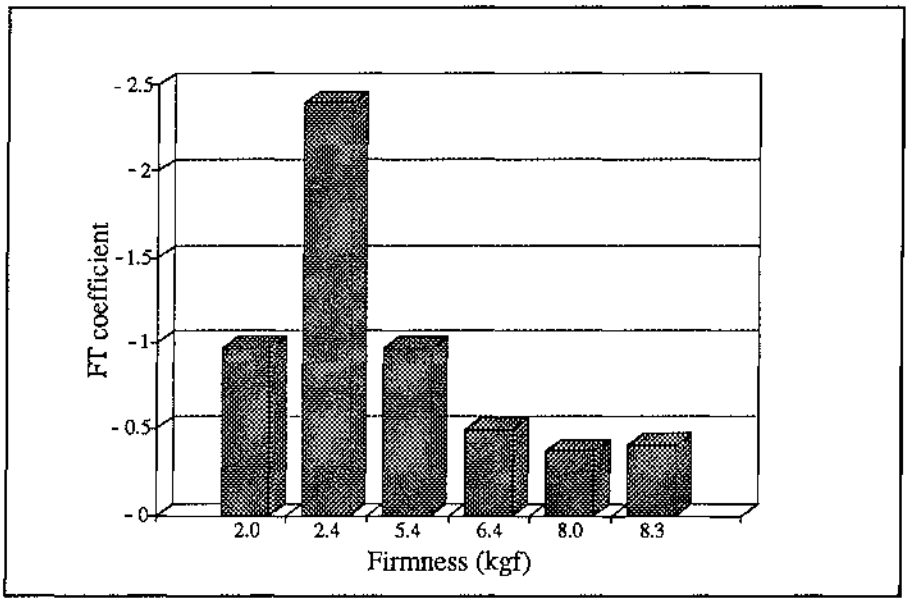


Fig. 2.2 Firmness-temperature coefficients for six growers at 0°C and 20°C.

to equilibrate to room temperature before measuring firmness. Further work in this area is clearly justified, so that FT coefficients for fruit of different initial firmness values can be established. Fluctuations in flesh firmness due to rewarming may result in variability in the firmness data that confounds the ability to clearly determine if handling has an influence on the rate of softening of kiwifruit.

Werner *et al.* (1978) observed peaches exhibited rehardening when returned to low temperature storage after softening at room temperature. Rehardening was more pronounced as the storage temperature was reduced. They suggested that low temperature induced rehardening was not related to metabolic changes in the fruit cell wall influenced by temperature, but in part to the gelling behaviour of the pectin fractions. Werner and Frenkel (1978) attributed the rehardening of peaches at low temperatures to a temperature effect on the behaviour of the pectic substances and probably other cell wall polysaccharides in the fruit. Low temperature was thought to promote thickening of solutions containing these compounds. They stated that in softening fruit, the soluble pectin fraction, apparently in

combination with sugar and acids, or multivalent metal ions, may form a solidified gel matrix at low temperature. At ordinary room temperature the gel matrix may liquefy with the resulting tissue being less firm than it was at the lower temperature. In ripening fruit the changes in firmness at different temperature may reflect the behaviour of soluble pectin fractions. It is possible that kiwifruit may also differ in firmness when tested at 0°C and 20°C due to a temperature effect on pectin gelling strength. We might expect FT coefficient to be affected by the fruit's calcium content given the known effects of calcium on firmness of a wide range of fruit tissues (Poovaiah *et al.*, 1988).

2.2.3 Ethylene

McDonald and Harman (1982) reported that kiwifruit are very susceptible to ethylene, and concentrations of 0.1 $\mu l.l^{-1}$, even at 0°C, will enhance fruit softening and therefore reduce storage life.

2.2.3.1 Endogenous

Pratt and Reid (1974) observed ethylene production in individual fruit always before or coinciding with the respiratory rise for fruit at 20°C. Fruit of apparently similar characteristics can have great variability in timing of the ripening processes, the reason for which may reside in the mechanism which regulates the production of ethylene. Damage to internal tissue in kiwifruit as a result of handling could perhaps stimulate mechanisms which regulate ethylene production, similar to the way in which wounding stimulates ethylene production in many plant tissues (Abeles, 1973).

Exposure of cucumbers to low temperature (Wang and Adams, 1982) for a period or low temperature stress advanced the onset of ethylene production in the fruit when transferred to 21°C, possibly by stimulation of 1-Aminocyclopropane-1-carboxylic acid (ACC) formation. This raises the possibility that exposure to prolonged low temperature could induce the onset of rapid ethylene production in kiwifruit, as is known to be the case in apples (Knee *et al.*, 1983) and pears (Hansen, 1939). Hyodo *et al.* (1987) found the time required for fruits to reach a threshold level of 0.1 $\mu l.l^{-1}$ became much shorter and the

previous wide range of variation in the time became less after fruits were stored for 4 months and longer at 2°C. It appears that exposure to a low temperature (2°C) or chilling stress may advance the onset of ethylene production at a greater rate in the fruit when transferred to a higher temperature (21°C).

Endogenous ethylene production may be enhanced by physical damage to fruit causing premature ethylene production. Fruit not exposed to ethylene at 20°C softened according to their maturity at harvest (Lallu *et al.*, 1989). Less mature fruit had a lag phase in their softening curve which disappeared with increasing maturity. Mature fruit had a high rate of ethylene production, while very mature fruit showed very little response to ethylene in their rate of softening. It would seem that fruit harvested later in the season accumulate sufficient ethylene from their own metabolism to saturate their potential responsiveness to ethylene in terms of ethylene because 0.1 to 1000 $\mu l.l^{-1}$ ethylene has little effect on promoting fruit softening once rapid softening has been achieved (Lallu *et al.*, 1989).

Sommer (1989) demonstrated that when plant tissue is wounded, such as at harvest, wound induced substances play an important part in the defense against infection. The first response of wounding (or any physical stress) is an increase in ethylene concentration. Compounds such as lignin, suberin, and cellulose, may help to thicken cell walls, and peroxidases, polyphenoloxidases, phenolic compounds, glycosides, histones, and phytoalexins are also known to contribute to a plant's resistance to infection. Handling fruit after harvest, so as to minimise their susceptibility to infection requires it to be of proper maturity, with minimum exposure to ethylene, physical stress, and moisture loss (Sommer, 1989).

2.2.3.2 Exogenous

Temperature and exogenous ethylene have a major effect on internal ethylene levels in kiwifruit and therefore can effect changes in quality of the fruit. McDonald and Harman, (1982) found that kiwifruit at harvest produce negligible ethylene but are very sensitive to exogenous ethylene. Both high CO_2 and low O_2 can inhibit ethylene production and action in fruit but it was doubtful whether this was the main reason for the effectiveness of

controlled atmosphere (CA) storage on kiwifruit firmness, as ethylene was measured at extremely low concentrations during the experiment (< 0.03 $\mu l.l^{-1}$). This may indicate that kiwifruit softening is initiated by even lower concentrations of ethylene. Such inhibition of metabolism by CA treatments could not only retard the rate of kiwifruit softening during CA cool storage but could alter the composition of the stored fruit (McDonald and Harman, 1982). A kiwifruit damaged during handling might produce ethylene prematurely and once packed in a tray, would cause the ethylene concentration to build up in the tray causing the other fruit in the tray to soften.

An ethylene concentration as low as 0.03 $\mu l.l^{-1}$ has been shown to have a slow softening effect (Harris and Ried, 1981). Kiwifruit exposed to 5 $\mu l.l^{-1}$ for 24 hours decreased from 6.5 kgf to 2.9 kgf in 24 hours at 20°C (Matsumoto *et al.*, 1983). There was little change in fruit firmness of the control samples. Kiwifruit harvested late in the season and ripened at 20°C softened as rapidly as similar fruit treated with ethylene. Fruit harvested at an intermediate maturity (5.5% SS) and ripened at 20°C, had cores that softened at much the same rate relative to fruit firmness both with and without ethylene treatment. Fruit more mature at harvest (> 7.1% SS) that were ethylene treated had cores that softened faster than the core of non ethylene treated fruit, whereas softening rates of the flesh were similar in both ethylene treated and non ethylene treated fruit.

Wright and Heatherbell (1967) exposed kiwifruit to ethylene at 20°C which showed a marked rise in their respiration, which did not occur if they were treated at 0°C. The kiwifruit used were picked from vines in late June and July. MacRae *et al.* (1989) suggested that these kiwifruit may have had time to produce enough internal ethylene to exceed the saturation level required for promotion of softening and therefore not respond to ethylene applied to the fruit at 0°C. Fruit that are very mature before being harvested (soluble solids = 8.0%) have a higher internal concentration of ethylene and their softening rate is not very responsive to exogenous ethylene concentrations. Less mature fruit held in storage at 0°C then allowed to ripen at 20°C are more responsive to ethylene, relative to mature fruit stored under similar conditions, indicating the internal build up of ethylene in kiwifruit as they mature. Ben-Arie and Sonego (1985) showed that kiwifruit in a modified atmosphere maintained their firmness for longer in the presence of an ethylene absorbent

(Ethysorb).

2.2.4 Calcium

Each season some lines of kiwifruit become prematurely soft for reasons still to be identified by the kiwifruit industry (Harker *et al.*, 1990; Smith *et al.*, 1991). It has been suggested that calcium may have a role to play in reducing the rate of softening (Prasad and Spiers, 1991). Calcium is involved in the structural components of the fruit flesh such as cell walls. The strength of these walls, and consequently the firmness of the fruit flesh, is partly related to the amount of calcium in the cell walls (Harker *et al.*, 1990). Trials have shown that a postharvest dip in calcium reduced softening rate, yet there is not always a consistent relationship between calcium levels and firmness (Hopkirk *et al.*, 1990). Total calcium levels in kiwifruit are high relative to other fruit (Smith *et al.*, 1991). The level of calcium in the fruit is higher in the stalk end than the blossom end, and the highest portion of fruit calcium is located in the inner cortex (Harker *et al.*, 1990). A high proportion of the total calcium accumulated by fruit occurs during early growth, were the xylem is the major transport pathway to the fruitlets. A high percentage of incoming calcium becomes associated with oxalate in the fruit (Clark and Smith, 1991).

Pectins found in fruit have a low degree of esterification (O. Campanella, Dept. Food Tech., Massey University; personal communication, 1991) and form gels in the presence of calcium and other divalent metal ions. Work with softening of cucumber tissue (McFeeters and Fleming, 1990) found that calcium ions inhibited softening. They made the assumption that the hyperbolic inhibition of softening by calcium was due to saturation of a binding site by calcium. The binding was considerably stronger than should occur if calcium was binding to pectin carboxyl groups under similar conditions. They thought it may be that there is a calcium-binding protein in tissue firmness changes (McFeeters and Fleming, 1990). Whatever calcium's ability to affect the strength of gels or binding proteins, the result is a reduction in softening. It may be that a similar process occurs in kiwifruit and fruit with higher concentrations of calcium might therefore be more able to resist injury due to handling at harvest.

2.3 Evaluation of fruit firmness

Assessment of kiwifruit firmness is important in determining fruit quality both in the commercial situation and in scientific research. In New Zealand the commercial standard instrument for quantifying firmness is a penetrometer. A penetrometer is used to assess firmness upon which marketing decisions on when to export fruit are made.

2.3.1 Commercial assessment of kiwifruit firmness

The packhouse is responsible for rejecting or accepting growers fruit for export, with audit checks on the packhouse being done by the Kiwifruit Marketing Board Field Officers. Firmness at condition checking is tested usually by hand, rather than by penetrometer. A person who is testing firmness is screened to make sure they can make an accurate subjective assessment of fruit firmness (G. McCandrew, Field Officer, NZKMB; personal communication, 1991). If fruit are thought to be under the export cut off firmness they can be tested by penetrometer to confirm the person's judgement. Some packhouses assess their fruit in coolstore while others bring pallets out of coolstore to be assessed. The temperature of fruit at which the firmness is tested is not routinely measured. However, since condition checking of a pallet completed within 2 hours of removal from coolstore, fruit temperature would rarely have increased above 5°C.

2.3.2 Research assessment of kiwifruit firmness

An assessment of kiwifruit firmness should perhaps ultimately determine texture as assessed by mouth-feel. Development of devices which measure texture have been the subject of numerous research trials over the years, and a substantial part of this effort has been on trying to develop an objective method for measuring texture. A great number of objective methods for measuring texture have been developed, and these measure many different properties of foods (Bourne, 1966). These are summarised in Table 2.2. Some of these instruments could be very useful for assessing kiwifruit firmness. Potentially the principles on which some of the instruments are based could be developed into commercial instruments that non-destructively assess kiwifruit firmness.

Table 2.2 Objective methods for measuring texture of horticultural products (Bourne, 1966; 1980).

1. Force measuring
a. puncture e.g. Magness-Taylor Pressure Tester (penetrometer; Effegi), Maturometer
b. extrusion e.g. Shear Press, Tenderometer
c. crushing
2. Distance measuring
a. deformation
3. Time measuring
4. Energy measuring
5. Ratio measuring
6. Multiple measuring (Texture Profile Analysis)
a. Instron, G. F.

2.3.3 Objective methods for measuring texture

The above classification (Table 2.2) is based upon the variable (or variables) that constitute the basis of the measurement. Force measuring instruments are the most common method used for measuring food texture. When the measured variable is force, distance and time are held constant or at least made repeatable. Force measurements are often based on compressive tests but may also measure the tensile strength of food. Distance measuring instruments keep force and time constant or replicated while some function of distance is measured. This group can be subdivided into distance, area, and volume measurements. With time measuring instruments, time is measured while force and distance are held constant or replicated. Energy measuring instruments measure work or energy, which is the product of force and distance. Ratio measuring methods require at least two measurements of the same variable, from which a ratio is calculated. Multiple measuring instruments measure more than one variable. Usually a chart is used on which a force-distance curve or approximation to a force-distance curve is drawn. It is possible to measure various forces, distances, and areas with these instruments.

2.3.4 Puncture assessment of texture

A puncture test measures the force required to push a probe or punch into a food to a depth that causes irreversible crushing (Bourne, 1979). The punch is usually made of metal and is cylindrical (circular in cross-section and uniform in diameter along its length) or conical in shape. The puncture test measures the depth of penetration of a probe into food under a constant force in a given time. Puncture testing is characterised by: a) force-measuring instrument (eg. dial gauge); b) penetration of the metal probe or punch into the food sufficient to cause irreversible changes; and c) the depth of penetration is held constant. The Magness-Taylor pressure tester and the Effegi pressure tester (penetrometer) are puncture tests widely used by horticulturists. With a puncture test there is an initial rapid rise in force over a short distance of movement as the pressure tip moves onto the commodity (Bourne, 1980). During this stage the commodity is deforming under load; there is no puncturing of the tissue. This stage ends abruptly when the punch begins to penetrate into the food causing irreversible crushing, which represents the yield point or bio-yield. With testing firmness of fruit the force continues to increase after the yield point. The hand tester must be pushed with increasing force after the yield point to make the pressure tip penetrate to the required depth. Since the shear strength of the skin is not necessarily related to the firmness of the underlying flesh, the skin should be removed before a pressure test is made, unless it is established that the skin causes a negligible increase in firmness reading (Bourne, 1980).

The New Zealand kiwifruit industry standard instrument for measuring firmness is the penetrometer using a 7.9 mm diameter tip (NZKMB, 1992). The Effegi fruit tester (penetrometer) is based on the Magness-Taylor fruit pressure tester. The penetrometer consists of a metal probe 7.9 mm in diameter attached to a calibrated spring with a dial needle graduated in pounds and kilograms force. A piece of skin is peeled from a fruit then the tip of the metal probe is pressed into the fruit to a constant depth marked on the metal probe, and the penetrating force is read on the dial. Being manually operated, the instrument readings have variable accuracy depending on the operator. The faster the penetration of the probe the higher the firmness reading. Measurements in apples have been reported to be more uniform if the instrument is mounted on a drill press (Blanpied *et al.*,

1978).

2.3.5 Deformation assessment of firmness

Softness of fruit is used as a criterion for describing quality of produce (Bourne, 1967). It is usually sensed by squeezing the food in the hand, or by biting it. A soft fruit is thought of as being more ripe than a hard fruit. A subjective estimate of softness is a measurement of the degree of deformation of the food, under the influence of a compression force applied by the fingers. The deformation test is the distance that the fruit is deformed by squeezing; this is sensed by the hand. The fingers are able to sense very small differences in distances. A simple example of the high degree of sensitivity of the human hand is the ability determine whether one or two sheets of paper are held between the fingers (Bourne, 1967). The fingers also sense the pressure applied due to the force of the fingers and the resistance of the fruit to that force. There are a number of different types of apparatus that can be used to measure deformation of foods objectively. They are frequently distance measuring instruments that measure the degree of compression of the fruit under a standard deforming force. Some instruments measure force required for a standard deformation. Any deformation test of fruit must have a precise method for measuring small distances if it is to give good results (Bourne, 1967). Deformation is widely used for measuring firmness of foods but there is little in the way of commercial instruments available for the test (Bourne, 1982b). A non-destructive measure of fruit firmness would greatly assist in identifying factors causing premature softening of fruit and if handling leads to development of localised areas of softening on the fruit surface.

The penetrometer is an inexpensive instrument that is easily adapted to the deformation testing of food (Bourne, 1973). This particular penetrometer is characterised by: a) being a distance-measuring instrument; b) penetration into the food sufficient to cause irreversible changes; and c) a constant force, usually achieved by the effects of gravity on a set mass. The penetrometer used by Bourne measured to the nearest 0.1mm on a dial gauge and a flat disc was used for the probe. Provided the food being tested was soft and of reasonable size this provided a simple, effective method for measuring the deformation of food. However, the dial readings were so small that for rigid foods the

precision of measurement was lost. The precision of such a test could be improved markedly with a more precise measurement of deformation. The majority of foods give a force-deformation curve that is concave downwards, which is typical of softer fruits and vegetables. Linear type force-deformation curves are found with rigid products such as firm green fruits and vegetables, and eggs. An "s" shaped curve is found with breads and some cheeses. Small irregularities in the surface of the test product can result in large errors in deformation (Bourne, 1982b).

