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Role of Calcium and Mechanical Damage in the Development of Localised Premature Softening in Coolstored Kiwifruit

A dissertation presented in partial fulfilment of the
requirements for the degree of

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at

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Ivan John Davie

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This thesis is dedicated to Nigel, Cliff and Nagin.

My thanks for the opportunity they provided, patience shown, motivation given and standard of excellence set.

"....know the truth and the truth will set you free."

Preharvest, harvest, and postharvest factor(s) were examined to identify the causes of premature quality loss during long term coolstorage of kiwifruit (*Actinidia deliciosa*). Investigation centred around the role of mechanical damage and calcium in the development of softening disorders, including soft patches (localised soft areas on fruit surface), premature softening, and low temperature breakdown (LTB) during storage.

Kiwifruit were vulnerable to compression and impact from harvest onwards, with damage usually being expressed after a period of coolstorage. Physical damage normally just affected the fruit tissue in direct contact with the applied force. Impact damage, and to a lesser extent compression damage, depended on the size of the force and firmness of fruit when damaged. As kiwifruit softened, their susceptibility to soft patch development as a result of physical damage increased whereas the likelihood of flesh fracture in response to impact declined. These changes are attributed to the change in nature of the flesh, which is 'brittle' at harvest and 'viscoelastic' after softening. Physical damage to coolstored kiwifruit caused a slight drop in final firmness whereas there was no effect on firmness if it occurred at harvest.

Fruit with softening disorders consistently had lower calcium contents (about 12% less) than equivalent healthy fruit. Fruit with soft patches had a high phosphate content, low dry matter, and at harvest, a low soluble solids content. A causative role for calcium in soft patch development was demonstrated by preharvest calcium treatments that elevated calcium content of the harvested fruit. Other orchard factor(s) were probably the cause of a weaker relationship between calcium content at harvest and storage behaviour of fruit. Although firmness at harvest declined with later picking, after coolstorage, fruit harvested more mature had a higher firmness and lower incidence of LTB. Symptoms for LTB were consistent with chilling injury whereas soft patches appeared to be due to localised premature senescence and not low temperature.

A conceptual model of key factor(s) which cause the initiation and development of softening disorders in kiwifruit is proposed. Implications of this model for further investigation of these phenomena and for commercial handling of fruit are discussed. Further development of this model to produce a predictive model of fruit storage potential would require further characterisation of other important influences in storage behaviour.

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Abs	absorbance
A^E	area of soft patches on fruit excluding those at the impact site (m^2 ; Sections 4.2.4, 7.2.2.2)
AH	treatment: compression 96 h immediately after harvest (Section 3.2.2)
A^I	area of soft patches at the impact site (m^2 ; Sections 4.2.4, 7.2.2.2)
ap	number of oil applications
A^{sp}	area of soft patches (m^2 ; Sections 3.2.3, 5.2.5, 6.2.4, 7.2.5.2, 8.2.3.2)
A^T	area of soft patches on the total fruit surface (m^2 ; Section 4.2.4)
B	treatment: fruit taken from the bottom layer of bin (Section 6.2.2.2)
C	treatment: control fruit, not graded (Section 6.2.2.2)
CA	controlled atmosphere
card	treatment: fruit held in a cardboard single layer tray (Section 6.2.2.2)
cp	phosphate concentration (mmol/kg)
C_0	treatment: fruit not graded with a flesh at 0°C (Section 6.2.2.2)
C_{16}	treatment: fruit not graded with a flesh at 16°C (Section 6.2.2.2)
d	number of calcium dips
DT	treatment: compression when fruit transported by truck (450 km; Section 3.2.2)
E^I	impact energy (J)
ET	treatment: compression during early phase of coolstorage (12 weeks; Section 3.2.2)
Δf	difference between initial and final firmness (N)
f	firmness (N)
$f^{initial}$	initial firmness (N)
f^{final}	final firmness (N)
g	gravitational constant (m/s^2)
G	treatment: graded (Section 6.2.2.2)
G_M	treatment: modified grader (Section 6.2.2.2)
G_0	treatment: fruit graded with flesh at 0°C (Section 6.2.2.2)
G_{16}	treatment: fruit graded with flesh at 16°C (Section 6.2.2.2)
h	hours
h^i	drop height (m)
LC	treatment: compression during late coolstorage (Section 3.2.2)
LTB	Low temperature breakdown
m	mass (kg)
NZKMB	New Zealand Kiwifruit Marketing Board
p	individual fruit positions within pipes
P_{H_2O}	permeance to water vapour ($mol/s.m^2.Pa$)
R^E	percentage of rejectable fruit due to soft patches outside the impact site (%)
R_j	percentage of rejectable fruit due to soft patches (%)
sg	severity of grading
SL	treatment: compression during simulated shelf-life (Section 3.2.2)
$SP_{contact}$	soft patches present on fruit at the contact site (m^2 ; Section 3.2.3)
$SP_{outside}$	soft patches present on fruit, but not at the contact site (m^2 ; Section 3.2.3)
ss	soluble solids (%)
t	time (weeks)
T	treatment: fruit taken from the top layer of bin (Section 6.2.2.2)
tp^B	treatment: fruit held in tri-pack bottom layer (Section 5.2.2)
tp^M	treatment: fruit held in tri-pack middle layer (Section 5.2.2)
tp^T	treatment: fruit held in tri-pack top layer (Section 5.2.2)
wood	treatment: fruit held in wooden single layer tray (Section 5.2.2)

General introduction

✧ 1.1 BACKGROUND

Kiwifruit (*Actinidia deliciosa* (A.Chev) C.F. Liang et A.R. Ferguson 'Hayward') were worth \$320.8 million in export returns to New Zealand in the year ending 30 June 1995 (SONZA 1996). However, the New Zealand kiwifruit industry lost c. \$5.2 million due to kiwifruit softening prematurely in the 1994/95 season (G. Sampson pers. comm.). This premature softening was due either to whole fruit rapidly softening during storage at 0°C (coolstorage) relative to other healthy fruit, or to a localised area on an otherwise healthy fruit softening prematurely (a *soft patch*; New Zealand Kiwifruit Marketing Board (NZKMB) 1996). Avoiding of the cost incurred by having to identify and remove these prematurely soft fruit from the postharvest system would prevent valuable potential income being lost to the New Zealand grower.

A large part of the NZKMB's success in marketing the large volume of kiwifruit produced in this country each year lies in the ability to provide the export market with fruit of very high quality for an extended (6 month) period after harvest. This creates opportunities to supply the fruit in an orderly way to different markets around the world without creating a glut around harvest time. However, kiwifruit quality must remain high throughout a long storage period and through the distribution chain until the fruit reaches the consumer. Kiwifruit quality is rigorously checked on all lines (fruit from individual orchards) of fruit on a pallet by pallet basis before export. New Zealand is competing against other kiwifruit exporting countries, so quality plays an important role in maintaining a premium price and market share for the New Zealand crop.

Kiwifruit are harvested by hand when the flesh soluble solids content (ss) is at 6.2% or above at 20°C (NZKMB 1996). Firmness of the fruit is usually c. 80 Newtons (N) when they are picked from the vine at the start of the harvesting season in mid April. Kiwifruit are harvested into picking

bags, then transferred into wooden bins. Bins full of fruit are transported to a packhouse where kiwifruit are graded and packed by machine or partly by hand within 96 h of harvest. They are then palletised and placed in coolstorage at 0°C within 24 h of being packed (NZKMB 1996). A large portion of the crop is immediately bulk-stored in wooden bins in air or controlled atmosphere (CA) coolstorage at 0°C. Fruit stored in bulk in air at 0°C are removed to be graded and packed before fruit that have been stored in CA. Fruit can be stored for up to 6 months in CA before being graded and packed. Bulk storage of fruit in air or CA enables grading and packing of kiwifruit to continue after harvest until the last of fruit stored in CA is removed.