Kader *et al.* (1978) developed a device which pressed two 1.3 cm steel balls against sides of a fruit using 2.2 newton compression force and measured its deformation after 1 second. The fruit was supported like a pendulum then two steel balls were moved close against the equator of the fruit, one to each of the opposite sides of the fruit, by moving a backstop or the fixed ball. Then the fixed ball was locked into position and the compressive force, produced by a dead weight, was exerted on the fruit. Deformation as a function of time was recorded; deformation increased with ripeness. Mehlschau *et al.* (1981) developed a deformeter for non-destructive maturity detection of pears based on the measurement of deformation resulting from pressing two steel balls to the opposite sides of the fruits with a fixed force. Delwiche *et al.* (1991) reported on a fruit firmness sorter based on impact response by means of a probe modified to allow coupling with a conveyor system operating at 5-10 fruit per second. The impact mass of the modified probe was attached to the rod of a horizontal air cylinder, which was triggered as the fruit entered the sensing area. Acceleration of the mass during impact was measured with a piezoelectric accelerometer and analyzed by computer. Impact response characteristics were used as features for classification into firmness ranges.

Perry (1977) developed a non-destructive firmness-test unit that applied low-pressure air simultaneously to small areas on opposite sides of peaches to generate a non-bruising maturity-indicating deformation. Mizrach, Nahir and Ronen (1985) used a 3 mm diameter pin as a mechanical thumb to sense firmness of oranges and tomatoes. Bernstein and Lustig (1985) developed a firmness tester for grape berries that involved the berry being compressed between two parallel surfaces by a force. The force was applied to an upper surface which was a glass plate, by means of a manual drive unit. The force was measured

by a dynamometer connected to the lower surface. The applanation area was observed and measured by an optical method. The reading of the dynamometer was taken as soon as a predetermined area was reached. Turgor pressure of the berry was also tested and an almost linear relationship was found between firmness index and turgor pressure. Lustig and Bernstein (1987) also developed a firmness tester for juicy fruit by compressing of fruit between two parallel surfaces with a measured force until a given constant area was reached. A hydrostatic measuring head allowed for the direct determination of this area. Meredith *et al.* (1988) reported on a rapid non-destructive method of firmness as an estimate of maturity in peaches. A coefficient of firmness was determined by two consecutive bounces of a peach onto a load-cell tripod.

Hopkirk *et al.* (1992) reported on their evaluation of "SoftSense", a system whereby individual kiwifruit were dropped a small distance (10 mm) onto a load cell, and characteristics of the fruit bounce were used to calculate the firmness and the weight of the fruit. They also reported on a hand-held wand probably measuring similar physical properties of the fruit SoftSense, developed by George Dawson at DSIR Industrial Development.

2.4 Sources of variation in kiwifruit firmness data

The penetrometer is highly dependent on the person taking the measurement for it's accuracy. There is variation in readings when using the penetrometer which can be compounded by kiwifruit's individual firmness variation. The penetrometer is destructive and therefore does not allow individual fruit firmness to be monitored over time. Other tests of fruit firmness that are non-destructive and less operator dependent in nature would help to give more accurate firmness readings. This would allow the removal of variation occurring as a result of the taking of readings and expose the natural variation between and within fruit. This would assist the identification of factors causing premature softening in individual fruit.

A storage curve workshop looked at the problems faced when assessing fruit firmness over time from different trays and different growers (Pyke, 1991). When taking

a tray of fruit to sample to get an average firmness for the tray, there is the risk of not being able to control or know the tray to tray variation in firmness compared to the actual treatment effect on fruit firmness. When storing fruit in coolstore there can be the risk of temperature variations in the coolstore, which may be related to position of fruit in store (McDonald *et al.*, 1992). Temperature of the fruit flesh may cause variations in firmness readings and variation between testers which may mask natural variation of the fruit. Small fruit are known to soften more rapidly than large fruit (Hopkirk *et al.*, 1990). All of these factors can lead to variation in firmness readings. Fruit firmness may be interpreted by using analysis of variance to characterise difference between means or using a fitted curve to a number of means at different times.

2.4.1 Prediction of fruit ripening

Kiwifruit in coolstorage have their firmness assessed to determine if a line of fruit meets the export firmness criterion (NZKMB, 1992). There is no system whereby those lines of fruit that will soften at a faster rate can be separated from other lines of fruit. Prediction of rate of softening of grower lines of fruit would greatly assist the management of the export crop. If the rate of fruit softening could be taken into account when deciding which lines of fruit to export first, rejection of fruit as a result of premature softening would be avoided. It may be possible to characterise accelerated fruit ripening and from this predict how fruit will soften in coolstorage. Accelerating ripening of fruit in trays at higher temperatures as a prediction is seen as full of unknown problems due ethylene having so much effect on the rate of softening at ambient temperatures (Pyke, 1991).

2.4.2 Use of mathematical models

A mathematical model comprises one or more equations which represent behaviour of the system under study (France and Thornley, 1984). Hypotheses expressed in the mathematics can provide a quantitative description and understanding of biological problems. In the context of this study, a mathematical model may provide at least an empirical description of changes in kiwifruit firmness over time. This should make it easier to ask questions about the data or to discriminate between alternative treatments.

Data presented by Lallu *et al.* (1989) and McDonald (1990) indicate that changes in kiwifruit firmness with time follow either an approximately exponential decline (mature fruit) or a sigmoidal decline (immature fruit). Equations describing these types of curve may therefore form the basis of mathematical model for the empirical characterisation of changes in kiwifruit firmness with time (Banks *et al.*, 1992).

2.5 Mechanical damage in postharvest handling of kiwifruit

One of the byproducts of mechanization in production and handling of horticultural crops is mechanical damage to the crop during harvesting and packing. In horticultural products tissue failure is usually manifested through a rupture in the internal and external cellular structure under the skin. The most common symptom of mechanical damage is bruising, whereby an external force causes a physical change in texture and/or eventual chemical alteration of colour, flavour, and texture (Mohsenin, 1986). Miller *et al.* (1987) exposed cucumbers to mechanical stress which promoted ethylene production and a reduction in firmness of tissue, although the effect of mechanical stress did not appear to be mediated through the action of ethylene.

Finch and Hopkirk (1987) stated that it was often assumed that kiwifruit do not bruise due to their firmness at the time of harvest and because there were no immediate visible symptoms of physical damage as there were in apples. Finch and Hopkirk (1987) found that kiwifruit exposed to physical stress after harvest may exhibit one or all of the following at the site of an impact; fracture lines, water-soaking, increased softening and ethylene production. An impact site may have fracture lines in the outer cortex running parallel to the skin or radiating towards the outer core and water-soaking of the outer cortex. Finch and Hopkirk (1987) found that regardless of fruit firmness, impacted fruit softened at the point of impact, which could lead to premature ethylene production and the whole fruit softening subsequently more quickly than non-impacted fruit. The sooner after harvest the impact occurred and the greater the height of the impact, the greater was the damage. Impacted fruit that had softened slowly at 0°C had considerably less damage compared to fruit ripened immediately at 20°C. Their data showed that although impacted fruit produced ethylene and ripened more quickly at 20°C, they did not ripen more quickly

if placed in cool storage. Sawanobori (1983) found bruised fruit that had been dropped six times from 0.6 m onto a hard wooden surface resulted in a rapid decline of flesh firmness after 8 days ripening at 20°C, but fruit held in cool storage had no consistent differences between treatments. Apart from one split fruit which developed a rot, no other fruits showed any disorders such as rots.

A study by Banks (1991) indicated that the handling operation at harvest results in an increased incidence of soft patches in fruit stored for 13 weeks and given a week's shelf-life treatment at 20°C. The patterns of soft patches found in tri-packs also indicated that compression damage can be a problem in current packaging systems.

Bollen and Dela Rue (1990) looked at handling impacts for kiwifruit. In most kiwifruit packhouses, bins of kiwifruit are dry-dumped onto a feed conveyer before being brushed. Fruit then pass over sorting tables and singulator before going to the grader. Fruit are usually sized by weight or in some packhouses by an optical sizer. Fruit are then transferred to packing tables where semiautomatic packing tables are common. In this system the empty single layer trays are guided by conveyor into place were they are filled with fruit by an out-feed belt. Kiwifruit may be exposed to very high impacts by handling machinery. The most potentially damaging impacts occurred for the first fruit exiting the bins hitting the steel chutes. Singulators with a steep chute feeding the fruit into the base, to ensure high cup fill, have the potential problem of fruit not building up at the base of the singluator and individual fruit fall directly onto rollers or lane dividers. An instrumented sphere showed that there were higher impacts for steel lane dividers than when fruit fell onto singulator rollers. Fruit sizer systems did not appear to show any potential to damage kiwifruit. It was the inverting bin cups and the singulator transfer that showed the biggest potential for impacts resulting in bruising. It appears that kiwifruit graders have a number of points at which significant damage could be caused to the fruit.

2.6 Conclusion

Being able to maintain fruit quality over extended periods in coolstore enables New Zealand to sustain its competitive edge on rival kiwifruit exporting countries. This requires

the control and manipulation of fruit firmness. Deterioration of fruit firmness over extended coolstorage periods is influenced strongly by storage temperature and endogenous and exogenous ethylene concentrations. Ability to sustain high fruit firmness under these influences depends on initial fruit maturity (Lallu *et al.*, 1989), possibly mineral content (Mowatt *et al.*, 1991) and handling after harvest (Banks, 1991). Handling damage may cause fruit to prematurely produce ethylene at 20°C, but at 0°C does not appear to have any effect (Finch and Hopkirk, 1987), even though the fruit are subjected to potentially damaging impacts during handling at harvest (Bollen and Dela Rue, 1990).

Monitoring of fruit firmness is very dependent on the equipment used and the temperature at which the test is carried out. Temperature can have a very critical effect on the firmness of fruit tissue (Bourne, 1982a). It would appear that kiwifruit not held at a constant temperature will have variations in firmness with fluctuations in temperature (Banks *et al.*, 1991). This becomes critical when the fruit firmness are near the minimum export cutoff firmness level of 1.0 kgf (NZKMB, 1992).

Many factors have been shown to affect fruit firmness data: natural variation in inherent fruit softening characteristics, fruit's postharvest history: (time since harvest, temperature, ethylene levels, mechanical damage, tray effects), measurement technique and interaction with the operator. What effect low temperature storage is having on rate of fruit softening, or how the effect of mechanical damage on the fruit is being masked by other processes associated with long term storage of fruit in trays still has to be determined. Comparing the storage behaviour of impacted and non-impacted fruit should demonstrate the effect of impacts (ie mechanical damage) on fruit firmness. This thesis deals with whether or not kiwifruit softening behaviour is affected by handling at harvest. It also develops a new, objective and non destructive method for measuring kiwifruit texture which could avoid much of the sampling problem associated with destructive testing.

Chapter Three

3.0 Influence of handling at harvest on softening

3.1 Introduction

The incidence of soft and diseased fruit in 1991 was a cause of major economic losses to the kiwifruit industry. Kiwifruit exposed to substantial impacts during postharvest handling, provide the potential for mechanical damage (Bollen and Dela Rue, 1990) which could be leading to premature softening of fruit (Finch and Hopkirk, 1987; Banks, 1992). Mechanical damage has been identified as a potential cause of premature ripening in kiwifruit in fruit kept at ambient temperatures (Finch and Hopkirk, 1987; Hopkirk and Finch, 1989). Finch and Hopkirk (1987) found that impacts to fruit resulted in fracture lines, water soaking and softening at the point of impact and these symptoms were greatest in fruit impacted straight after harvest. Impacted fruit at 20°C and 0°C began rapid ethylene production earlier than controls, providing a mechanism by which impacts could affect whole fruit softening behaviour. Although fruit at 20°C ripened more quickly than controls the fruit at 0°C did not appear to soften much more quickly. The difference in rate of softening for fruit in coolstorage was not detectable until the fruit had been store for more than 20 weeks.

Commercial handling could be resulting in kiwifruit being exposed to potentially damaging impacts. These impacts may be inducing premature production of ethylene by individual fruit and ethylene produced by one fruit may stimulate ripening of other fruit within a tray. Given the high susceptibility of kiwifruit to ethylene-induced softening (section 2.2.3), premature softening of kiwifruit may be due in part to the way fruit were handled once they have been harvested. The present study sought to determine whether premature softening for fruit kept at 0°C and 20°C might be associated with the physical damage resulting from handling at harvest. This was investigated by comparing the softening behaviour of fruit sampled straight after harvest from the vine with fruit from the same orchard block that had been handled through the normal postharvest handling chain and packed in a packhouse. The hypothesis was therefore that kiwifruit exposed to

mechanical damage due to handling at harvest would soften at a faster rate than those fruit taken straight from the vine.

3.2 Materials and Methods

3.2.1 Fruit

Fruit were sampled from eleven kiwifruit properties from the Bay of Plenty region in New Zealand between 13 and 17 May 1991 during normal commercial harvest (SS = 8.2%; average firmness = 6.08 kgf). Fruit used in the experiment were of 33 count size (106 to 116 grams fresh weight). The orchards extended from Te Puke in the eastern Bay of Plenty to Katikati in the northern Bay of Plenty. On each orchard three rows of vines were chosen from which fruit for both treatments were harvested.

3.2.2 Design

The experiment had two treatments;

(a) **VINE**: fruit sampled straight after harvest from the vine straight into trays with no physical damage.

Vine treatment fruit were harvested randomly from different vines within three rows before remaining fruit in block were commercially harvested. Vine treatment fruit were placed immediately into 33 count trays without polyliners. The vine fruit were completely randomised between trays within a grower's line of fruit. Vine treatment fruit were kept temporarily in a packhouse shed.

(b) **PACKHOUSE**: fruit taken after they had been packed into trays in the packhouse.

Bins containing fruit that had been harvested from the three rows the vine treatment fruit had come from were labelled for easy identification at the packhouse. The bins containing the packhouse treatment fruit were stored at the packhouse till they were graded using a

grading machine.

Polyliners were put in place in vine treatment trays as soon as the packhouse sample had been packed. Trays of vine and packhouse fruit of the same grower were then precooled and coolstored at 0°C with the. Fruit used for the packhouse treatment were taken once they had been packed into 33 count trays at a packhouse and they were assumed to have been completely randomised by the grading and packing process. Single layer tray packaging material differed between some growers and treatments. Growers were used as blocks in the analysis of variance.

3.2.3 Transportation

All kiwifruit were transported by non-refrigerated truck to Massey University overnight on 22 May 1991. During transportation fruit had rewarmed to a flesh temperature of 4 to 6°C upon arrival. Ethylene contents of tray atmospheres were negligible (< 5 $nl.l^{-1}$) at that time. Kiwifruit trays were then placed in a coolstore in stacks being blocked according to grower line and position within store, using alternate vine/packhouse tray stacking.

3.2.4 Sampling

Time zero was taken as the day of harvest for both vine and packhouse treatments. Fruit held at 0°C had firmness readings for all growers taken on 24 May, 31 May, 11 June, 27 June, 17 July, 8 August, 27 September, 7 and 13 November 1991, 23 January 1992 and 5 March 1992. Fruit stored at 20°C had firmness assessed on 22 May, 25 May, 30 May, 7 July, 20 July 1991. Harvests from the different orchards varied by three days. This was taken into account in the construction of individual softening curves.

3.2.5 Firmness monitoring

Fruit firmness was assessed on a single whole tray of fruit per treatment per grower at each sampling time. Fruit were removed from storage and immediately destructive

firmness readings were taken using a penetrometer (Effegi) mounted in a drill press. Two firmness readings were taken on each fruit on areas from which the skin had been removed and which were at 90° from each other when viewed down the fruit's longitudinal axis. From these readings the average firmness for a tray was calculated and plotted against time.

3.2.6 Data analysis

A number of different approaches were examined in an effort to clearly describe the changing firmness of fruit over time. Statistical Analysis System (SAS) was used to perform analyses on firmness data as outlined below.

3.2.7 Analysis of variance

Mean firmness values per tray for each grower at each sampling time were first subjected to analysis of variance using a linear models approach using the GLM (general linear models) procedure of SAS looking at differences between growers (blocks) and between treatments over time (Littell *et al.*, 1991). The factors considered in the model were growers, treatments, time and the interaction between treatments and time. The mean firmness value for each treatment over time was determined over all growers.

3.2.8 Nonlinear models

Characterisation of fruit softening patterns over time was then attempted using a number of nonlinear models based upon exponential equations to fit curves to mean firmness values using SAS:

Model 1:

$$\text{Firmness} = a\, e^{-b\, t} \quad \text{(starting values: } a = 6 \text{ and } b = 0.01\text{)}$$

a = initial firmness

b = exponent describing rate of decline in firmness

Model 2:

$$\text{Firmness} = a\, e^{-b\, t} + c \text{ (starting values: } a = 6,\ b = 0.01 \text{ and } c = 0.5)$$

a = difference between initial and final asymptotic firmness

b = exponent describing rate of decline in firmness

c = final asymptotic value for fitted firmness

Model 3:

$$\text{Firmness} = a\, e^{-b\, t} + ct + d \text{ (starting values: } a = 5,\ b = 5,\ c = 1.8 \text{ and } d = 0$$

a = difference between initial and final asymptotic firmness (for exponential component of firmness loss)

b = exponent describing rate of decline in firmness

c = linear effect of time over and above the exponential decline

d = final asymptote

In models 2 and 3, initial firmness was the sum of $(a + c)$ and $(a + ct + d)$ respectively (ie. a represented the difference between initial firmness and final asymptotic firmness when time equals infinity). An analysis of variance was then performed on the parameter values for model 2 (as it best characterised the data), to see if there were consistent treatment or grower differences. This analysis was repeated on the parameter values for a, b and c obtained from model 2 fits for a restricted data set in which data from the first 6 weeks after harvest were excluded (Andrew Hodgson, MAF. Hastings; personal communications. 1991).