During storage, kiwifruit softens from its original high value at harvest. The residual firmness it has at the time of export must be sufficient to enable it to undergo a further period of transportation and handling without becoming excessively soft. Kiwifruit firmness is, therefore, used by the NZKMB as a quality criterion in deciding if a line of kiwifruit can be accepted, or is rejected, for export. Once kiwifruit has been in a coolstore at 0°C for as long as 10 weeks from the packing date, the condition of the kiwifruit is required to be checked before export, according to guidelines in the NZKMB quality manual. This "condition checking" is an essential part of the NZKMB quality assurance programme. Condition checking, as its name implies, provides an opportunity to reject poor quality kiwifruit prior to market sale and often before export. At the time of condition checking, a sample tray is removed from a pallet and based on the number of soft kiwifruit (or levels of other defects) found in the tray, the need for repacking is determined. Kiwifruit firmness is measured by penetrometer: all areas on a kiwifruit must be above the minimum firmness set by the NZKMB for the relevant time period during the storage season from harvest (from September onwards this is greater than 10 N for fruit tested at between 0 and 5°C; NZKMB 1996).

Firmness is very critical later in the season when kiwifruit have softened close to the export firmness threshold. It is, therefore, very

important to growers that their kiwifruit remains above this threshold level of firmness at least until fruit has been exported. It is essential for the industry that the fruit retains sufficient firmness after storage to be regarded as high quality. At present it is not possible for the NZKMB to predict accurately which orchard lines of kiwifruit will have the fastest rate of softening or the proportion of individual kiwifruit in an orchard line that would be rejectable due to localised soft areas. Nor is it possible to assess the likely storage performance of a given line of kiwifruit from its storage behaviour in previous years. There is, therefore, considerable industry interest in identifying those factor(s) most responsible for influencing kiwifruit firmness and the factor(s) which cause localised or whole fruit premature softening in storage. It is thought that mechanical damage resulting in bruising of kiwifruit tissue can cause whole or localised areas on fruit to soften prematurely (Hopkirk & Finch 1989). Handling at harvest has been associated with the tendency of kiwifruit to develop water-soaked localised soft areas (soft patch). Kiwifruit mineral composition has been shown to be associated with fruit quality in storage, with low relative calcium (Ca^{+2}) concentrations in fruit linked to localised premature softening of kiwifruit (soft patches; Banks et al. 1992; Prasad & Spiers 1992). On the other hand, excess phosphate in apple has been associated with poor fruit quality, such as an increased incidence of bitter bit (Olivier et al. 1994). Therefore, it could be feasible that high phosphate may cause storage disorders in kiwifruit during long term coolstorage.

1.2 SCOPE

This thesis examines a number of issues relating to the softening behaviour of kiwifruit and the identification and prevention of premature softening of kiwifruit. Literature on factor(s) affecting kiwifruit softening is reviewed in the second chapter. In chapter 3, the potential role of compression damage in softening behaviour and development of soft patches is examined.

Kiwifruit were compressed at harvest, while being transported, during long term air coolstorage at 0°C , and while being given a simulated shelf-life at

20°C. In chapter 4, kiwifruit impacted at harvest or at intervals during long term air coolstorage at 0°C were examined for their rate of softening and level of soft patches that developed after storage. In chapter 5, the incidence of soft patches and rate of softening of kiwifruit graded on commercial graders or stored in different packaging were examined after long term air coolstorage at 0°C. In chapter 6, softening of air coolstored kiwifruit at 0°C that had been removed from CA after 20 weeks storage at 0°C, and then graded at different temperatures and firmness values, was investigated. Kiwifruit were assessed for their incidence of soft patches and fruit not graded had their calcium and phosphate (PO_4^{3-}) concentrations determined. In chapter 7, kiwifruit were given preharvest treatments to directly or naturally enhance their calcium concentrations, then their rate of softening and incidence of soft patches after long term air coolstorage at 0°C was examined. In chapter 8, kiwifruit of different maturities and from different orchards were stored long term at different temperatures at, above, or below 0°C, in air and were then assessed for their incidence of soft patches and low temperature breakdown (LTB), and their calcium concentration. Chapter 9 presents a general discussion of issues arising from all of the earlier chapters and presents a conceptual model of various influences in the softening behaviour of coolstored kiwifruit. Chapters within this thesis are written in the form of papers using the same format as in the *New Zealand journal of crop and horticultural science*.

1.3 REFERENCES

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Softening of kiwifruit: literature review

2.1 ONTOGENETIC DEVELOPMENT

2.1.1 Normal pattern of kiwifruit development

Pratt & Reid (1974) described kiwifruit growth as being made up of 5 phases (Table 2.1). It appears that kiwifruit volume reaches a maximum from 21 to 23 weeks from anthesis which corresponds with the initiation of irreversible ripening in kiwifruit. Ethylene is produced in trace amounts throughout the life of the fruit, so that only low concentrations are present within the fruit tissue (e.g., $< 0.01 \mu\text{L/l}$; Pratt & 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. Initially at harvest, kiwifruit have a high firmness (80 to 100 N) and a long storage potential when held at 0°C.

2.1.2 Preharvest changes in kiwifruit composition

Very young kiwifruit have a high starch content and the contents of soluble solids and sugars are low and constant (Pratt & Reid 1974). Okuse & Ryugo (1981) found that total carbohydrate content increased rapidly with fruit growth as a kiwifruit developed. Green immature kiwifruit were rich in glucose but the level decreased while starch accumulated rapidly late in the season. In early April there was an initial rise in soluble solids content. As starch hydrolysis began, glucose level increased rapidly, attaining nearly 10% by harvest. Harvested kiwifruit continued to increase in soluble solids content, as the residual starch was converted to sugar. Fructose increased gradually from the youngest stage of kiwifruit development until harvest. Continued accumulation of dry matter by the fruit of starch was reflected by an increase in total soluble solids content. This accumulation indicates that photosynthates were still being imported until the fruit were harvested. Seager et al. (1991) reported a faster rate of change in soluble solids content

with a lower night temperature. A lower night temperature resulted in a higher soluble solids content level at harvest with no effect on final firmness after storage. Soluble solids content is used by the New Zealand Kiwifruit Marketing Board (NZKMB) as a maturity criterion for harvesting of the crop (NZKMB 1996).

2.1.3 Physiological processes associated with softening

Storage at 0°C causes physiological changes associated with kiwifruit softening to progress more slowly leading to a significant reduction in ripening (Wright & Heatherbell 1967). The changes in the chemical nature of the pectic materials are the primary cause of changes that occur in the softening of horticultural products (Tucker 1993). Pectic substances have been shown to solubilize during ripening in kiwifruit after harvest (Arpaia et al. 1987; Redgwell et al. 1992). MacRae et al. (1990) proposed that softening of kiwifruit is partly due to enzymatic solubilization and degradation of the pectic substances. As a kiwifruit ripens, chain length of the pectin polymers decreases, forming water soluble pectin, and the structure becomes increasingly soft. During the early phase of kiwifruit softening (when firmness decreases from 90 to 15-20 N; Fig 2.1) large amounts of pectin are solubilised in the cell wall, allowing pectins previously insoluble in the cell wall to become degradable.