3.3 Results

Fruit softening at 20°C had very variable drops in firmness and it was not possible to characterise the rate of softening statistically due to the nature of the data (see appendix

II). The different approaches and models used are outlined below and the resulting outcomes from these methods presented.

3.3.1 Analysis of variance of firmness data

On average, firmness differed between growers and declined over time ($P < 0.0001$ for both effects; Table 3.1). There was no difference in firmness between the packhouse and vine fruit (Fig. 3.1).

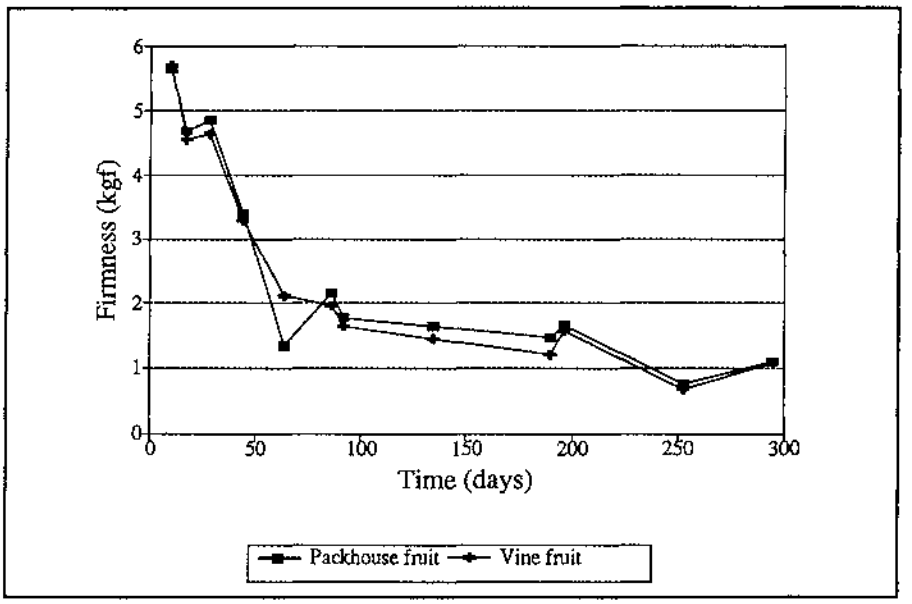


Fig. 3.1 Changes in kiwifruit firmness over time for packhouse and vine treatments averaged across growers for fruit stored at 0°C.

By far the greatest proportion of overall variation in firmness was found to be associated with changes over time. The interaction of time with treatment effects was not significant.

Table 3.1. Skeleton analysis of differences in kiwifruit firmness between growers and treatments and sampled over time for fruit held in coolstorage at 0°C.

Source	df	F value	Significance level
Growers	10	13.75	****
Treatments	1	0.83	NS
Time	11	757.91	****
Treatment and time interaction	11	0.66	NS

NS,****Nonsignificant or significant at P = 0.0001, respectively.

A further analysis was carried out to determine if different grower lines of fruit behaved differently over time (Table 3.2). The interaction of grower and time effects was not significant.

Table 3.2 Skeleton analysis of variance for differences in kiwifruit firmness between growers, treatments, and sampling times for coolstored kiwifruit.

Source	df	F value	Significance level
Grower	10	15.56	****
Treatments	1	0.94	NS
Time	11	857.43	****
Grower and time interaction	93	1.27	NS

NS,****Nonsignificant or significant at P = 0.0001, respectively.

It is not clear how much of the difference in firmness values between growers was real and how much was due to other effects associated with blocks such as position tray stacks in coolstore and difference between packaging (Fig. 3.2).

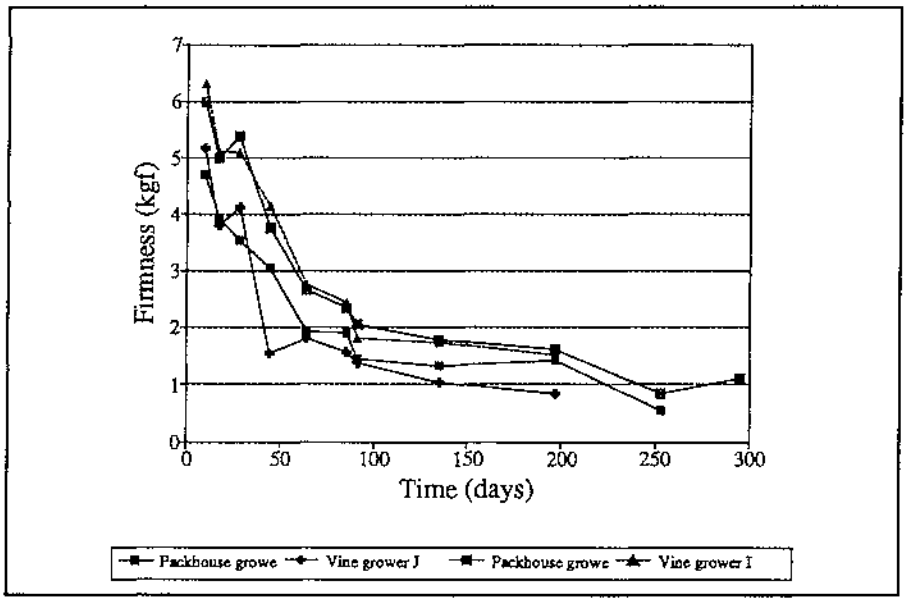


Fig. 3.2 Range in softening behaviour between growers for fruit stored at 0°C.

3.3.2 Nonlinear models

Fitting the two parameter model to the data (model 1, exponential decline) did not give a very good characterisation of the actual softening data (Fig. 3.3). The final firmness values were underestimated by model 1, with the fitted line declining too rapidly to zero. Three parameter model (2) was then fitted in an attempt to see if this problem could be overcome by adding a non-zero asymptote to the model. This gave a more accurate description of the data (Fig. 3.4).

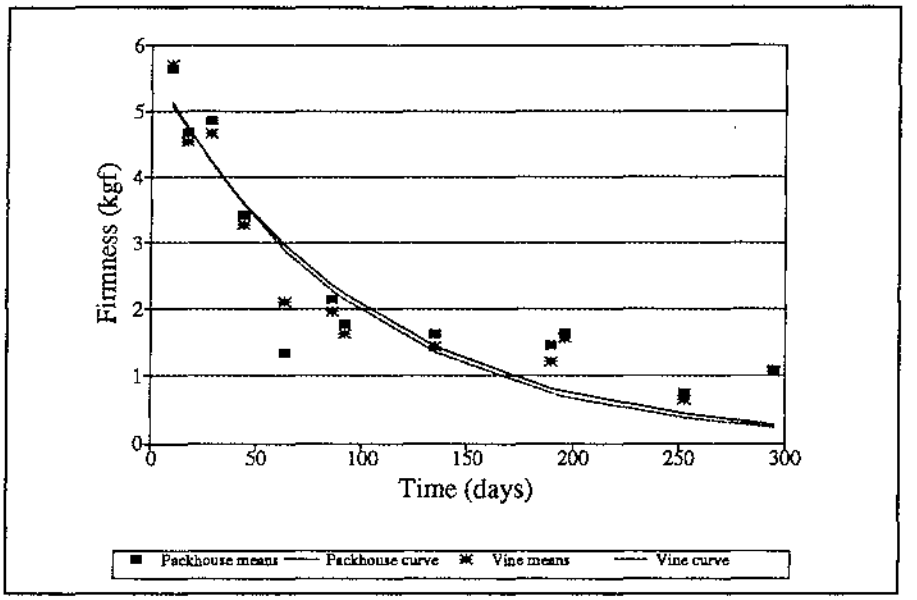


Fig. 3.3 Fitted curve obtained using model 1 (2 parameter) to mean firmness values for vine and packhouse samples at each time for fruit at 0°C.

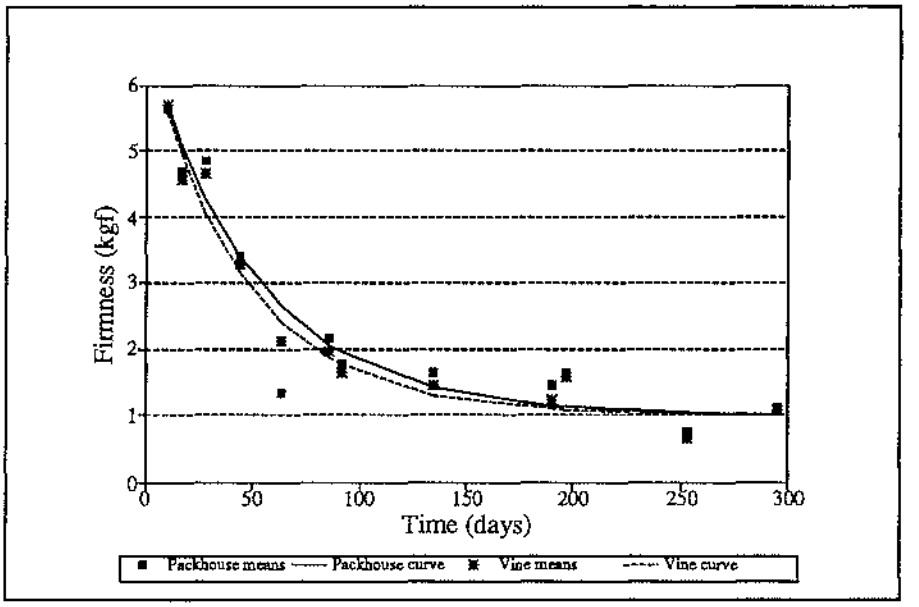


Fig. 3.4 Fitted curve obtained using model 2 (3 parameters) to mean firmness values for vine and packhouse samples at each time for fruit at 0°C.

The initial firmness value for the ***a*** estimate was 5.59 ± 0.50 kgf for the packhouse fruit and 5.79 ± 0.37 kgf for the vine fruit (Table 3.3). There was no difference between

treatments but there were differences between the initial firmness of different grower lines of fruit (Fig. 3.5).

Table 3.3 Analysis of ***a*** estimate values for model 2 for the fitted curves for firmness data of kiwifruit held in coolstorage at 0°C.

Source	df	F value	Significance level
Grower	10	5.26	*
Treatments	1	1.45	NS

NS,*Nonsignificant or significant at P = 0.05 respectively.

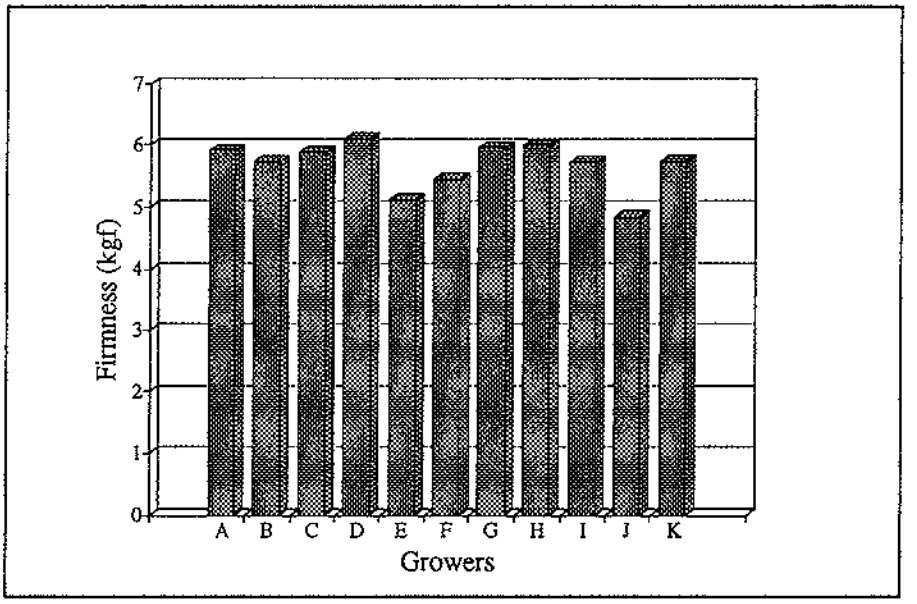


Fig. 3.5 Initial kiwifruit firmness averaged for growers from ***a*** + ***c*** estimates for fruit stored at 0°C.

There was a higher value for parameter ***b*** in model 2 ($P < 0.05$; Table 3.4; Fig. 3.6) for the vine fruit (0.022) than for the packhouse fruit (0.019). The standard error of the difference between the two paramters was 0.0012, indicating that vine fruit declined in firmness more rapidly than packhouse fruit. The average values of ***b*** across the two treatments between growers for the ***b*** estimate ranged from 0.0175 ± 0.00364 to 0.0269 ± 0.00006.

Table 3.4 Skeleton analysis of variance of *b* estimate values for model 2 for the fitted curves for firmness data of kiwifruit held in coolstorage at 0°C.

Source	df	F value	Significance level
Grower	10	3.87	*
Treatments	1	6.18	*

*Significant at P = 0.05.

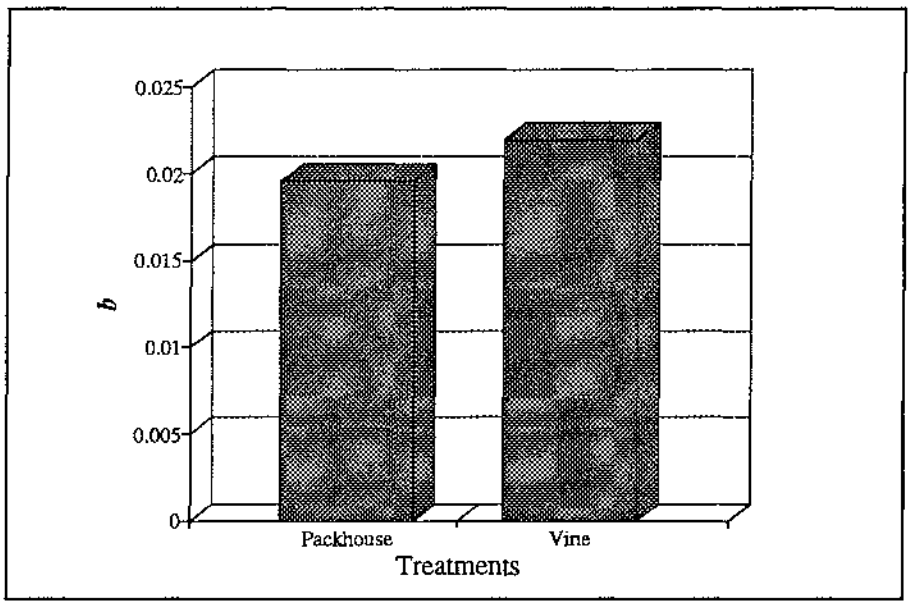


Fig 3.6 Average *b* estimate for vine and packhouse samples fruit stored at 0°C.

The asymptotic value for final firmness (*c*) did not differ significantly between growers or treatments (Table 3.5; average value = 1.01 ± 0.17 kgf).

Table 3.5 Analysis of ***c*** estimate values for model 2 for the fitted curves for firmness data of kiwifruit held in coolstorage at 0°C.

Source	df	F value	Significance level
Grower	10	1.56	NS
Treatments	1	0.77	NS

[NS]Nonsignificant.

Plots of fitted curves and table of ***a***, ***b*** and ***c*** values for all eleven growers and vine and packhouse treatments are presented appendix I.

Fitting the three parameter model (model 2) to the data for time greater than 42 days did not increase the precision with which the curve was fitting (Fig 3.7).

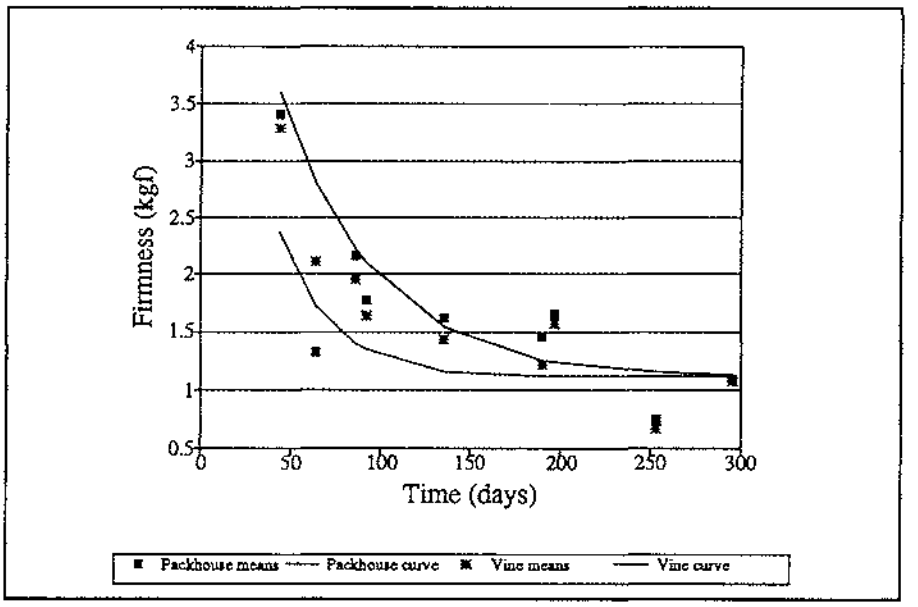


Fig. 3.7 Fitted curve using model 2 to firmness data greater than 42 days.

Estimates of ***a***, ***b*** and ***c*** were similar for all growers and treatments for the changing firmness values taken after 42 days from harvest (Table 3.6).

Table 3.6 Analysis of parameter estimates for model 2 for the fitted curves for firmness data of kiwifruit held in coolstorage at 0°C for greater than 42 days.