Soda et al. (1986) reported that polygalacturonase plays a role in the solubilization of pectic substances and in textural changes involved in kiwifruit ripening. Pectin solubilization and degradation have been identified as major features of cell wall changes which occur during kiwifruit ripening (Redgwell et al. 1990, 1992). Polygalacturonase was involved in degradation of the middle lamella of the cell wall. There was also a decrease in the size of another group of cell wall polymers called hemicelluloses. These polysaccharides were thought to be tightly bound to the cellulose fibres of the fruit wall, and function in maintaining the integrity of the cell wall. Swelling of kiwifruit cell walls initially starts early on during fruit softening and reaches a peak towards the end of

softening (Hallet et al. 1992; Redgwell et al. 1992). During the latter phase of softening (Fig. 2.1) most pectins had been solubilized, but degradation of soluble pectins to smaller polymers continued. The cell wall at the latter phase of softening consisted primarily of cellulose, hemicellulose, and some highly galactosylated pectin (Redgwell et al. 1992). Most galactose was lost from the cell wall material when the cell wall was swelling the most (Redgwell et al. 1992).

Harker & Hallet (1994) found that cells ruptured during tensile tests made on fruit at harvest. On the other hand, during the early kiwifruit softening phase (Fig. 2.1) neighbouring cells separated from each other without breaking open. These early changes to kiwifruit texture at harvest were thought to be due to degradation of the middle lamella and decreases in cell-to-cell adhesion (Hallet et al. 1992; Harker & Hallet 1994). Kiwifruit in the final stages of softening showed an increased plasticity of the cell wall, and proportion of cells that separated at the middle lamella. Rapid enzymic breakdown of the middle lamella may result in softening of the overall kiwifruit texture. The strengthening of pectin bonds between cell walls might be expected to enable a kiwifruit to better withstand factors that promote softening (Section 2.2.8.1).

2.2 FACTOR(S) AFFECTING KIWIFRUIT SOFTENING

2.2.1 Time

MacRae et al. (1989) demonstrated that kiwifruit lose firmness progressively with time after harvest. The softening pattern during storage depended upon kiwifruit maturity at harvest. The softening pattern for mature kiwifruit held at 0°C comprises an initial rapid phase then followed by a slower rate of reduction in fruit firmness (Arpaia 1980; cited in Arpaia et al. 1987; Fig. 2.1). During the rapid softening phase, decreases in flesh firmness have been observed to occur rapidly from 80-90 N to 20 N (MacRae et al. 1990). During the slow phase from 15-20 N, flesh firmness decreased at a much slower rate (MacRae et al. 1990). Kiwifruit that are not fully mature (e.g.,

at 21 weeks from anthesis) may have a lag phase in their softening curve (A; Fig. 2.1). The lag phase is followed by a period of acceleration in fruit softening (B; Fig. 2.1). Then there is a slowing in the rate of fruit softening, a period of deceleration (C; Fig. 2.1). This final period of deceleration finishes when the final firmness level becomes almost constant.

There can be wide variation in the time at which ripening occurs in kiwifruit which were set and harvested at the same time, and which might be expected to be physiologically more alike (Pratt & Reid 1974). Lallu et al. (1989) harvested kiwifruit from the same orchard block over 2 seasons and applied the same treatments of time and temperature to fruit, but the time for fruit to reach 10 N differed by up to 2 weeks between years. There were also differences between kiwifruit within a given harvest. Variability in the softening behaviour of individual kiwifruit is one of the main problems in the commercial storage of kiwifruit since the sub-standard fruit have to be graded out. On a commercial level there is a difference between mean softening rates of kiwifruit from different orchards in the same region (Crisosto et al. 1984).

2.2.2 Turgor

Arpaia et al. (1987) showed that the initial stages of softening in both air and controlled atmosphere storage may be influenced as much by starch hydrolysis and consequent cell turgor changes as by solubilization of the cell wall components. Transmission electron microscopy of kiwifruit pericarp tissue in fruit which had been freshly harvested or air stored for 6 to 8 weeks at 0°C had amyloplasts of different sizes. Hatfield & Knee (1988) proposed that apple firmness was influenced by cell turgor, with loss of water from fruit leading to greater cell cohesion during ripening. The loss of cell cohesion in the control fruit with less water loss, was derived from an increase in air space caused by the cells becoming more spherical at high turgor, which caused them to have less surface contact with neighbouring cells. Hatfield & Knee (1988) implied that the average area of contact between cells was reduced in more turgid cells, whereas in fruit with high

weight loss the cell contact was maintained and air spaces did not increase. The findings by Arpaia et al. (1987) and Hatfield & Knee (1988) indicate the potential for a similar process to occur in kiwifruit whereby starch hydrolysis may increase cell turgor, so reducing cell cohesion and producing a reduction in kiwifruit firmness. However, the extent to which this reduction in cell cohesion could occur would depend upon some relaxation of intercellular bonding and, therefore, would also be dependent upon enzymatic degradation of cell wall materials. Arpaia et al. (1987) found that changes in the kiwifruit cell wall degradation process were contributing to fruit softening. Starch degradation possibly also caused cell turgor changes to be involved in low-temperature softening of kiwifruit.

On the other hand, there is some evidence that the higher the rate of water loss of fruit, the faster they may soften. Kiwifruit stored at a 95% relative humidity softened faster than equivalent fruit stored at a slightly higher humidity (99%; McDonald & Harman 1982). Rate of softening in kiwifruit could, therefore, be influenced in either direction by their rate of water loss during storage.

2.2.3 Temperature

Coolstorage at 0°C is the main control in delaying the reduction of kiwifruit firmness below the export firmness threshold (NZKMB 1996). Temperature has a considerable influence on fruit firmness, which can be reversible or irreversible (Jeffery & Banks 1994) depending upon what stage of ripening the fruit is at. Werner et al. (1978) observed that peaches exhibited rehardening when returned to low temperature storage after softening at room temperature. Rehardenig was more pronounced as the storage temperature was reduced. They suggested that low temperature which induced rehardening was not related to metabolic changes in the fruit cell wall due to the influence of temperature, but in part to the gelling behaviour of the pectin fractions. Werner & 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 and liquify at ordinary room temperature. In ripening fruits, the changes in firmness at different temperature may reflect the behaviour of soluble pectin fractions. We might expect the firmness-temperature relationship to be affected by the fruit's calcium content given the known effects of calcium on firmness of a wide range of fruit tissues (Ferguson 1984; Poovaiah 1988).

2.2.3.1 Physical effects of temperature

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 (1982) on a range of commodities involved measuring their firmness with different firmness instruments over a range of temperatures. With a few exceptions, firmness decreased with increasing temperature for all commodities and for every type of firmness measurement, with the relationship being linear for most commodities. Firmness-temperature coefficients (percentage change in firmness per degree temperature increase over the temperature range studied) varied widely. They varied between commodities, and depended on the cultivars, the test method, storage method, and season involved. Most commodities had a firmness-temperature 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 firmness-temperature coefficient, the smaller the temperature change that would be needed to detect a temperature effect.

Jeffery & Banks (1994) examined the differences in firmness of kiwifruit between 0°C and 20°C at a range of firmness levels. Kiwifruit with a firmness value of c. 20 N, sustained a loss of measured firmness of c. 35% when fruit temperature was changed from 0°C to 20°C. At this level of

firmness, kiwifruit had a firmness-temperature coefficient ($-1.7\ \%/^{\circ}\text{C}$) that was higher than the values reported for most other raw fruits and vegetables by Bourne (1982). This revealed the potential for major effects of temperature on firmness in kiwifruit. There is clearly a need to be consistent about the temperature at which firmness measurements are made.

2.2.3.2 *Physiological effects of temperature*

Jeffery & Banks (1994) found that kiwifruit that were softening rapidly which were warmed then re-cooled, did not re-gain their original firmness. This permanent loss of firmness reflected the physiological softening associated with fruit ripening. When the physiological processes associated with softening act on fruit tissue they induce a drop in firmness (MacRae & Redgwell 1992), separate from the reversible physical drop in firmness due to the firmness-temperature coefficient of the fruit (Jeffery & Banks 1994).