Source		df	F Value	Significance Level
a estimate				
	Grower	10	0.95	NS
	Treatments	1	0.00	NS
b estimate				
	Grower	10	1.22	NS
	Treatments	1	0.10	NS
c estimate				
	Grower	10	0.94	NS
	Treatments	1	0.57	NS

[NS]Nonsignificant.

The fitting of four parameters (model 3) was not possible because most of the nonlinear regressions failed to converge on reasonable parameter estimates. Where convergence occurred three of the four parameter estimates were not significantly different from zero.

There was no relationship between patterns of softening of the fruit at 20°C and at 0°C (Figs. 3.8 and 3.9)

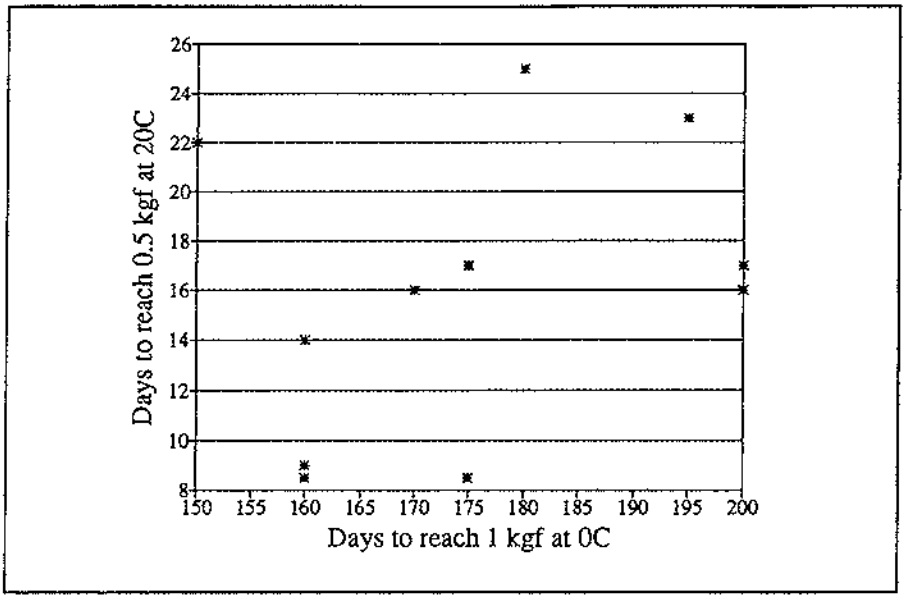


Fig. 3.8 Comparison of number of days for fruit at 20°C to reach 0.5 kgf and at 0°C to reach 1 kgf.

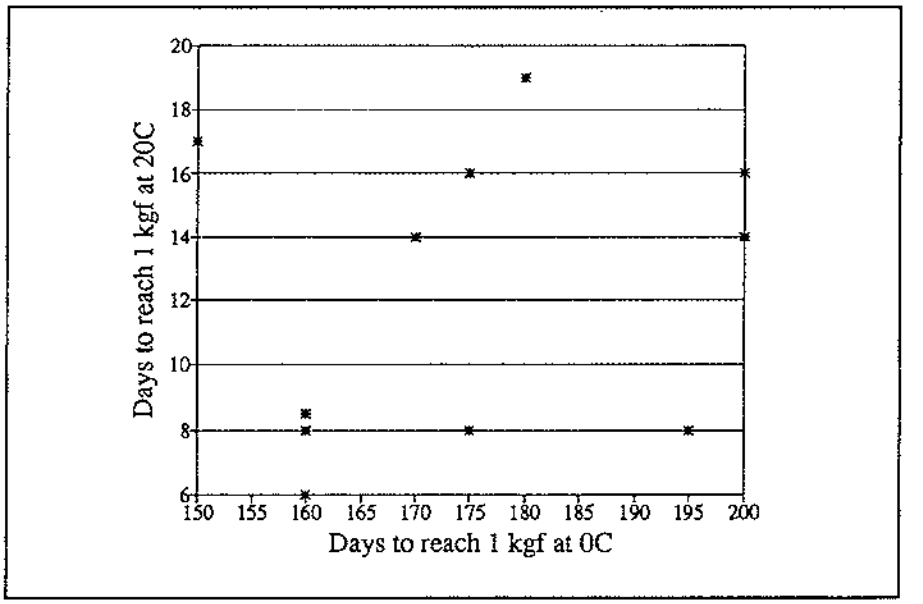


Fig. 3.9 Comparison of number of days for fruit at 20°C and 0°C to reach 1 kgf.

3.4 Discussion

Premature softening of kiwifruit induced as a result of possible handling damage at harvest is examined below together with the effect of temperature on rate of fruit softening in trays.

3.4.1 Handling treatments and softening behaviour of kiwifruit

The initial hypothesis proposed that fruit exposed to mechanical damage due to handling at harvest (packhouse fruit) should have softened quicker than fruit harvested straight from the vine. Packhouse fruit, on average, had the same firmness as vine fruit which should have received no damage (Table 3.1) which implies that impacts to fruit occurring during postharvest handling were not predisposing packhouse fruit to premature softening. This result was similar to that found by Finch and Hopkirk (1987) in that impacted fruit stored at 0°C softened at the same rate as non-impacted fruit. This trial examined whether or not the packhouse fruit (exposed to varying degrees of potentially damaging impacts during postharvest handling; Bollen and Dela Rue, 1990) may result in mechanical damage to the fruit. This mechanical damage could lead to premature ethylene production (Finch and Hopkirk, 1987) by damaged fruit that would cause the packhouse treatment fruit on average to soften more quickly than the vine fruit. The absence of any such stimulation suggests that there may be no effect of mechanical damage such as impacts on the firmness of fruit subsequently stored at 0°C. Alternatively, the potential reduction in packhouse fruit firmness due to impacts compared to vine fruit may have been masked by other influences that occurred to the vine and not the packhouse fruit (see section 3.4.5).

3.4.2 Analysis of variance and nonlinear models approach

Analysis of variance indicated that packhouse fruit kept at 0°C had the same average firmness as vine fruit throughout the experiment. This analysis made it possible to quantify average differences in firmness between growers and treatments but did not characterise the relationship between firmness and time. With a nonlinear approach, the individual

parameter values from the models were tested by analysis of variance. Initially the two parameter model (model 1) was tried, but the exponential nature of the fit coupled with zero intercept caused the estimated curve to fall below the mean firmness values at the later storage times. It appeared that three parameter values (model 2) were needed to accurately characterise the data. Overall this model was a better fit to the data, particularly between 100 and 300 days. However this model still failed to characterise kiwifruit softening adequately because it predicted that no further softening would occur once the fruit reached approximately 1.0 kgf. In fact, kiwifruit would still have some further decline in firmness before eventually reaching a very low firmness value. The ***a*** and ***c*** variables characterised initial firmness values which differed between growers ($P < 0.05$; Table 3.3) for model 2 (Fig 3.5). The absence of a treatment effect confirmed the expectation that both treatments began with similar firmness values. In contrast analysis of the ***b*** estimate from model 2 using the nonlinear approach showed that the vine fruit softened at a faster rate compared to the packhouse fruit. Nonlinear regression enabled the characterisation of three different parts to the softening curve: the treatments differed only in rate at which the difference between initial and final firmness declined. This subtle effect was not detected by the analysis of variance.

Removal of data from the first few sampling times was expected to allow the model to get a better estimate of the final slope by not having to accommodate the variations in the initial rate of decline. However, removing the data for the first 42 days did not help the model to more accurately fit curves to the mean firmness values. Use of a four parameter model was not viable as there was a lack of convergence of the parameter values.

3.4.3 Application of softening curves

The problem of trying to plot curves to mean firmness data was the tray effect, which is shown by how much the mean firmness values per tray for a grower vary from a smooth curve (Fig. 3.10). The variation between mean tray firmness values was much more pronounced at 20°C, probably due to the higher rate of ethylene production by individual fruit at that temperature (Lallu *et al.*, 1989; Pyke, 1991) leading to a higher ethylene concentration build up in a tray. This would cause a wide amount of variation

between means for individual trays of fruit, making the fitting of curves to the mean firmness values very difficult (eg. see data for fruit at 20°C; Appendix II).

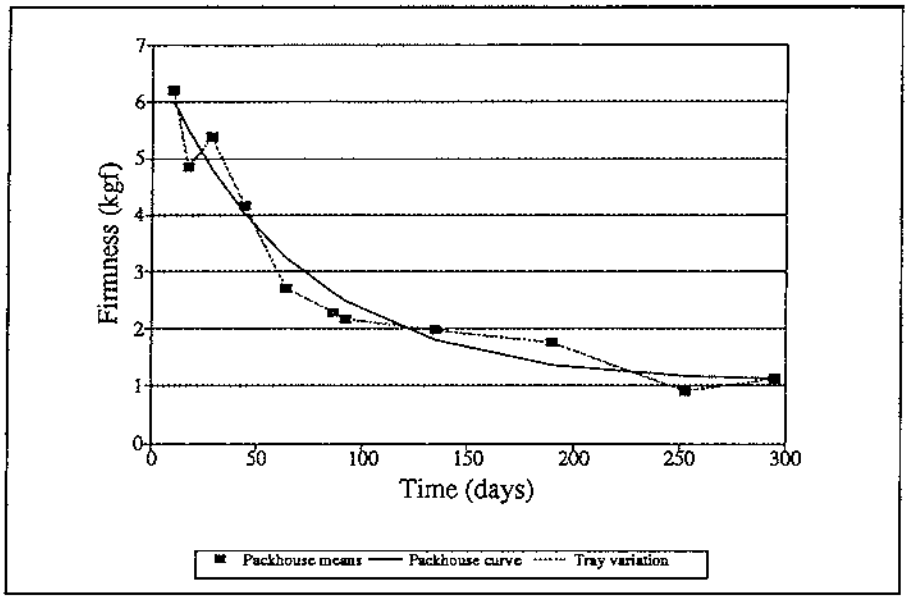


Fig. 3.10 Variation in packhouse fruit firmness means limited ability to characterise fruit softening behaviour at 0°C.

Growers are most concerned with firmness at the later stages of softening rather than the overall average rate. The NZKMB (1992) export quality criterion is that any individual fruit below 1.0 kgf is rejected for export. Average firmness values for the whole curves do not clearly indicate which individual fruit are at or below 1.0 kgf. Even though fruit firmness values were normally distributed in a tray (data not shown) of greater concern to a grower might be how many fruit in a tray were below the 1.0 kgf reject firmness. Growers should be concerned about the mean firmness for a tray of fruit, but as the average fruit firmness nears 1.0 kgf how quickly an individual fruits' firmness decreases and how many individual fruit in the tray have dropped below 1.0 kgf are of even greater concern. Therefore other models which look at the frequency distribution of fruit firmness in a tray may be of greater use than simply fitting a curve to the mean firmness data. This may enable a grower to be able to predict the time it will take for average firmness for a line of fruit to reach 1.2 kgf. A model based on this approach would require more trays per sample than was available in this trial.

3.4.4 Temperature effects on softening

Kiwifruit firmness changes were greatly influenced by temperature in this experiment. Fruit at 20°C had softened to 1.0 kgf in a few days whereas fruit at 0°C took on average over 5 months to reach 1.0 kgf. The dramatic reduction in firmness of fruit in trays at 20°C made it very difficult to accurately characterise their softening behaviour. This was presumably due to ethylene given off by individual fruit at 20°C being able to build up inside trays and so greatly influence the individual rate of softening of all other fruit in a tray (Pratt and Reid, 1974; Lallu *et al.*, 1989), ie. rate of softening of the whole tray was probably influenced by the most advanced fruit within the tray. At 0°C the rate of fruit softening was more uniform and ethylene build up in trays may have occurred to a lesser extent than it did at 20°C (Finch and Hopkirk, 1987), so the tray to tray variation effect on fruit firmness would have been less pronounced. Even so, very small concentrations of ethylene in trays may be enough to significantly affect overall tray fruit firmness (McDonald and Harman, 1982).

3.4.5 Grower differences

All growers had the same variety of kiwifruit, yet variation occurred, presumably due to differences between properties and management of the crop. Some growers had better storing fruit than others (Fig. 3.2) and yet the same fruit can vary in rate of decline in firmness between years, even thought they were stored in similar conditions (Lallu *et al.*, 1989). Research needs to be under taken to establish factors influencing the difference in fruit softening behaviour between different grower lines. At present there has not been sufficient work in trying the quantify the factors responsible for different storage potentials between growers.

3.4.6 Random (unidentified) effects

It could be that something occurred to the vine fruit at the beginning of the experiment predisposing them to soften at a faster rate than the packhouse fruit. This potentially could have been due to vine fruit being smaller size than packhouse fruit as a

result of size grading by hand. Vine fruit appeared to be smaller on average than the packhouse fruit (although no weight data were collected to confirm this) which could have resulted in a faster rate of softening by the vine fruit (Hopkirk *et al.*, 1990; see section 2.3.4). Before all fruit were precooled, vine fruit were stored inside the packhouse while the packhouse fruit were stored in bins against the outside of the packhouse shed under cover. This may have allowed the packhouse fruit to become slightly cooler at night compared to the vine fruit.

There were confounding effects of pack type and tray location in the cool store which could not be distinguished in the analysis to test if they were contributing to the differing firmness of fruit. In the coolstore there may have been temperature differentials between trays due to their position in the coolstore (McDonald *et al.*, 1992). Temperature differentials could have been caused by ventilation and uneven air movement due to fans in the coolstore which would have resulted in some trays of fruit softening at differing rates. Physiological factors may be causing fruit to reduce firmness prematurely such as differing fruit mineral nutrient contents (Mowatt *et al.*,1991) and fruit ability to with withstand prolonged storage at 0°C (Lallu *et al.*, 1992). Some packaging may not have maintained its structure consistently over time to prevent compression of fruit.

It may be that advanced ethylene production by individual fruit contributed most to the variation in mean firmness values for fruit held at 20°C and to a lesser extent at 0°C. This would have added to the variation between mean fruit firmness values, making it harder to the differentiate between real variation in firmness due to treatments and that due to experimental error.

3.5 Conclusion

Vine fruit had the same average firmness and a slightly higher rate of softening compared to packhouse fruit. This must lead to the rejection of the initial hypothesis that fruit exposed to mechanical damage at harvest due to handling would soften at a faster rate than those taken straight from the vine. Handling of fruit at harvest did not appear to affect the firmness of kiwifruit in this experiment for a number of potential reasons. Kiwifruit are

exposed to damaging forces (Bollen and Dela Rue, 1990) during postharvest handling, which could presumably result in the mechanical damage of fruit causing premature ethylene production, and cause a promotion of softening rate in affected fruit. How individual fruit vary in their response to different handling forces at harvest and why a reduction in firmness has been found with fruit stored at 20°C and not 0°C by some research workers (Finch and Hopkirk, 1987) still requires investigation.

Low temperature storage reduced the variation in mean tray firmness values over time, resulting in a more even decline in rate of overall softening. Rapid softening of fruit in trays at 20°C had so much variation between mean firmness values that it bore no clear relationship to fruit softening at 0°C. The rate of fruit softening at 20°C could therefore not be used to accurately predict the rate of softening of similar fruit at 0°C.

More information was yielded using a nonlinear, curve fitting approach than with analysis of variance. The three parameter model was most useful in answering questions about the data. Use of models to fit curves to data may give a good characterisation of the data but does not necessarily mean an accurate description of the final phase in fruit softening which is of so much importance to a grower. It may be of more relevance to growers to have a model based on the proportion per tray of fruit above the export cut-off than the mean firmness value per tray. Future investigation into the causes of premature softening requires improved control of potential variation in firmness values due to tray position in coolstore, ethylene build up in trays, tray to tray variation, fruit size difference, pack-type difference and grower differences.

Chapter Four

4.0 Non-destructive measure of fruit firmness

4.1 Introduction

Fruit to fruit firmness variability is one of the main problems in researching kiwifruit softening behaviour because it decreases the precision with which treatment effects can be identified. The penetrometer is the standard instrument used by the kiwifruit industry to assess firmness but, unfortunately, its use is destructive; once measured, fruit must be discarded. An accurate non-destructive means of assessing fruit texture would largely overcome these problems by enabling repeated measurements to be made on the same fruit over time. A non-destructive technique for measuring kiwifruit firmness could therefore be very useful in postharvest research.

Bourne (1973) described a method using a distance-measuring penetrometer to measure the total deformation of a fruit surface exposed to a constant load exerted through a 5 cm diameter disk for a period of 5 s. In my preliminary trials, a similar approach was used in which the flat disk was replaced by small, spherical metal probe through which a constant load was applied to a kiwifruit surface for a set time period. However, the total deformation recorded on adjacent spots on an individual fruit was highly variable. This problem was overcome by a novel approach to describing the measurement of deformation as a function of time from application of the probe to the fruit surface. This chapter describes the development and testing of this "softness meter", with a comparison of softness meter and penetrometer data obtained on the same fruit. The softness meter has for the first time permitted a preliminary characterisation of the softening behaviour of individual kiwifruit over time.