Commercially, kiwifruit are stored for long periods of time at 0°C and kiwifruit tissue could be exposed to physiological damage due to a long time period at low temperature (Wright & Heatherbell 1967; Parkin et al. 1989). Physiological damage such as cellular membrane decay and solute leakage from cells occurs due to chilling (Wang 1990). Chilling injury prevents normal cellular activities; this in turn promotes loss of calcium compartmentation and, therefore, premature senescence of fruit. Loss of calcium from cellular gradients impairs energy production and associated breakdown in vital membrane activities. In some fruit, enhancing calcium concentration reduces susceptibility to chilling injury (Wang 1990).

Chilling injury causes the deterioration of cellular membrane systems, leading to disorganisation of tissue and ultimate decay. Kiwifruit have a freezing point of approximately -1.5°C and it has been suggested that they may be stored long term at -1 to 2°C (Wright & Heatherbell 1967). Commercially the NZKMB recommends a storage temperature of 0°C (NZKMB 1996); how vulnerable kiwifruit is to chilling injury at 0°C is unclear. Lallu et al. (1992) has suggested that some kiwifruit have a form of chilling injury or LTB at 0°C . At 0.5°C there were negligible amounts of

LTB observed. Fruit susceptible to LTB may have a low calcium content as it has been observed that high calcium levels in fruits can result in less susceptible to chilling injury (Wang 1990).

2.2.4 Ethylene

McDonald & Harman (1982) reported that kiwifruit are very susceptible to ethylene. They can respond to ethylene produced within their own tissues (endogenous ethylene) and to ethylene arising from external sources (exogenous ethylene). Pratt & Reid (1974) observed ethylene production in individual kiwifruit always before or coinciding with the respiratory rise for kiwifruit at 20°C. Kiwifruit 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 can stimulate mechanisms which regulate ethylene production (Finch & Hopkirk 1987).

2.2.4.1 *Endogenous*

Endogenous ethylene production may be enhanced by physical damage to kiwifruit, causing premature ripening. Kiwifruit not exposed to ethylene at 20°C soften according to their maturity at harvest (Lallu et al. 1989). Less mature kiwifruit have a lag phase in their softening curve which disappears with increasing maturity (Section 2.2.1). Mature kiwifruit had a high rate of ethylene production, while very mature kiwifruit showed very little response in their rate of softening. Kiwifruit harvested later in the season accumulated sufficient ethylene from their own metabolism to saturate their potential responsiveness to ethylene in terms of ethylene, because 0.1 to 1000 $\mu\text{l/l}$ ethylene has little effect on promoting kiwifruit softening once rapid softening has been initiated (Lallu et al. 1989).

Fruit that were compressed produce ethylene to detectable levels sooner than equivalent fruit that were not compressed (Hopkirk 1985; Hopkirk & Finch 1989). The softer fruit were when compressed, the quicker they produced ethylene. However, harvested fruit that were given a

long term compression during coolstorage and then transferred to 20°C, took the same amount of time as controls to reach a peak ethylene production (Hopkirk 1985). Fruit with a range of firmness values were given an impact after being removed from coolstorage and the softest fruit took the least time to produce ethylene (Finch & Hopkirk 1987). Impacted fruit took less time to produce ethylene than control fruit and the time difference between impacted and control fruit was greatest for fruit which had the highest firmness.

Temporary exposure of cucumbers to low temperature stress advanced the onset of ethylene production in fruit when transferred back to 21°C, possibly by stimulation of 1-aminocyclopropane-1-carboxylic acid formation (Wang & Adams 1982). Similarly, the onset of rapid ethylene production associated with the initiation of ripening in apples (Knee et al. 1983) and pears (Hansen 1939), can be stimulated by exposure to low temperatures. This raises the possibility that exposure to prolonged low temperature might also induce the onset of rapid ethylene production in kiwifruit. Hyodo et al. (1987) found that the longer kiwifruit were stored at 2°C, the less time was required for fruit to reach a threshold ethylene level of 0.001 nmol/kg s at 21°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).

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. One of the first responses to wounding (or any physical stress) is an increase in the ethylene production that leads to an increase in ethylene concentration within the tissue. 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. At harvest, kiwifruit should be handled so their susceptibility to ethylene production due to physical stress is minimised (Sommer 1989).

2.2.4.2 *Exogenous*

Temperature and exogenous ethylene have a major effect on internal ethylene levels in kiwifruit and, therefore, can affect changes in quality of the fruit. McDonald & Harman (1982) found that kiwifruit at harvest produce negligible ethylene but were very sensitive to exogenous ethylene. A kiwifruit damaged during handling may prematurely produce ethylene (Section 2.2.4.1). Once packed in a tray, these damaged fruit would cause ethylene to accumulate within the tray, causing undamaged fruit to soften prematurely (Jeffery et al. 1992).

Wright & Heatherbell (1967) exposed kiwifruit to ethylene at 20°C which then 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 when they were already advanced in their maturity. MacRae et al. (1989) suggested that these kiwifruit may have had time to produce enough internal ethylene to exceed a threshold level required for promotion of softening and, therefore, not respond to ethylene applied to the fruit at 0°C. Less mature kiwifruit, held in storage at 0°C and then allowed to ripen at 20°C, were more responsive to ethylene sources relative to mature kiwifruit stored under similar conditions, indicating that kiwifruit have an internal build up of ethylene as they mature. Ben-Arie & Sonogo (1985) showed that kiwifruit in a modified atmosphere maintained their firmness for longer in the presence of an ethylene absorbent (e.g., 'Ethsorb').

Partial pressures of 10 mPa ethylene, even at 0°C, have been known to accelerate kiwifruit softening and, therefore, reduce fruit storage life (McDonald & Harman 1982). Ethylene partial pressures as low as 3 mPa have since been shown to have a significant softening effect on kiwifruit (Jeffery & Banks 1996).

2.2.5 **Light**

Kiwifruit exposed to high light levels during growth have a higher firmness, soluble solids content, fresh weight, and mature earlier than comparable shaded kiwifruit (Snelgar & Hopkirk 1988; Tombesi et al. 1993; Antognozzi

et al. 1995). Antognozzi et al. (1995) suggested that only kiwifruit that intercept a light intensity of $80 \mu\text{mol}/\text{m}^2 \text{ s}$ or higher, during sunny days could be stored for a long time. Kiwifruit that received a lower light intensity did not reach an optimum soluble solids content prior to harvest and softened prematurely in storage. Hopkirk et al. (1990) found that kiwifruit exposed to direct sunlight during growth had a higher calcium concentration and firmness, than fruit from similar positions on the same vine that had been shaded. Fruit exposed to direct light can have a higher surface temperature than shaded fruit which would cause fruit in direct sunlight to transpire at a faster rate (Woods 1990). It seems feasible, therefore, that severely shaded kiwifruit may not develop adequate soluble solids and calcium contents to prevent the whole fruit or localised areas on fruit becoming prematurely soft in storage. Cultural techniques such as pruning and thinning could perhaps be used to manage the crop so that adequate light exposure of kiwifruit can be achieved.

2.2.6 Maturity

Storage life and eating quality of kiwifruit is influenced by maturity at harvest (Kempler et al. 1992). Fruit maturity varies between orchards and seasons (Lallu et al. 1989). Late harvested kiwifruit store better than early harvested kiwifruit. Early harvested kiwifruit usually have a lower soluble solids content and a higher firmness than later harvested kiwifruit, but early harvested fruit soften faster in coolstorage (Beever & Hopkirk 1990; Kempler et al. 1992).

2.2.7 Mechanical damage

One of the side effects of mechanization in production and handling systems of horticultural crops is mechanical damage to the crop during harvesting, transport, grading, and packing. In horticultural products, tissue failure is sometimes 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 (such as impact or

compression) causes a physical change in texture and/or eventual chemical alteration of colour and flavour, and texture (Mohsenin 1986). It is sometimes assumed that kiwifruit do not bruise readily due to their high firmness at the time of harvest and because there are no immediate visible symptoms of physical damage as there are in apples (Finch & Hopkirk 1987). However, quality of kiwifruit can be impaired by a number of different types of mechanical damage.