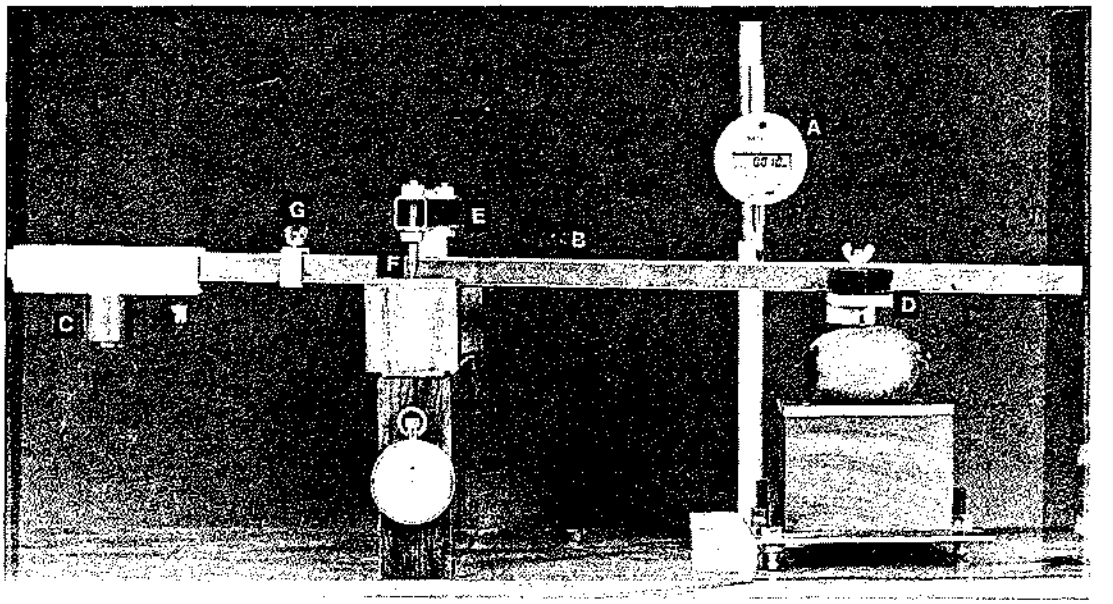
4.2 Materials and methods

4.2.1 Softness meter design

4.2.1.1 Construction of the softness meter

The first prototype of the softness meter (Fig. 4.1) comprised a dial gauge micrometer (Mitutoyo Instruments Ltd) (**A**) which measured the displacement of a lever (**B**). The lever

Fig. 4.1 First prototype of the softness meter (based on a design by Dr N. H. Banks[1], Dr C.J. Studman[2] and C. Mowatt[1]).



[1]Plant Science Department. Massey University. [2]Agricultural Engineering Department. Massey University.

had an adjustable large weight at one end (**C**) and a 5 mm spherical probe mounted near the other end of the lever below a metal platform (**D**). This allowed weights to be placed directly above the metal probe. The lever was supported on a small, perpendicular cross bar (**E**) which was itself pivoted on two metal pins (**F**), one attached to each end of the cross bar.

The softness-meter was balanced by raising or lowering the metal pivots (**F**) on the

cross bar, adjusting the distance of the large weight (C; 550 grams) from the pivots or by moving the small weight (G; 31 grams) located between the cross bar and the weight. This enabled the whole system to be balanced so the lever was almost in a state of neutral equilibrium, but with a slight downward force on the spherical probe tip. This allowed the spherical probe to rest on the surface of the fruit with negligible deformation occurring to the fruit.

4.2.1.2 Measurement of deformation

Measurements were taken by pressing a button which transferred the current dial gauge reading to a computer data acquisition system. Initially the micrometer was 60 mm from the pivot. With a range of weights applied to the metal platform, the movement of the micrometer probe over a 30 s period never exceeded 0.01 mm even on soft fruit. Given that the gauge had a maximum resolution of 0.001 mm, this provided an insensitive measure of the deformation occurring at the fruit surface. The micrometer was therefore relocated to a position 217 mm from the central pivot of the cross bar and 63 mm from the probe. This resulted in much greater measured micrometer probe movements for a given degree of deformation at the fruit surface.

It was important to avoid severe irreversible damage to the fruit tissue. Weights of different masses (5, 10, 20, 50, 100, 150, and 200 g) were therefore applied to several kiwifruit with a range of firmness values to determine the deformation after a 30 second time interval. A 100 gram weight gave a deformation after 30 second of less than 0.5 mm for a very soft fruit. These readings were acceptable as they appeared not to cause large deformations that could result in permanent damage to tissue. It was decided that a time interval longer than 30 seconds would make repeated measurements impractical.

Several different approaches were used in recording changes in deformation over time. All were aimed at obtaining repeatable measurements of fruit softness. Initially deformation readings were determined by zeroing the micrometer when the probe was sitting on the fruit surface, then applying a 100 gram weight for 30 seconds and calculating the change in deformation. With soft fruit there were fluctuations in 0.01 mm resolution

due to the slight downward displacement of the probe on the fruit surface. These fluctuations in values of the micrometer occurred before and after the micrometer was being zeroed and the period of time before the weight was applied while the probe was resting on the fruit surface. There was also variability between readings due the manual application of the weight at 0 seconds and accurately recording the final deformation after 30 seconds. These all contributed to causing considerable variation in readings for the same fruit.

Next the rate of change in deformation over time was examined. The micrometer was zeroed and the weight was applied at time 0. The change in deformation was recorded at 1, 2, 3, 4, 5, 10, 15, 20, 25 and 30 second time intervals and these data were plotted against time (e.g. Fig. 4.2).

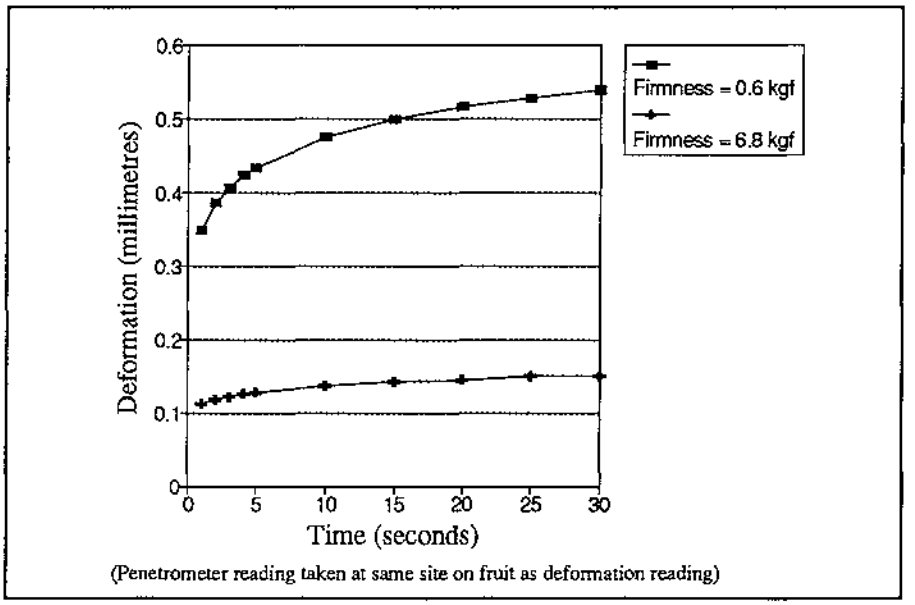


Fig. 4.2 Change in deformation over time for a fruit using softness meter.

This avoided the errors incurred when determining firmness by calculating the change in deformation after 30 seconds due to application of a weight. A straight line was obtained by plotting deformation against log of time (Fig 4.3). The data were then regressed and the R - squared and gradient of the line were calculated. The gradient of the line (X-coefficient) was used as a measure of fruit softness (the "softness coefficient"). The

recorded values for deformation were corrected to take into account the distance between the metal probe and the micrometer as the probe was further from the pivot than the micrometer (Fig. 4.1), using the formula:

True deformation = (1.29) x Measured deformation

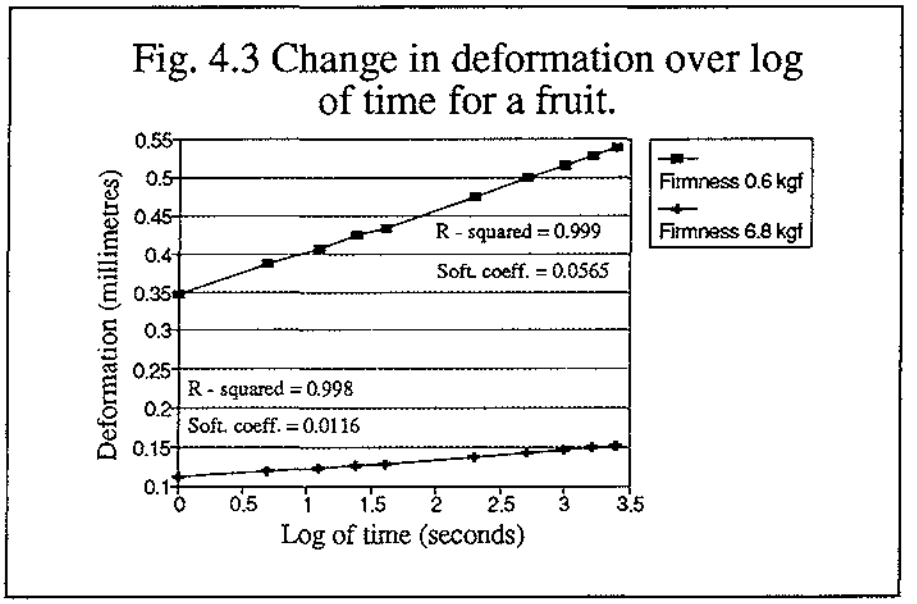


Fig. 4.3 Change in deformation over natural log of time for a fruit.

It was unnecessary to remove fruit hairs since the initial zero load overcame hair resistance, and the sphere sat in contact with the fruit skin. This is thought to be due to the downward displacement of the probe being enough to overcome any resistant forces of the hairs, and a sphere incurring less resistance compared to a flat plate of 50 mm diameter.

4.2.2 Evaluation of softness meter

4.2.2.1 Comparison of softness meter and penetrometer

Twenty two fruit covering a range of firmness from 7.3 kgf to 0.0 kgf (no reading on penetrometer) had their softness measured using the softness meter at four sites on each fruit. These sites were at 90° from each other when viewed along the longitudinal axis of the fruit. A 100 gram weight was applied and the deformations were recorded at the same

time intervals over 30 seconds. The deformations were regressed against natural log of time and the X-coefficient (softness coefficients) for the slope of the regressions were obtained. The skin was then removed from the site of the softness meter reading, and Effegi penetrometer reading was taken and tagged with the softness coefficient reading at the same site of each fruit. Analysis of variance was performed on the data using SAS.

4.2.2.2 Measuring fruit softening over time using softness meter

On 14 May 1991 two trays containing twelve fruit from the same grower had their softness measured using the softness meter. For each fruit four readings were taken which were at 90° from each other when viewed along the longitudinal axis of the fruit. Each reading was taken and then the site was marked on the fruit skin with a pen so that each additional reading would be taken from a new position in the same adjacent local area. Further readings were taken on 10 June, 21 June, 24 July, 4 August, 20 August, 10 September, 15 October, 7 November, 13 November 1991 and 22 January 1992. Softness-coefficients for straight line regressions were calculated and then SAS was used to perform analysis of variance of readings for fruit and positions around fruit over time using the general linear models procedure.

4.2.2.3 Fruit firmness optimised sampling plan

The variance of firmness values due to number of fruit and number of readings per fruit were used to calculate an optimum sampling plan. The variance due to different levels of factors in the experiment were calculated by using the formula:

$$\text{Estimate of experiment variance} = (c \div a + e \div (a \times b))$$

where:

a = number of fruit

b = number readings per fruit

c = variance due to number fruit

e = variance due to number readings per fruit

From the formula it could be estimated if it was the number of fruit or the number of readings per fruit that was causing the most variation in firmness values and therefore what the optimum sampling plan would be.

4.3 Results

4.3.1 Measure of deformation using softness meter

Softness for each fruit was characterised by a softness coefficient which quantified the ease with which each fruit surface became deformed following application of a small load to a spherical probe (Fig. 4.3). Softness coefficients bore a consistent inverse relationship to penetrometer data obtained on the same fruit (Fig. 4.4).

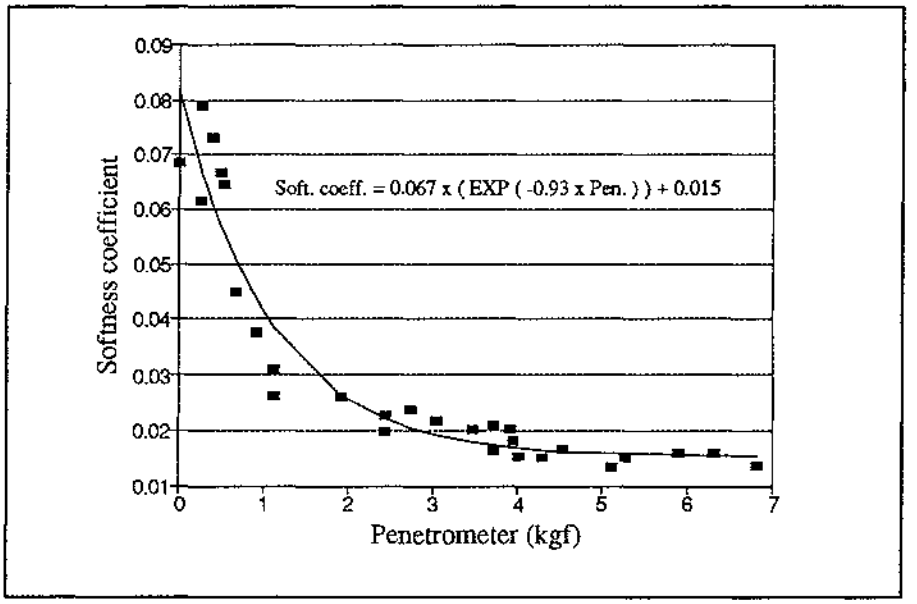


Fig. 4.4 Relationship between softness meter coefficients and penetrometer data.

Within-fruit variation for both softness coefficients and penetrometer data was strongly related to fruit firmness, with coefficients of variation remaining approximately constant at about 10% for each variable (Figs. 4.5 and 4.6).

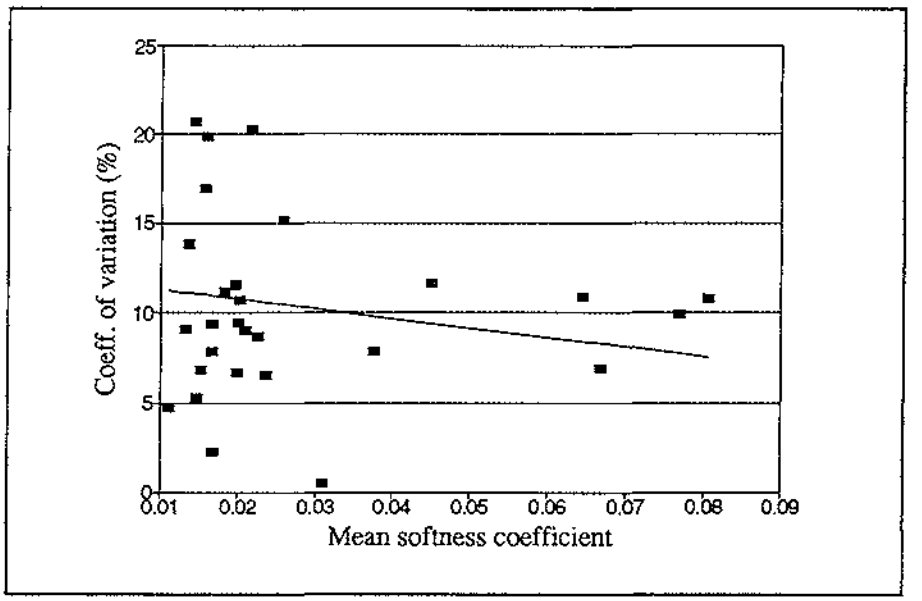


Fig. 4.5 Within-fruit variability of softness coefficients versus firmness.

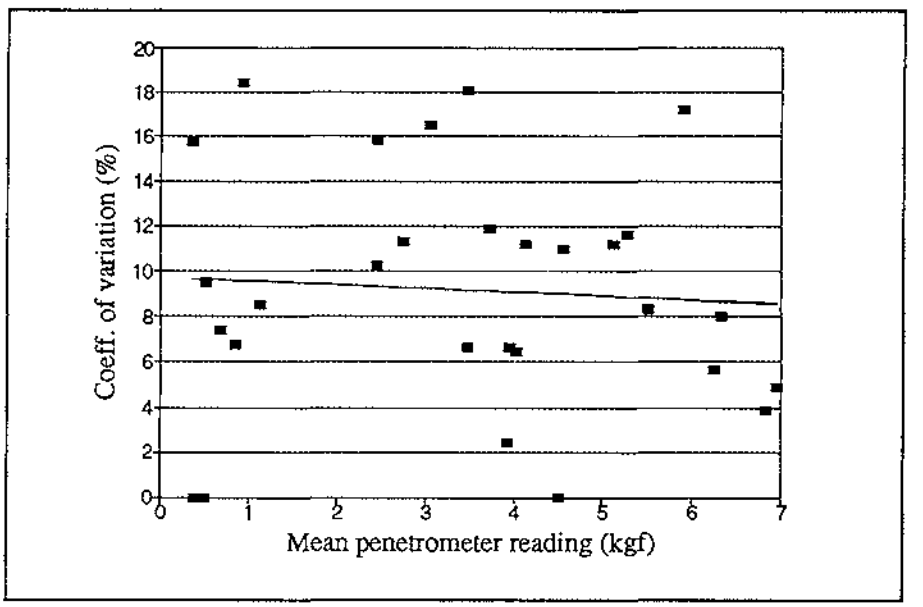


Fig. 4.6 Within-fruit variability of penetrometer readings versus firmness.

The inverse of softness coefficients plotted against penetrometer values was approximately a straight line (Fig. 4.7). This approach meant that the values obtained with the softness

meter decreased as the fruit softened these inverse data provided a true measure of firmness (ie, the values become larger as the fruit softened).

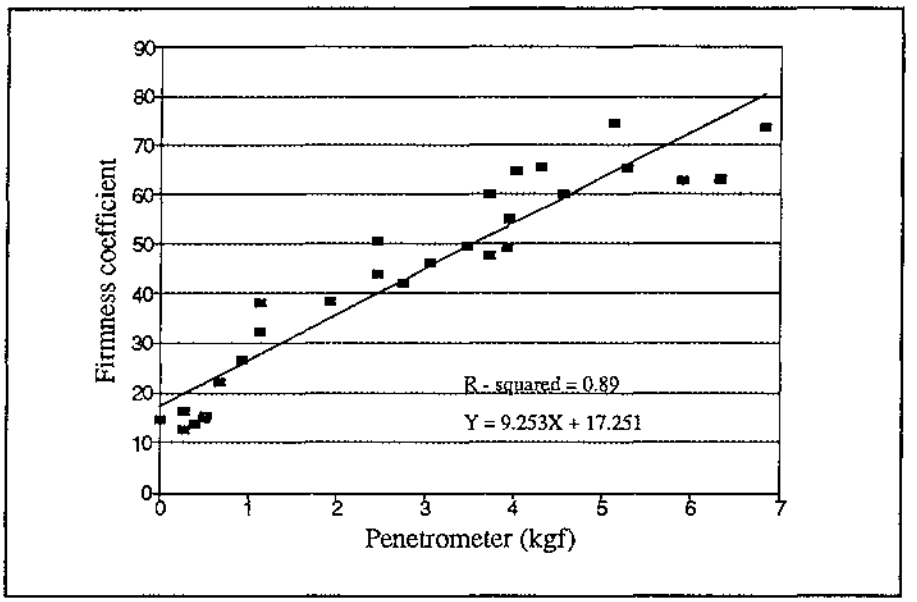


Fig. 4.7 Correlation of firmness coefficients with penetrometer.

4.3.2 Measurement of fruit softening

Variation in repeated softness meter readings over time was mostly found to be due to fruit and time (Table 4.1; $P < 0.0001$); different position readings around a fruit gave no consistent difference between side and flat of a fruit.

Table 4.1 Repeated measures of softness coefficients within and between fruit using the softness meter over time.

Source	df	F value	Significance level
Fruit	23	8.33	****
Position	73	0.72	N.S.
Time	10	188.14	****

NS, ****Non significant, significant to P = 0.0001, respectively.

Two sample softening curves constructed with the softness coefficients obtained from using the softness-meter on individual fruit over time are shown in Fig. 4.8. As the fruit softened over time the softness coefficient became larger.

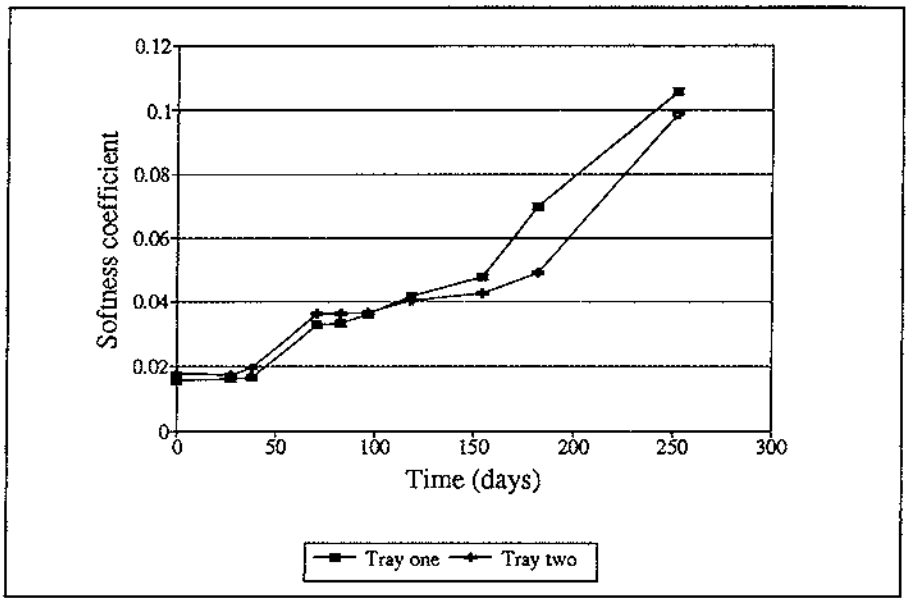


Fig. 4.8 Softening curve for kiwifruit measured with softness meter.

4.3.3 Optimised sampling plan for fruit firmness

A sampling plan allows the optimising of future experimental designs, so that resources such as fruit and time are best used. This occurs by quantifying the magnitude of variation attributable to the different sources to identify where the most variation in firmness values occurs. The variation in estimating firmness is reduced more by the increasing number of fruit than increasing the number of readings per fruit (Table. 4.2). The number of readings per fruit had little influence on the overall variation of mean fruit firmness values.

Table 4.2 Calculated variance for different numbers of fruit and different number of readings per fruit.

Variance of fruit firmness values for experiment:		
Source		Variance
Number of fruit		2.50
Number of readings per fruit		0.0000211
Variance of mean due to number of fruit and readings per fruit:		
Number of fruit per sample	Number of readings per fruit	Variance of mean
840	1	0.0029762
420	2	0.0059524
280	3	0.0089286
210	4	0.0119048
168	5	0.0148809
140	6	0.0178571
120	7	0.0208333
105	8	0.0238095

4.4 Discussion.

4.4.1 Correlation of softness meter with penetrometer

In this study the softness meter gave a similar precision of measurement to the penetrometer (Figs. 4.5 and 4.6). Both instruments had about the same amount of variation of around 10%. The softness meter enables the calculation of the coefficient based on a very small amount of fruit tissue compared to the penetrometer. The softness meter could be used to characterise soft patch development on a whole fruit, as it would be able to determine changes in flesh firmness over a small localised area of the fruit. The penetrometer gives a representative estimate of fruit firmness as it uses a bigger area of

tissue to estimate firmness from and be less influenced by variability in firmness of flesh tissue near the fruit surface. The relative change in the softness coefficient became quite large as fruit firmness approached the minimum cut-off export firmness of 1.0 kgf for an individual fruit (Fig. 4.4). This could allow the difference in firmness between fruit around this firmness to be clearly determined. The penetrometer does not give as meaningful a reading around this firmness as it is only detecting slight variation in force on the probe and is near the limit of its accuracy, therefore open to slight errors induced by a person taking a reading (Bourne, 1982a). The Effegi penetrometer widely used in the industry requires a needle to be read to obtain the reading whereas the softness meter has values being automatically down loaded to a computer.

4.4.2 Measure of deformation

There do not appear to be many instruments that characterise texture by calculating the rate of change of deformation over time of an applied force. Probes which cause induce the deformation in the fruit surface may be like a flat plate or similar to a small pin, with all resulting in an accurate repeatable measure of deformation (Bourne, 1973; Mizrach *et al.*, 1985). Characteristic of deformation instruments is that the amount of deformation increases as the fruit becomes softer. The advantage of the softness meter is that by using a small metal sphere it becomes possible to more accurately control the area of fruit that is measured compared to a metal plate.

Much of the potential error in obtaining the reading are overcome by using the rate of deformation change. Any potential errors induced by the co-ordination of recording values at time zero and the initial application of the weight to the plate above the probe are overcome by taking the rate of change over time. The softness meter's use of a metal probe to take a reading did not appear to be affected by fruit hairs, and the most the probe deformed the fruit surface was less than 1 mm for fruit near 0.0 kgf. The softness meter is considered non-destructive, as the probe never deformed the fruit surface to such an extent as to cause readily visible deformation of the fruit tissue. The rate of deformation change over time was such that plotting deformation against the natural log of time resulted in a straight line, which when regressed always resulted in an R-squared of greater than

0.9.

4.4.3 Fruit to fruit variation

The penetrometer has an amount of variation occurring between repeated readings taken on individual fruit and it is not easily determined if they are real or due to the way the device interacts with operator technique (Pyke, 1991). The softness meter may be used to test if localised treatments applied to the fruit are able to affect fruit firmness over time. The softness meter provides a very suitable tool to monitor individual fruit changes in flesh firmness over time (Fig. 4.7). Firmness of fruit involved in this study, did not appear to differ greatly around a fruit compared to firmness variations between fruit. Changes in individual fruit firmness over time cannot be measured with a destructive penetrometer. Softness-meter assessment of fruit to fruit variation might be used to detect early in storage prematurely softening fruit that may also be more likely to have a greater incidence of soft patches. The fruit in this trial were all from the same grower, harvested at same time, from the same orchard block. Yet when stored in separate trays in the same position in a cool store there were some differences in the average softening curves for fruit in each tray (Fig 4.8). This demonstrates the problem of trying to monitor fruit softening and the high degree of variation in fruit softening due to influences beyond that of the individual fruit themselves. Therefore when designing an experiment it is better to have a large number of fruit as more variation will be accounted for than having a large number of readings per fruit (Table 4.2).

4.4.4 Application of softness meter

The understanding of the current problems of premature softening facing the kiwifruit industry would be greatly assisted with a non-destructive measure of firmness (Hopkirk *et al.*, 1992). Causes of soft patches and bruising involve solutions to problems on an individual fruit basis. Being able to take repeated measurements over time will greatly assist the investigation of localised changes in fruit firmness associated with these handling and storage disorders. Purely taking the firmness of fruit at one point in time as with a penetrometer hides the variation occurring to firmness within the fruit over time.

Condition checking at present involves the breaking of pallets and removal of trays of fruit, which once tested by penetrometer have to be replaced. Use of the softness meter could remove this wastage of fruit and, unlike the penetrometer, procurement of a reading does not involve removal of the fruit's skin, a procedure which can occasionally result in injury to the operator. The softness meter would also allow for all fruit to have their firmness objectively tested, instead of people determining fruit firmness by squeezing the fruit (NZKMB, 1992).

4.4.5 Design of the softness meter

The working concept of the softness meter could be re-designed to produce a smaller device that could offer commercial possibilities to the kiwifruit industry such as firmness monitoring at condition checking. The softness meter could provide a rapid and effective measure of fruit firmness as sufficient deformation occurs in the first few seconds to determine the softness coefficient. With more technical development, as little as one second may be adequate to give a sufficiently accurate measure of fruit firmness, allowing it to be estimated as quickly as by using a penetrometer. The softness meter is simple to operate and variations that may occur due to application of the weight or subjective error due to the operator are overcome by taking rate of deformation over time. Whether or not 100 grams is the ideal weight could be further investigated, but it depends on the design of the softness meter. An ideal weight would result in a consistent change in deformation without causing any damage to fruit tissue.

4.5 Conclusions

The precision of the softness meter and penetrometer were similar, despite softness coefficients being based on a much smaller proportion of the total fruit tissue. This should make this method an ideal tool for investigating localised changes in fruit firmness associated with bruising and the storage disorder known as soft patches (localised water soaking of tissue). Testing fruit in this way resulted in negligible visible damage to the fruit. The softness meter was able to accurately describe fruit softening over time (Fig 4.8) and demonstrate that it is the individual fruit firmness that causes most variation to

firmness values rather than variation in firmness around a fruit surface (Table 4.2).

The softness meter appears to have great potential as a research tool for investigating the softening responses of kiwifruit to a number of environmental and internal factors owing to its simplicity, lack of damage to the fruit and low coefficient of variation. If the same concept could be extended into a rapid and compact instrument suitable for routine industry fruit testing then this approach could have exciting commercial possibilities.

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Appendix I

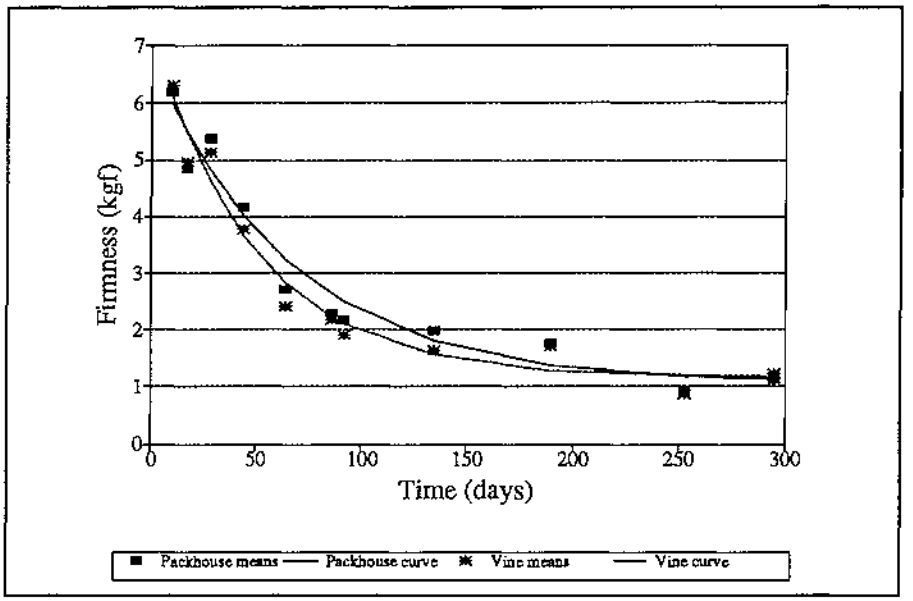

Fig. I.1 Changes in kiwifruit firmness over time for packhouse and vine treatments stored at 0°C for grower **A**.

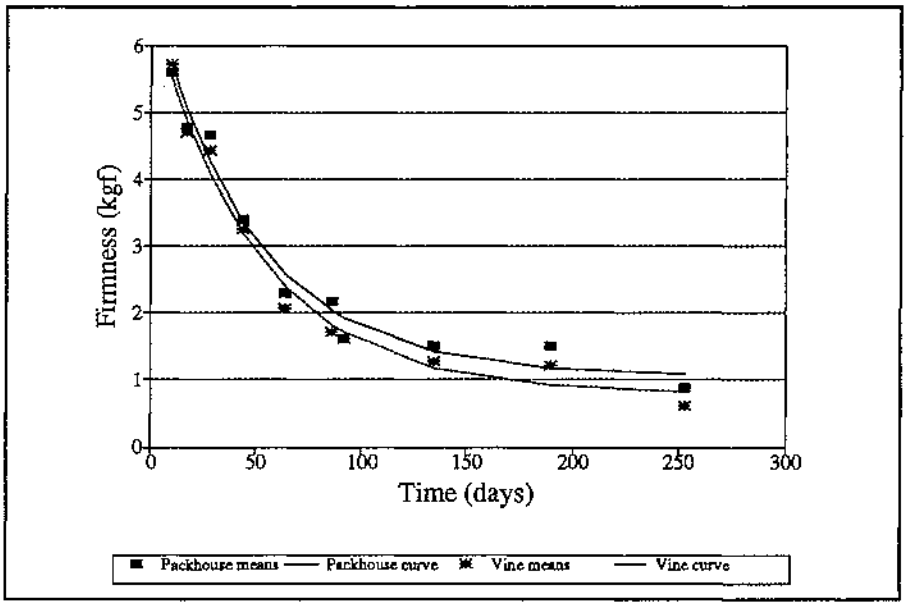

Fig. I.2 Changes in kiwifruit firmness over time for packhouse and vine treatments stored at 0°C for grower **B**.

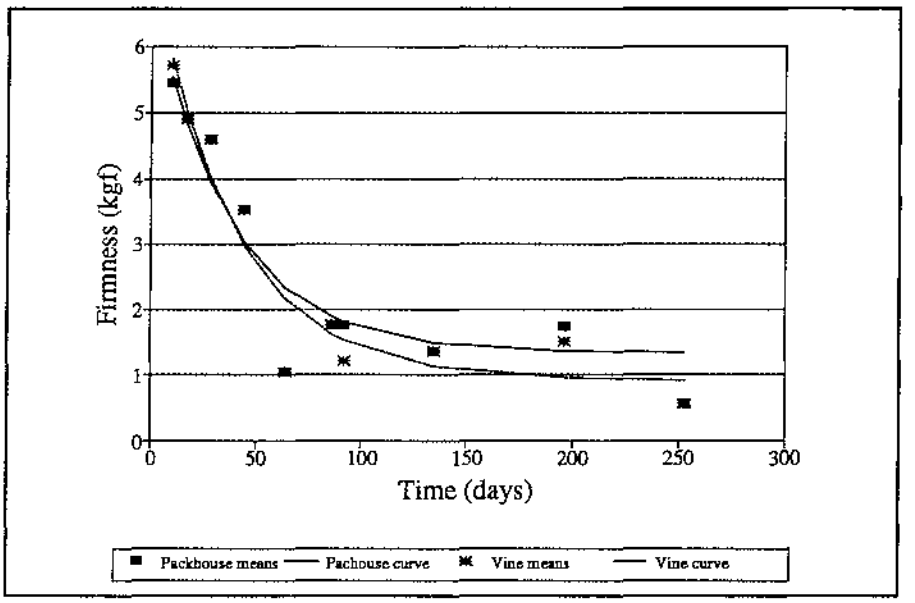

Fig. I.3 Changes in kiwifruit firmness over time for packhouse and vine treatments stored at 0°C for grower **C**.

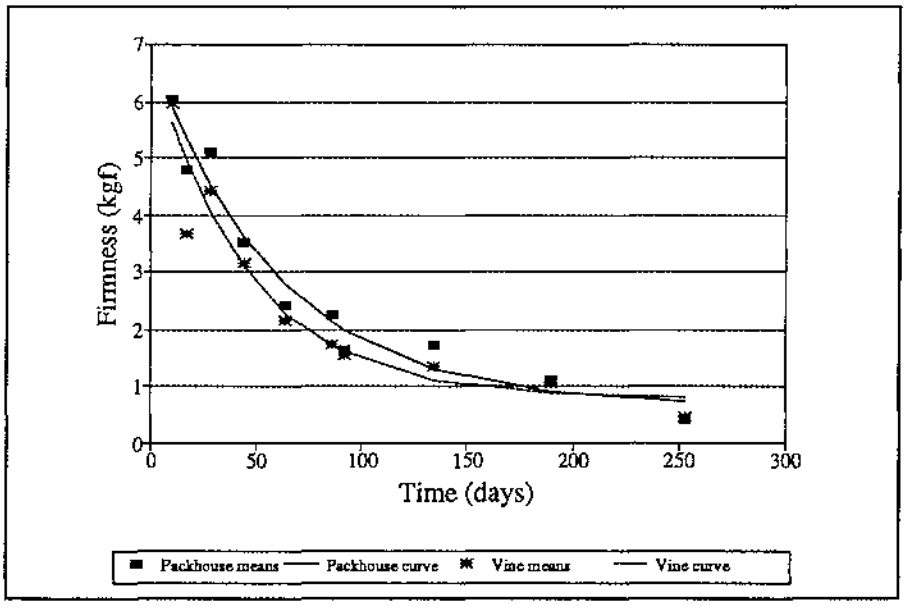

Fig. I.4 Changes in kiwifruit firmness over time for packhouse and vine treatments stored at 0°C for grower **D**.