2.2.7.1 *Impact*

Finch & Hopkirk (1987) found that kiwifruit exposed to physical stress 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 inner core, and water-soaking of the outer cortex. Impact may damage the fruit flesh of kiwifruit and not the skin. Finch & Hopkirk (1987) found that, regardless of kiwifruit firmness, impacted fruit soften at the point of impact (drop heights > 0.1 m). In fruit held at 20°C, this led to the whole fruit softening subsequently more quickly than non-impacted fruit, an effect which was associated with premature ethylene production. The sooner after harvest fruit were impacted and the larger the impact energy, the greater was the damage. Impacted kiwifruit that had softened slowly at 0°C had considerably less damage compared to kiwifruit ripened immediately at 20°C. Sawanobori (1983) reported that impacted kiwifruit held in coolstorage at 0°C had no consistent differences from non-impacted controls. The NZKMB Quality Manual (NZKMB 1996) states that kiwifruit should not to be dropped more than 0.3 m onto a hard surface e.g., onto ground, into wooden bins, or on grading equipment. The type of surface a kiwifruit impacts against can influence its rate of water loss and rate of ethylene production (Mencarelli et al. 1996). Kiwifruit incurred more skin damage per unit area when dropped onto fine sandpaper than onto coarse sandpaper. Impacts to fruit caused the skin tissue to break which enhanced water loss and stimulated ethylene production. The damage

caused by impact led to premature softening of the fruit (Mencarelli et al. 1996).

2.2.7.2 *Compression*

Kiwifruit susceptibility to damage under compression increases with softening (Hopkirk 1985). Compression loads on a kiwifruit surface result in external flattening that may recover once the load is removed (Hopkirk 1985). Such fruit did not exhibit the tissue rupture characteristic of fruit that had been impacted, but did soften prematurely at the point of loading: the damaged tissue became water-soaked. Compression damages kiwifruit and causes ethylene to be prematurely produced at 20°C (compression loads > 9.8 N; Hopkirk & Finch 1989). Water-soaking in compression damaged kiwifruit was more common in softer kiwifruit. Hopkirk & Finch (1989) found that more energy was required to compress equivalent kiwifruit to failure at 0°C than at 20°C, possibly because the fruit at 0°C would have been firmer as a direct result of temperature and were, therefore, more resistant to the load (cf. firmness-temperature coefficient; Section 2.2.3.1). During storage, packaging materials and individual kiwifruit configuration within packs can lead to compression of kiwifruit (Hopkirk & Finch 1989). Compression damage to kiwifruit within packs is due to fruit contact with packaging or other fruit (Hopkirk & Finch 1989). The patterns of soft patches found in tri-packs indicates that compression damage can be a problem in current packaging systems (Banks et al. 1992).

2.2.7.3 *Vibration*

Vibration of crops during handling results in loss of fruit quality (Mohsenin 1986). The intensity and duration of vibration determines the severity of damage. For fruit in bins, vibration damage depends on the magnitude of [acceleration](#) in fruit in the upper layers of a bin where most will occur (Mohsenin 1986). Extent of damage can depend on factors such as depth of fruit in bin, tightness of fill, type of suspension system of truck, and evenness of the road surface (Mohsenin 1986). Apples in the top of a bulk

bin can receive 30 times the level of vibration of those at the bin's base (Pang et al. 1995, 1996). Pang et al. (1995) identified that speed of bin transportation and uneven road surfaces can enhance the vibration levels in bins. Well trained and careful drivers could significantly reduce the level of fruit vibration. Kiwifruit also can have a loss of fruit quality due to vibration damage (Mencarelli et al. 1996; G. Finch pers. comm.). Vibration damage can cause localised premature softening of kiwifruit tissue. In a study by Mencarelli et al. (1996), where kiwifruit were vibrated against wood, there was a loss of trichomes and damage to the fruit skin. The damaged area on the kiwifruit had enhanced water loss, premature ethylene production, and rapid localised softening.

2.2.7.4 *Grading equipment*

Bollen & Dela Rue (1990) identified potentially damaging impacts to kiwifruit through the postharvest system. In most kiwifruit packhouses, bins of kiwifruit were dry dumped onto a feed conveyer before being brushed. Kiwifruit then passed over sorting tables and a singulator before being sized. Kiwifruit were usually sized by weight or in some packhouses by an optical sizer. Fruit were then transferred to packing tables, many of which were semi-automatic, in which the empty single layer trays were fed out under the fruit "out-feed" belt. Kiwifruit may be exposed to a series of impacts by handling machinery. An instrumented sphere showed that there were higher impacts for fruit impacting onto steel lane dividers, than when kiwifruit fell onto the singulator rollers. The inverting bin tips and the singulator transfer showed the biggest potential for impacts resulting in bruising.

A study by Banks et al. (1992) indicated that the handling operation at harvest resulted in an increased incidence of soft patches in kiwifruit after 13 weeks storage at 0°C and a simulated week's shelf-life treatment at 20°C. Massantini et al. (1995) found that brushes used when grading kiwifruit to remove trichomes caused small surface wounds in kiwifruit that stimulated ethylene evolution, which led to accelerated ripening. Temperature at which these fruit were kept after brushing was not stated.

2.2.7.5 *Packaging*

Packaging may expose kiwifruit to bruising during storage (Hopkirk 1990). Bruised fruit can have water-soaking, premature softening of localised areas, and premature ethylene production (Hopkirk 1990). After harvest packed trays of kiwifruit are stacked onto pallets in columns. Columns of trays are held rigidly on a pallet by several horizontal and vertical polypropylene straps (NZKMB 1996). Kiwifruit may develop external flattening or creasing, resulting from them being subjected to sustained pressure in a bin or tray (NZKMB 1996). In principle, the packaging is designed to avoid loading on the fruit. However, in storage, trays may come out of alignment causing the heel of one tray to sit within the tray beneath. This causes kiwifruit to take the load of the tray above and become compressed (Hopkirk 1985). Individual kiwifruit in single layer trays that were not packed lying flat would also be compressed by the tray above. Similarly, kiwifruit that do not sit evenly in bulk packs may become compressed when the pack lid is closed (Hopkirk 1985). There has been no work on the level of compressive force required to cause abnormal patterns of softening behaviour of kiwifruit once they are put into long term coolstorage.

2.2.8 **Mineral composition**

For kiwifruit to be of high quality at harvest and after storage, they require an adequate supply of mineral nutrients. Mineral nutrients are required in many physiological processes within the fruit. Without an adequate supply, the storage potential of fruits can be reduced (Sharples 1980).

2.2.8.1 *Calcium*

Calcium has an important role in the biological processes occurring within fruits (Poovaiah 1988). The loss of calcium from the middle lamella makes a major contribution to fruit softening (Stow 1993). Calcium is an important component of pectin strength and thus the amount of contact the middle lamella maintains between cell walls (Dematry et al. 1984; Ferguson 1984). Calcium has an important influence on membrane stability and its

susceptibility to breakdown (Kirkby & Pilbeam 1984). The strength of cell walls, and consequently the firmness of the kiwifruit flesh, is partly related to the amount of calcium in the cell walls (Harker et al. 1990). Glenn (1987) found that calcium treated apples had greater middle lamella strength than control fruit. Considerably less cell wall degradation had taken place in the calcium treated fruit than in the control fruit. A lack of calcium in a number of pipfruit crops results in premature fruit softening and loss of quality relative to fruit with adequate levels (Ferguson 1984). It seems feasible that a similar situation could occur in kiwifruit: kiwifruit with low calcium concentration may be more likely to soften prematurely during long term coolstorage than fruit with higher calcium status.

Each season some lines of kiwifruit prematurely soften for reasons still to be identified (Harker et al. 1990; Smith et al. 1991). Calcium may have a role to play in reducing the rate of softening of such fruit. On the other hand, calcium concentration in kiwifruit is high, being 8 and 2 fold higher than apple and grape, respectively (Ferguson 1980). Despite this high level of calcium relative to other crops, individual kiwifruit within a population could have a low calcium concentration relative to other kiwifruit. These fruit may then develop storage disorders due to a deficiency. However, according to Smith et al. (1991) no reported calcium deficiency has been found in the crop. Some trials have shown that postharvest calcium dips results in kiwifruit with a reduced softening rate, yet not always is a consistent relationship between calcium levels and firmness found (Hopkirk et al. 1990). There is divergent opinion on the possibility of a link between calcium concentration in kiwifruit and fruit softening, ranging from the view that there is no association (Clark & Smith 1988; Harker et al. 1990; Hopkirk et al. 1990; Clark & Smith 1991; Smith et al. 1991), uncertain of what the association might be (Harker et al. 1990), to strong support for there being one (Prasad & Spiers 1992; Resnizky & Sive 1993; Tagliavini et al. 1995; Gerasopoulos et al. 1996). It has been suggested that no association was found in some trials because kiwifruit were assessed prematurely (Pyke et al. 1996): fruit were still at a high

firmness and had not reached their final softening phase when treatment differences may have become evident. None of the studies considered the relationship of calcium with disorders such as LTB and soft patches, only whole fruit softening was examined.

It is thought that calcium accumulation into kiwifruit occurs mainly as a result of water flow via the xylem into fruit (Ferguson 1980; Kirkby & Pilbeam 1984; Clark & Smith 1988; Kotze & de Villiers 1989). Calcium accumulation into kiwifruit ceases at an early stage in fruit development, probably around the time when cell division ends (Ferguson 1980). Calcium concentrations are highest in the skin and seeds, followed by the core; the flesh (cortex) is low in calcium concentration relative to the other parts of the fruit (Ferguson 1980). Calcium concentrations in kiwifruit decrease from the basal to distal end of the fruit, reflecting vascular unloading of calcium.

In apples, the quantity of calcium taken up by roots and then transported to shoots and leaves is closely related to the rate at which plants transpire (Stebbins & Dewey 1972). Kiwifruit leaves have a higher transpiration rate than fruit and also a higher calcium concentration relative to fruit (Ferguson 1980).

Calcium accumulation in grapes was enhanced in proportion to the increase in the rate of transpiration achieved by application of an olive oil and sodium carbonate (Na_2CO_3) emulsion (During & Oggionni 1986). Oil is used commercially to facilitate the drying of grapes in many countries as its use increases the rate of water loss from fruit (Grncarevic & Radler 1971). The cuticular wax on grapes is the main barrier to water evaporation from the fruit (Grncarevic & Radler 1971). The cuticular wax is made up of a series of overlapping platelets which reduce the rate of water vapour movement out of the fruit. Oil applied to the grape surface is thought to facilitate the movement of water vapour between the wax platelets and out of the fruit (Possingham 1972). Drying oils are used to enhance water movement out of grapes for the commercial production of dried table grapes. Drying oils consist mainly of ethyl esters of fatty acids of which

ethyl oleate was the most effective (Ponting & McBean 1970). It may, therefore, be possible to increase kiwifruit permeance to water vapour by application of oils containing ethyl oleate. Enhanced fruit permeance to water vapour, through its effects on transpiration and xylem uptake, could lead to an increase in the calcium concentration in fruit and thereby improve kiwifruit quality. In addition, this proposition may explain why kiwifruit exposed to sunlight during their development have a higher calcium concentration (and firmness after long term coolstorage) compared to equivalent shaded kiwifruit (Hopkirk et al. 1990; Tombesi et al. 1993): such exposure would increase fruit transpiration.

Direct application of calcium salts to the kiwifruit surface applied as dips have resulted in kiwifruit that had a higher firmness than controls (Hopkirk et al. 1990; Prasad & Spiers 1992). Application of calcium to fruit before harvest resulted in enhanced coolstorage and shelf-life of sprayed fruit relative to controls (Gerasopoulos et al. 1996). The salt calcium chloride (CaCl_2) is mostly used when dipping or spraying fruit before or after harvest (Harker et al. 1990; Hopkirk et al. 1990; Prasad & Spiers 1992; Gerasopoulos et al. 1996) although, calcium nitrate ($\text{Ca}(\text{NO}_3)_2$) has also been used (Harker et al. 1990). Dipping and spraying solutions used have ranged from 0.5 to 5% CaCl_2 , and have in some cases been applied several times during fruit development. Skin damage such as pitting has been observed on kiwifruit after application of CaCl_2 and $\text{Ca}(\text{NO}_3)_2$ at some levels (Harker et al. 1990; Hopkirk et al. 1990), and severity of damage varied between orchard sites (Prasad & Spiers 1992). Dipping of harvested kiwifruit caused severe damage to skin when using solutions at 5%, whereas 2.5% caused only occasional damage to kiwifruit (Hopkirk et al. 1990; Brohier & Dooley 1986 cited in Prasad & Spiers 1992). However, Prasad & Spiers (1992) reported no skin damage on postharvest dipped kiwifruit using 5% CaCl_2 . Hopkirk et al. (1990) and Harker et al. (1990) reported that 3% CaCl_2 improved firmness in kiwifruit equivalent to an effect achieved using higher concentrations before harvest. Unfortunately, spraying 0.5 and 1.0% calcium solutions to fruit has been reported to result in skin damage with

no improvement in kiwifruit firmness (Harker et al. 1990). However, Gerasopoulos et al. (1996) sprayed preharvest kiwifruit with 0.375 to 1.5% CaCl_2 up to 3 times which enhanced calcium content and delayed fruit rate of softening at 20 and 0°C relative to unsprayed kiwifruit. It, therefore, seems likely that a preharvest spray treatment of kiwifruit that enhances fruit calcium concentration would result in fruit that have a higher firmness relative to unsprayed fruit after long term coolstorage at 0°C.

2.2.8.2 *Phosphorus*

Most concerns with phosphorus nutrition of fruit is in relation to a lack of phosphate, rather than an excess of it (Priestley 1980). Apple yield, fruit size, and colour is improved with the addition of phosphate fertilizer to the soil (Olivier et al. 1994; Wooldridge & Olivier 1995). However, Wooldridge & Olivier (1990) reported that an excess of phosphate can reduce the storage quality of apples. Applications of phosphate to soils surrounding apple trees have increased the incidence of bitter bit, and lowered leaf calcium and potassium levels (Olivier et al. 1994). Apple trees in soils with low levels of phosphorus, relative to those in soils with high levels, produced fruit with a higher total soluble solids content and firmness, with a reduced incidence of bitter pit, superficial scald, and rots (Kotze et al. 1989). It is feasible that high phosphate levels may also be associated with storage disorders in kiwifruit, but this has not been investigated.