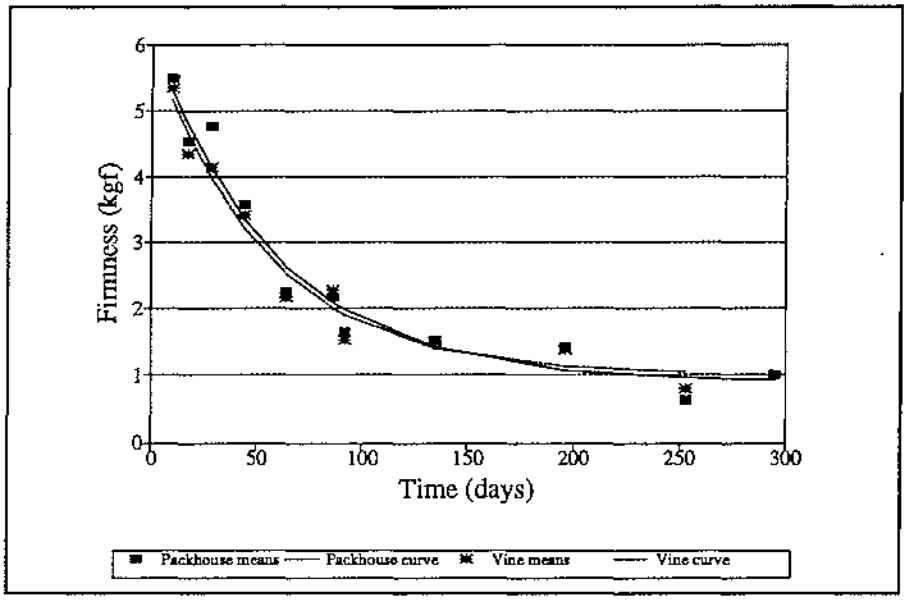

Fig. I.5 Changes in kiwifruit firmness over time for packhouse and vine treatments stored at 0°C for grower E.

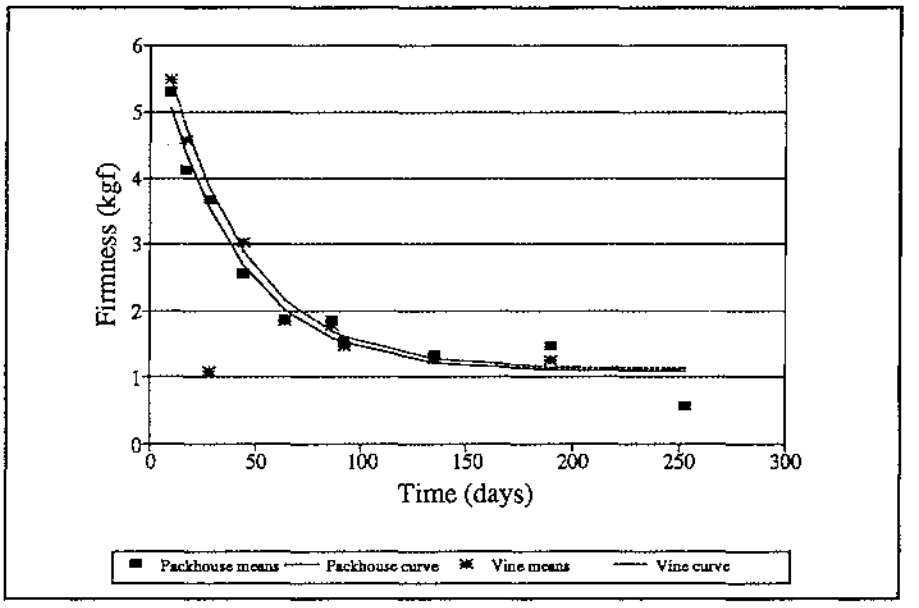

Fig. I.6 Changes in kiwifruit firmness over time for packhouse and vine treatments stored at 0°C for grower F.

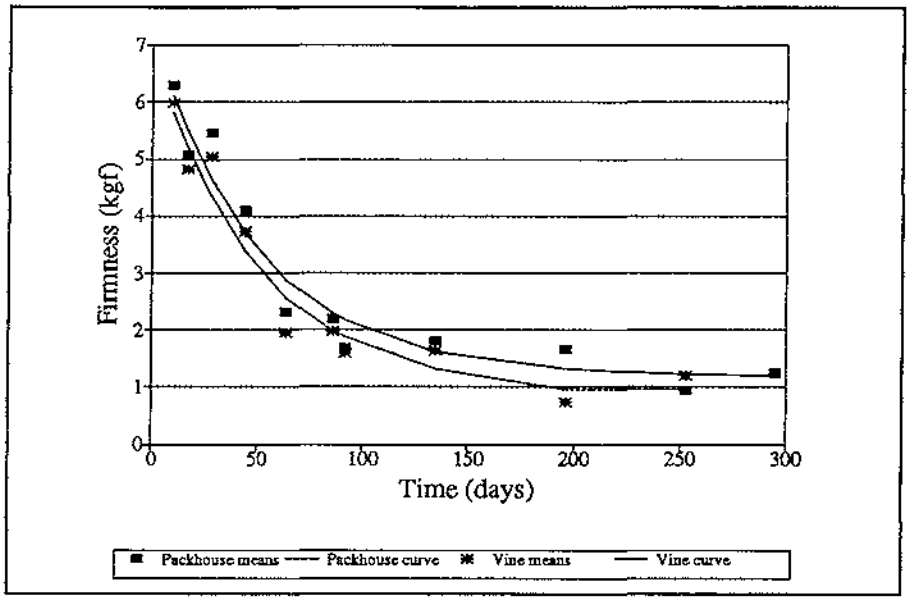

Fig. I.7 Changes in kiwifruit firmness over time for packhouse and vine treatments stored at 0°C for grower G.

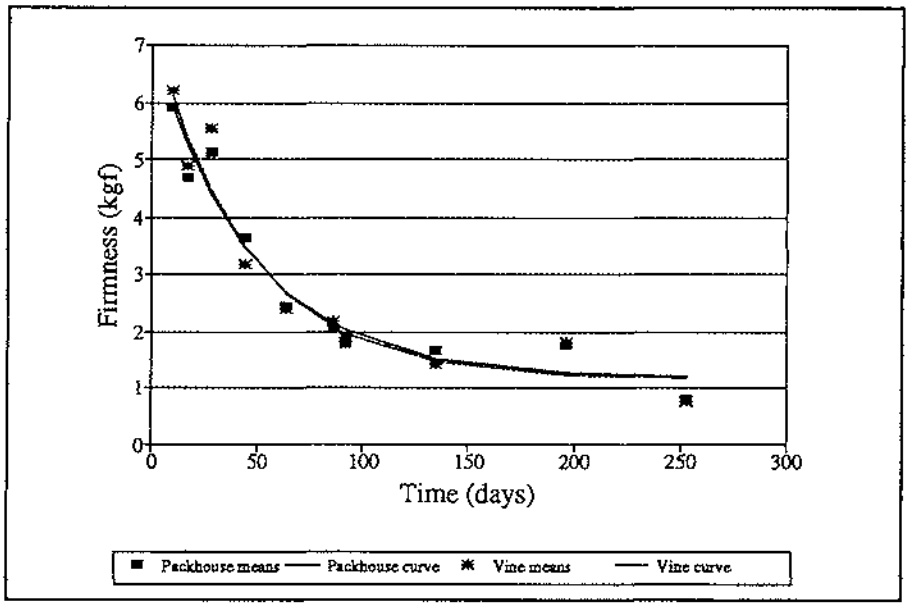

Fig. I.8 Changes in kiwifruit firmness over time for packhouse and vine treatments stored at 0°C for grower H.

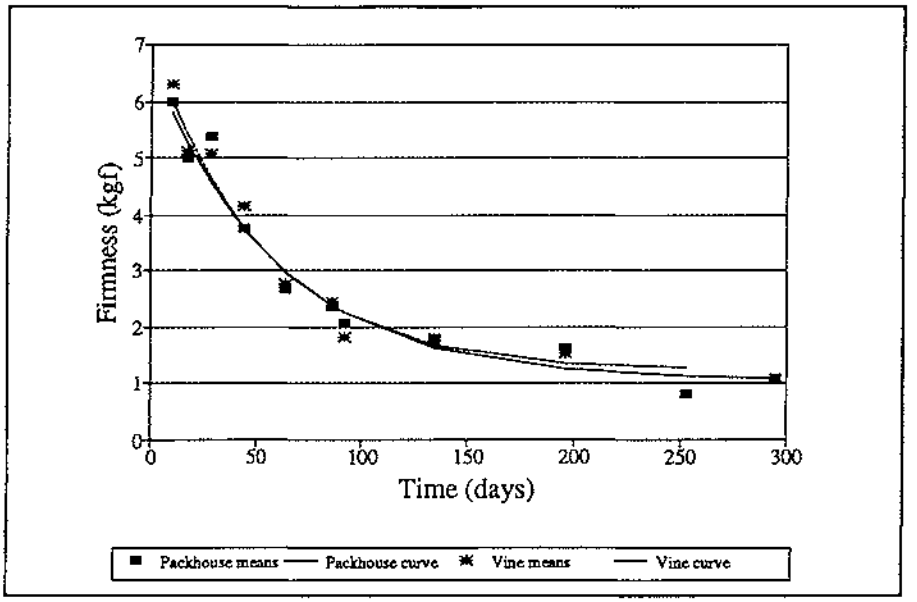

Fig. I.9 Changes in kiwifruit firmness over time for packhouse and vine treatments stored at 0°C for grower **I**.

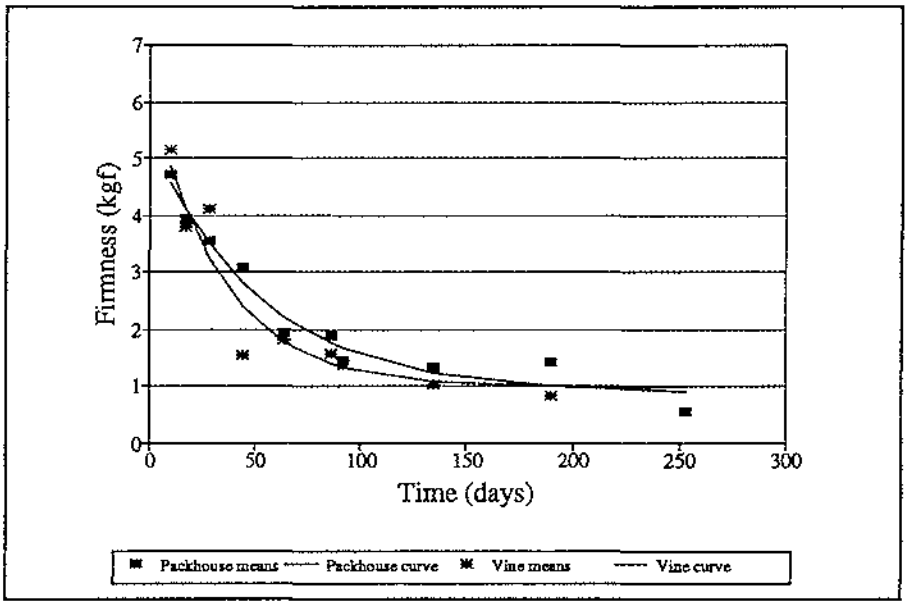

Fig. I.10 Changes in kiwifruit firmness over time for packhouse and vine treatments stored at 0°C for grower **J**.

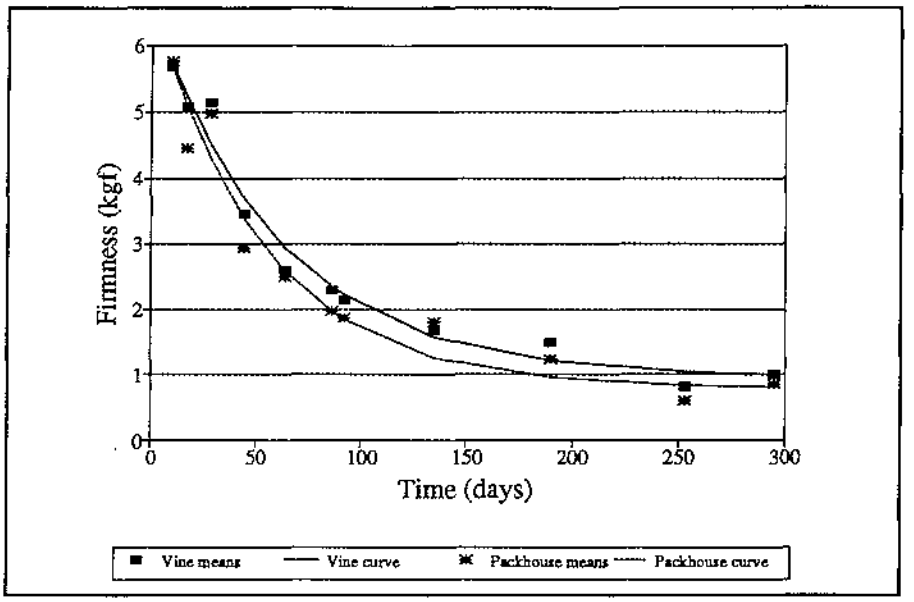

Fig. I.11 Changes in kiwifruit firmness over time for packhouse and vine treatments stored at 0°C for grower K.

Table I.1 Model 2 parameter values for kiwifruit stored at 0°C.

Grower	Treatment	Parameter values		
		a	*b*	*c*
A	Packhouse	5.7584	0.0152	1.0536
	Vine	6.1002	0.0203	1.1567
B	Packhouse	5.7167	0.0207	1.0721
	Vine	5.7691	0.0201	0.7915
C	Packhouse	5.4877	0.0267	1.3341
	Vine	6.2924	0.0254	0.9203
D	Packhouse	6.2089	0.0167	0.6467
	Vine	6.0074	0.0217	0.7889
E	Packhouse	5.2357	0.0172	0.5957
	Vine	5.0205	0.0187	1.0054
F	Packhouse	5.1724	0.0268	1.0919
	Vine	5.7488	0.0269	1.1300
G	Packhouse	5.9757	0.0196	1.1825
	Vine	5.9667	0.0202	0.9363
H	Packhouse	6.1702	0.0220	1.1520
	Vine	5.8408	0.0212	1.1877
I	Packhouse	5.6619	0.0168	1.0414
	Vine	5.7889	0.0186	1.2074
J	Packhouse	4.4658	0.0190	0.8869
	Vine	5.2404	0.0300	0.9909
K	Packhouse	5.6059	0.0162	0.9533
	Vine	5.9061	0.01882	0.7982

Appendix II

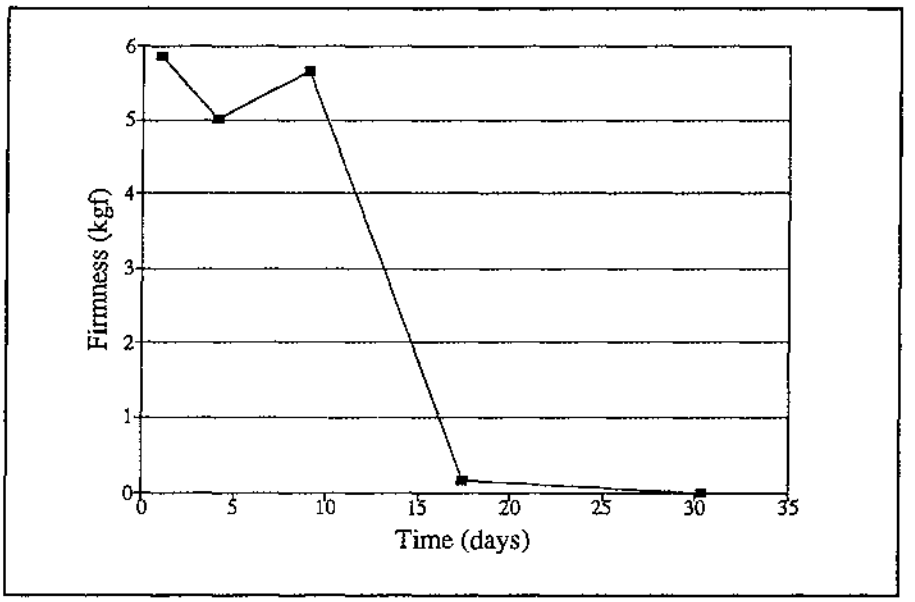

Fig. II.1 Changes in kiwifruit firmness over time for packhouse treatment stored at 20°C for grower **A**.

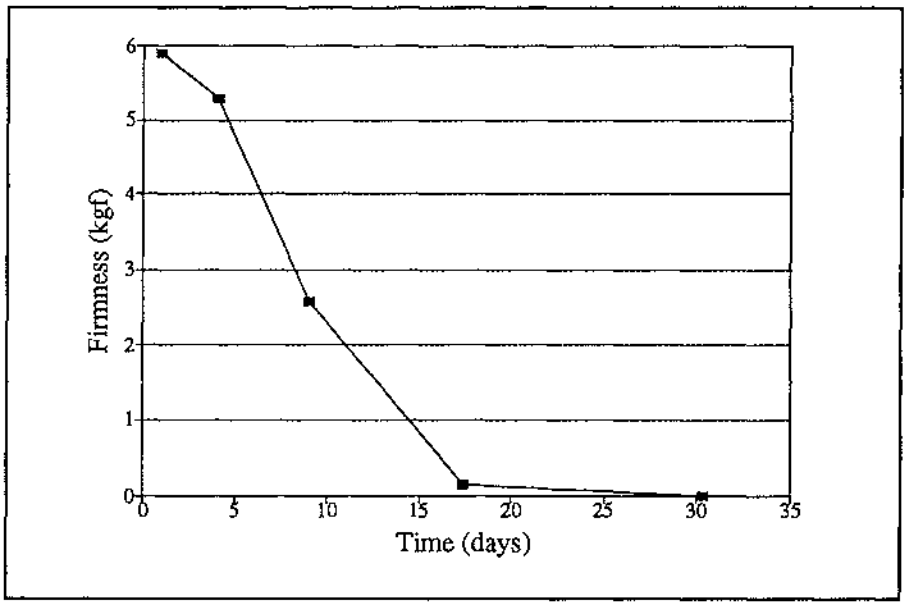

Fig. II.2 Changes in kiwifruit firmness over time for packhouse treatment stored at 20°C for grower **B**.