2.3 EVALUATION OF KIWIFRUIT SOFTENING

The New Zealand kiwifruit industry standard instrument for measuring firmness is the penetrometer, fitted with a 7.9 mm diameter plunger (NZKMB 1996). The Effegi fruit tester (penetrometer) is based on the Magness-Taylor fruit pressure tester (Abbott et al. 1976). The penetrometer plunger is attached to a calibrated spring with a dial needle graduated in pounds and kilograms force (1 kgf = 9.8 N). A piece of skin is peeled from a fruit then the tip of the plunger is pressed into the fruit to a constant depth (11.0 mm) marked on the plunger, and the penetrating force is read on the

dial. Being manually operated, the instrument readings have variable accuracy depending on the operator (Voisey 1977). The faster the penetration of the probe, the higher the firmness reading. More uniform measurements have been obtained when using the instrument mounted in a drill press (Bourne 1979; Harker et al. 1996). The standard error of firmness readings obtained with a penetrometer on kiwifruit initially increases as fruit softens (Studman 1995), but decreases again as all fruit in the population reach very low levels of firmness; variations are minor compared to the total drop in firmness for a fruit between harvest and by the time it is ripe to eat (Harker et al. 1996). The penetrometer is used commercially in New Zealand to make judgements about kiwifruit quality, and acceptance for export when fruit are approaching 10 N firmness (NZKMB 1996). A more objective instrument is required for making more accurate measurements of soft kiwifruit. At present, there does not appear to be an alternative instrument with commercial potential that is more accurate than the penetrometer (Hopkirk et al. 1996).

2.4 LOSS OF FRUIT QUALITY DURING COOLSTORAGE

2.4.1 Soft patches

The NZKMB defines a soft patch as a localised area on kiwifruit below the minimum acceptable firmness (measured by penetrometer) for the relevant time period (from September onwards, the threshold is 10 N), for kiwifruit tested at between 0 and 5°C (NZKMB 1996). Soft patches occur when the localised pericarp tissue becomes soft, in advance of the surrounding tissue. These localised soft areas can be found on kiwifruit which have softened close to or are in their final phase of fruit softening (15-20 N; Fig. 2.1). Water-soaking of the softened area sometimes becomes visible through the skin in very ripe kiwifruit (Finch & Hopkirk 1987).

Soft patches have been associated with physical factor(s) such as impacts at grading or compression during storage, or physiological ones such as a low calcium concentration (Finch & Hopkirk 1987; Hopkirk &

Finch 1989; Banks et al. 1992, 1995). Kiwifruit stored at New Zealand ambient temperatures initiate soft patches due to impact or compression, and the rate of development could be due to physiological factor(s) (Finch & Hopkirk 1987; Hopkirk & Finch 1989; Banks et al. 1992). At such ambient temperatures kiwifruit soften more quickly than at 0°C.

Soft patches could be associated with low fruit calcium concentrations (Banks et al. 1995), in a similar way to bitter pit in apples (Ferguson 1984). Bitter pit is prevented by application of calcium sprays to apples; such sprays enhance fruit calcium concentration. Given that dips and sprays of calcium salts enhance kiwifruit calcium concentration (Harker et al. 1990; Prasad & Spiers 1992; Resnizky & Sive 1993; Tagliavini et al. 1995; Gerasopoulos et al. 1996), then application of preharvest calcium salts to fruit could be tested as a potential means to reduce the incidence of soft patches.

2.4.2 Low temperature breakdown

Effects of temperature on the storage life of fruits have been extensively researched (Fidler et al. 1973; Parkin et al. 1989; Wang 1990; Lallu et al. 1992). Fidler et al. (1973) conceptualised these effects in diagrammatic form (Fig. 2.2). Some fruit have extended storage life as temperature is lowered until the tissue reaches its freezing point (curve A). The lowest temperature at which such fruit could be safely stored would be c. -1 to 0°C. However, for some crops this would be too low because it would cause chilling injury. Tropical or sub-tropical fruit exposed to low temperature often develop injuries due to disruption in normal metabolic function (Fidler et al. 1973; Parkin et al. 1989; Wang 1990). For many tropical and sub-tropical fruit this occurs when fruit is exposed to temperature below 10°C. Curves in Fig. 2.2 show how sensitive (B) and very sensitive (C) fruit storage life peaks and then decreases as temperatures decreases. The appearance of injury is conditional on time of exposure and temperature. The time-temperature relationship differs between crops and cultivars. A temperature of 0°C does not result in freezing of kiwifruit tissue (Wright &

Heatherbell 1967). At present, it is not certain if kiwifruit are susceptible to chilling injury, though this possibility has recently been suggested (Lallu et al. 1992). If this was so, there may be a time-temperature relationship for storage life of kiwifruit similar to curve B (Fig. 2.2). In this case, prolonged storage of kiwifruit at 0°C could maintain firmness but cause chilling injury.

Storage of some apple varieties at low temperatures results in the breakdown of their internal tissue (Sharples 1980). Nutritional factor(s) have been shown to be associated with low temperature breakdown (LTB): apples with low calcium status develop a mealy texture, which subsequently breaks down in storage. As with apples there could also be an association between kiwifruit with low calcium concentrations developing LTB in long term coolstorage.

2.5 CONCLUSIONS

Being able to maintain kiwifruit quality over extended periods in coolstore at 0°C enables New Zealand to sustain its competitive edge on rival kiwifruit exporting countries. This requires the control of kiwifruit softening. Kiwifruit softening during long term coolstorage is influenced by preharvest and postharvest factors. The remaining firmness a kiwifruit will have after a period in storage, will depend on: the storage duration (MacRae et al. 1989), the storage temperature (Wright & Heatherbell 1967), ethylene concentrations (McDonald & Harman 1982), light levels during fruit development (Tombesi et al. 1993), its maturity at harvest (Kempler et al. 1992), its mineral composition (Gerasopoulos et al. 1996), and severity of mechanical damage (Finch & Hopkirk 1987). These factors may contribute to the development of whole or localised premature softening (soft patches) on kiwifruit during long term coolstorage. To what extent soft patch development is associated with physiological or physical factor(s) is uncertain. The role that calcium has in preventing the development of soft patches requires further investigation.

This study deals with whether or not premature softening of the

whole fruit or localised areas on the fruit is affected by mechanical damage. It also investigates the association of calcium with fruit softening and examines if low calcium has a causal role in susceptibility of kiwifruit to soft patches.

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2.7 TABLE

Table 2.1 Different growth phases associated with kiwifruit development (Pratt & 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, seed harden and start to colour, first very large respiratory response to ethylene
Period III	12 to 17 weeks	Rapid growth, seeds become dark brown, response to ethylene increases
Period IV	17 to 21 weeks	Very little growth, seeds dark brown, softening starts, soluble solids content start to increase, respiratory response to ethylene rises to a maximum and then decreases
Period V	21 to 23 weeks	Smaller growth increases to approximate fruit size, fruit matures, seeds become dark brown and free in tissue. Respiratory peak induced by ethylene treatments is 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.