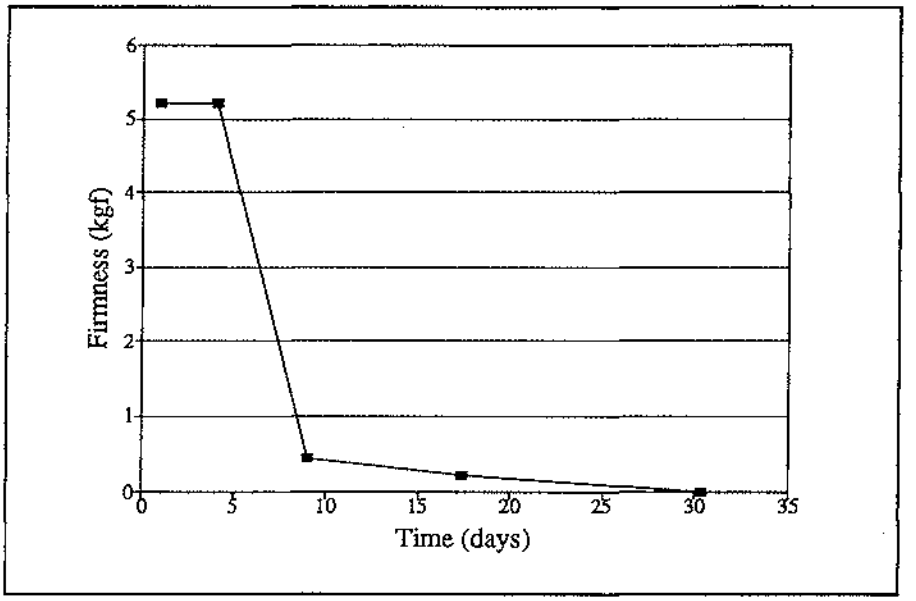

Fig. II.3 Changes in kiwifruit firmness over time for packhouse treatment stored at 20°C for grower **C**.

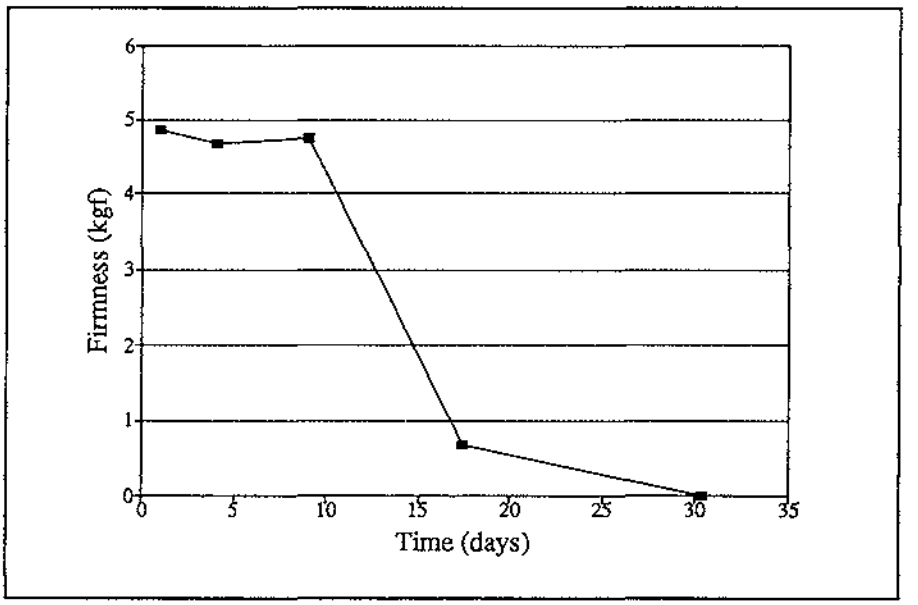

Fig. II.4 Changes in kiwifruit firmness over time for packhouse treatment stored at 20°C for grower **D**.

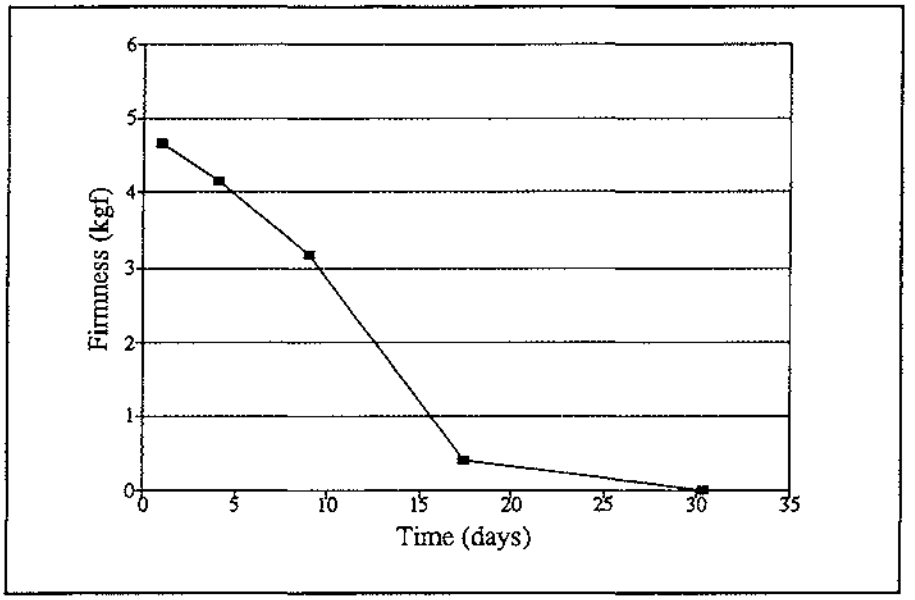

Fig. II.5 Changes in kiwifruit firmness over time for packhouse treatment stored at 20°C for grower **E**.

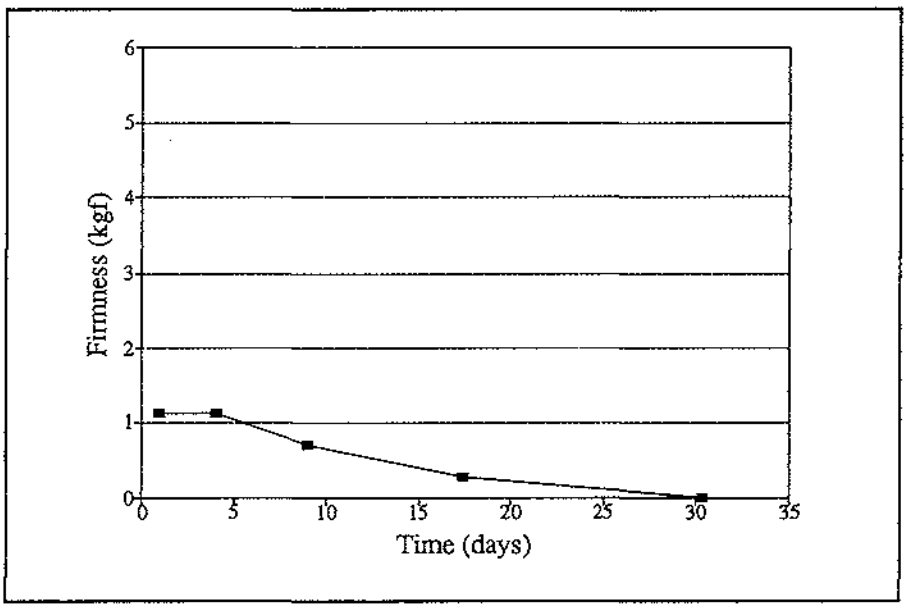

Fig. II.6 Changes in kiwifruit firmness over time for packhouse treatment stored at 20°C for grower **F**.

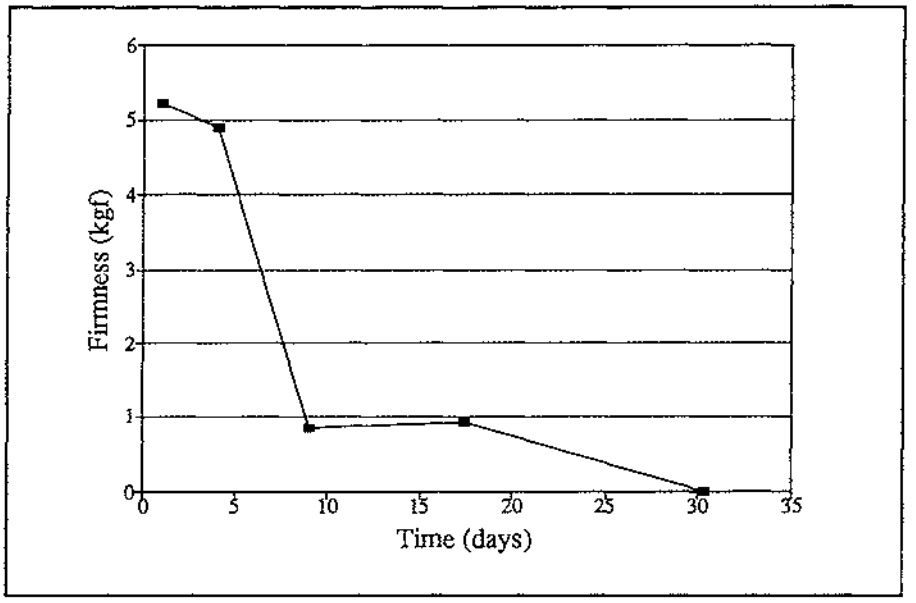

Fig. II.7 Changes in kiwifruit firmness over time for packhouse treatment stored at 20°C for grower **G**.

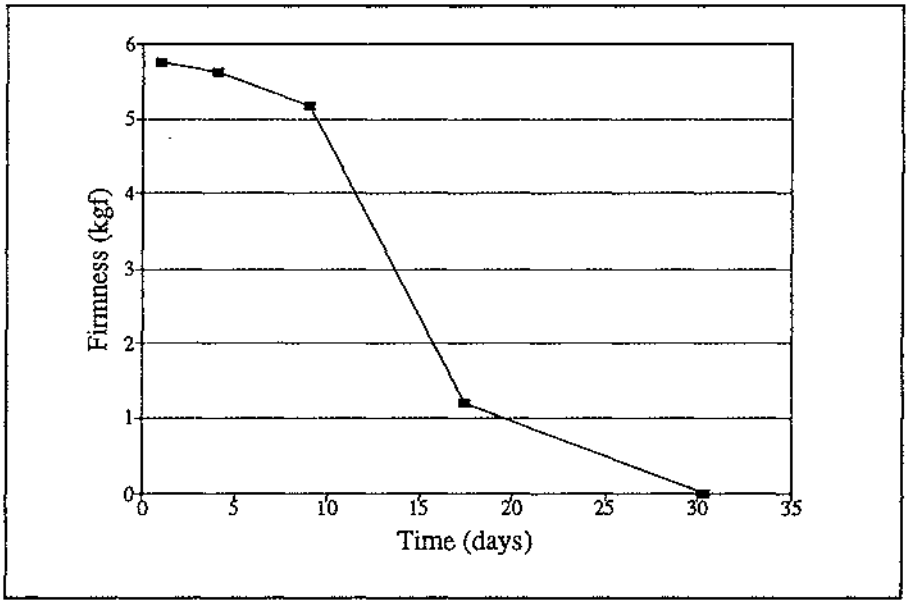

Fig. II.8 Changes in kiwifruit firmness over time for packhouse treatment stored at 20°C for grower **H**.

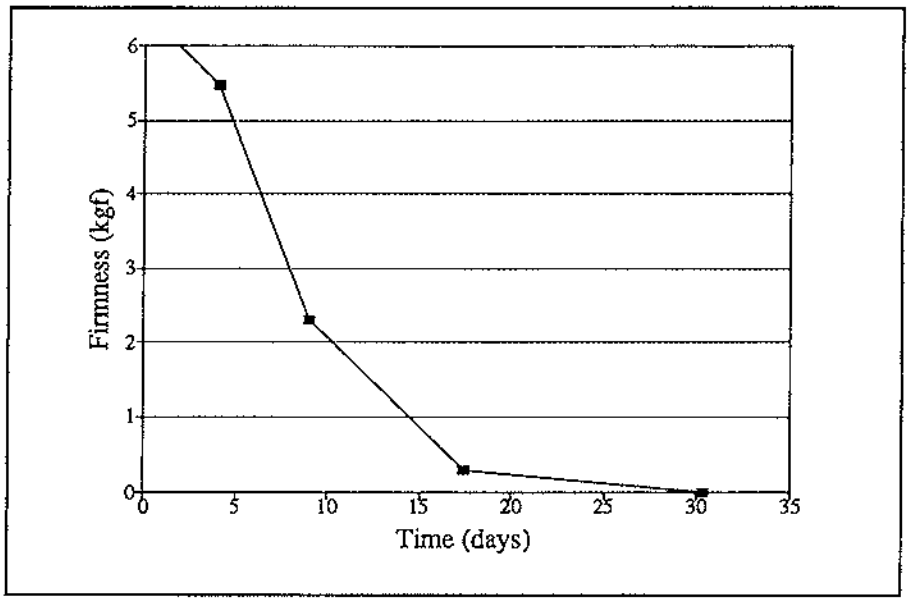

Fig. II.9 Changes in kiwifruit firmness over time for packhouse treatment stored at 20°C for grower **I**.

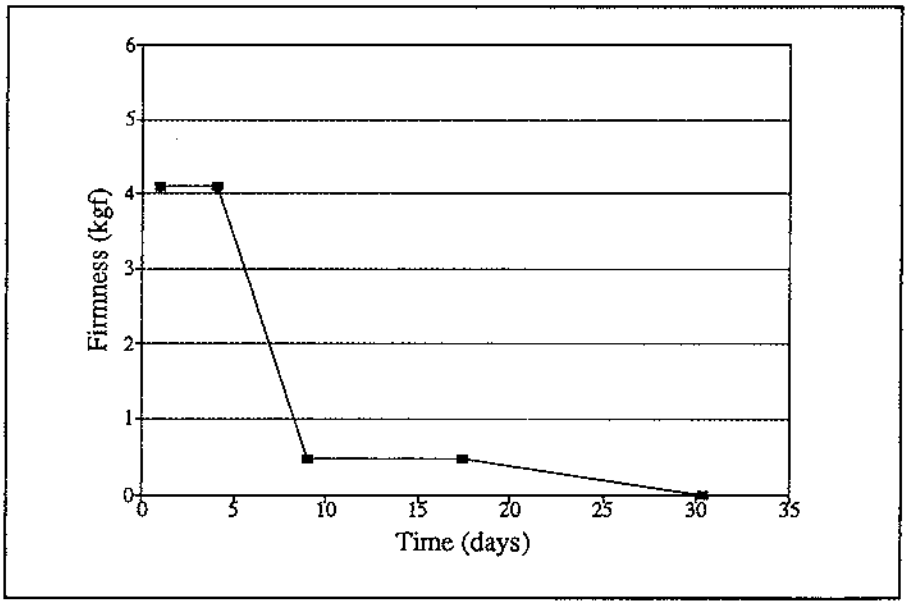

Fig. II.10 Changes in kiwifruit firmness over time for packhouse treatment stored at 20°C for grower **J**.

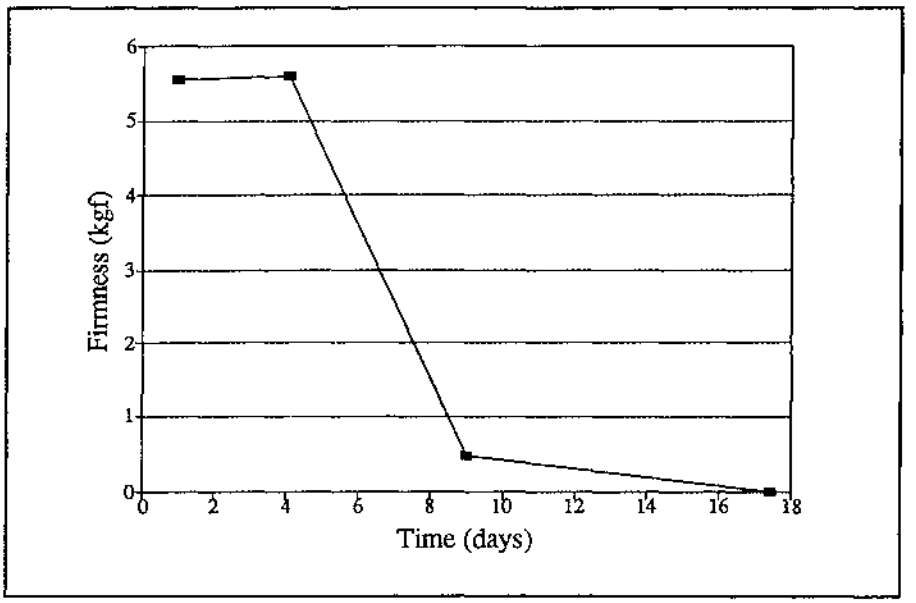

Fig. II.11 Changes in kiwifruit firmness over time for packhouse treatment stored at 20°C for grower K.