2.8 FIGURES

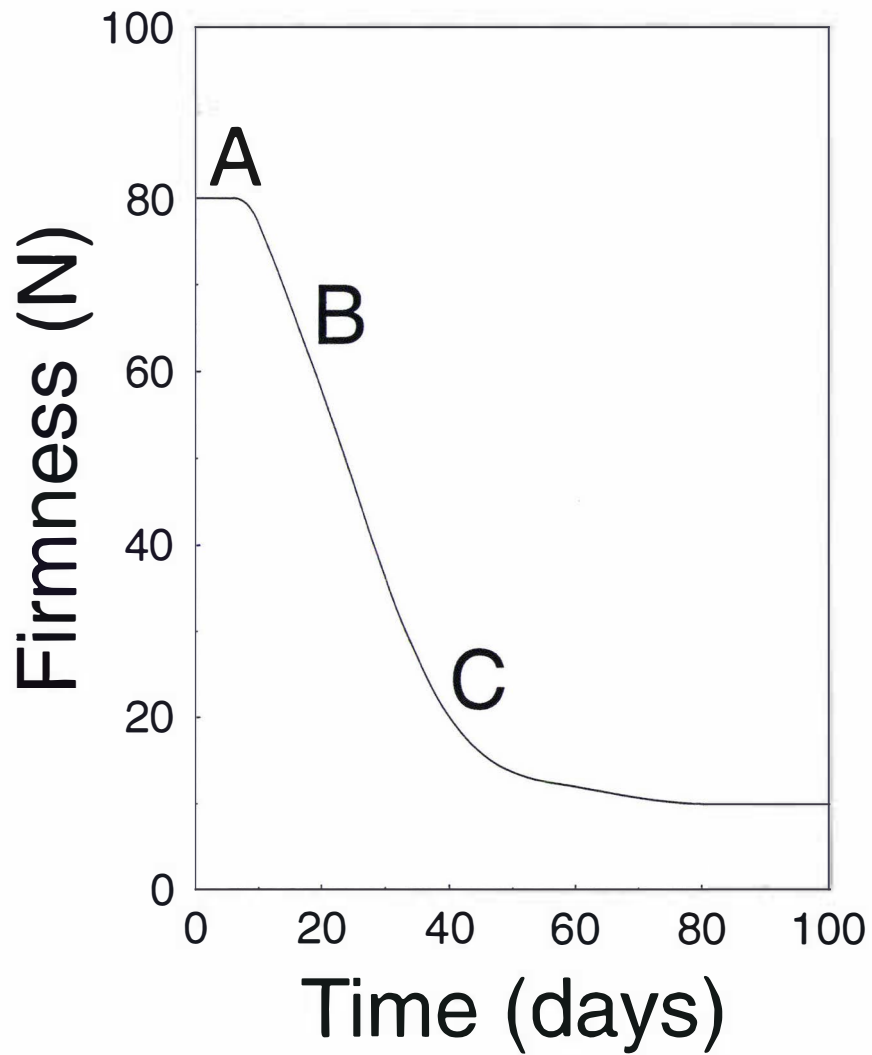


Fig. 2.1 Diagrammatic representation of softening in kiwifruit, where: A, is the lag phase; B, is the period of accelerated softening; and C, is the period of softening deceleration.

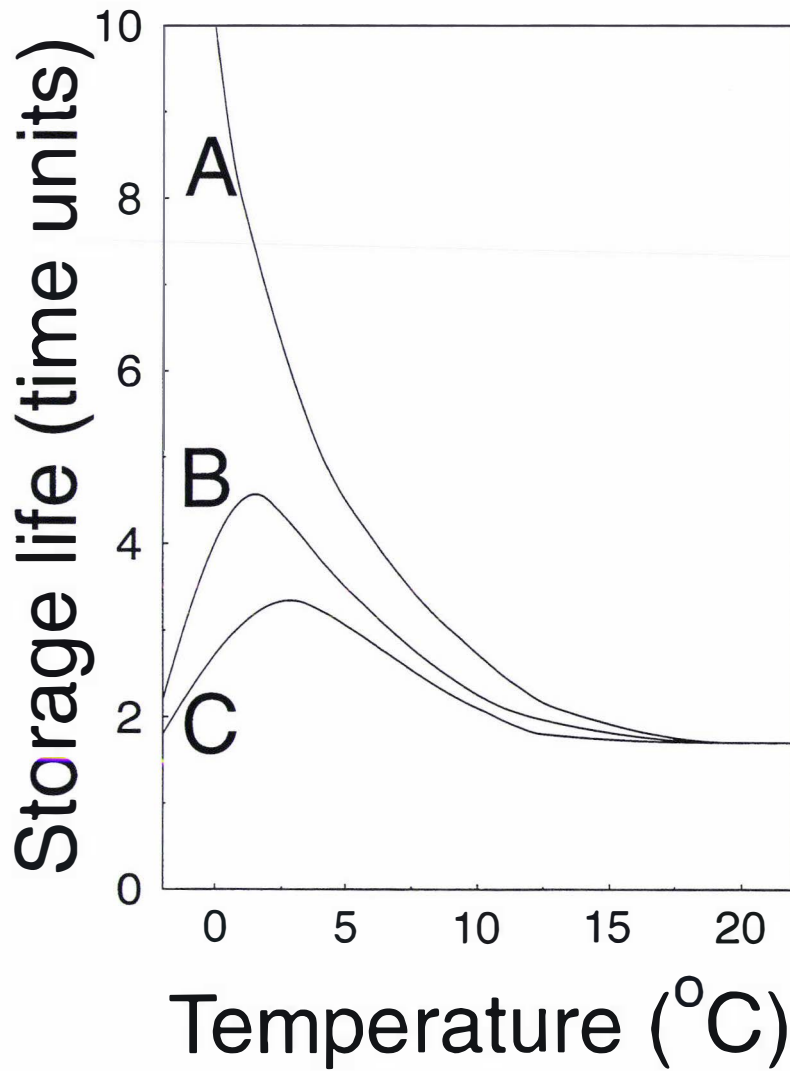


Fig. 2.2 Relationship between temperature and storage life of fruit (Fidler et al. 1973). Curve A, is a fruit that has an extended storage life as temperature is lowered until the tissue freezes. Curves B and C, are for fruit that have differing levels of susceptibility to chilling injury (likely to be of tropical and subtropical in origin, respectively), in which storage life peaks and then decreases as temperature is lowered.

Compression damage in kiwifruit

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3.i Abstract Kiwifruit (*Actinidia deliciosa*) were exposed to a range of compression forces (up to 30 N) of different durations by virtue of their position in a vertical column of fruit. These forces were applied to different fruit immediately after harvest, during transportation, during the first 12 weeks in coolstorage at 0°C, during the subsequent 18 weeks in coolstorage at 0°C, or during a week's simulated shelf-life treatment at 20°C. Generally, whole fruit firmness was not affected by compression, though fruit exposed to very high levels of compression during late coolstorage and simulated shelf-life treatment had reduced firmness. Compression caused soft patches (localised soft areas on the fruit surface) to develop at the point of fruit to fruit contact when examined after 30 weeks in coolstorage, even when that compression occurred immediately after harvest. For fruit given late coolstorage and simulated shelf-life treatments, the size of soft patches at the contact site was proportional to the compression load. Incidence of soft patch rejects (those fruit with more than 100 mm² soft patches) was about twice as great in compressed kiwifruit as in controls, with the greatest difference seen in fruit compressed during simulated shelf-life. These findings suggest that compression should be avoided throughout all phases of the postharvest handling operation, particularly once fruit have softened through ripening. Fruit without soft patches had a higher level of calcium than soft patch affected fruit. Therefore, fruit may be particularly at risk of development of soft patches if they have low calcium status.

3.ii Keywords kiwifruit; *Actinidia deliciosa*; compression; firmness; soft patch; coolstorage; calcium

3.1 INTRODUCTION

Kiwifruit (*Actinidia deliciosa* (A.Chev) C.F. Liang et A.R. Ferguson 'Hayward') have a high firmness at harvest and yet are still prone to injury caused by compression forces occurring during postharvest handling; this can cause fruit to ripen prematurely (Hopkirk & Finch 1989). Compression forces acting on kiwifruit caused external flattening of fruit, water-soaking of the outer cortex, a soft spot (or *soft patch*) at the point of compression, and premature ethylene production in fruit stored at ambient temperature (Hopkirk 1985; Hopkirk & Finch 1989). The type and extent of compression damage symptoms depended on firmness, temperature, and force experienced by fruit. Fruit at the bottom of 'tri-packs' (jumble packs c. 3 fruit deep) have been reported to develop twice the incidence of soft patches of those in the top layer, possibly due to compression from the fruit above (Banks et al. 1992). Although compression loads on such fruit must have been small, this indicated a potential role for compression in the development of soft patches on fruit in tri-packs. Given the current trend towards bulk packaging of kiwifruit during storage and transportation, it would be valuable to determine how much effect compression has on quality of localised areas on fruit. In the present work, we sought to confirm how much compression contributed to the development of soft patches or influenced firmness in kiwifruit after long term coolstorage.

Blueberries treated with different calcium chloride (CaCl_2) solutions have been shown to resist compression damage in direct proportion to CaCl_2 concentration (Hanson et al. 1993). Banks et al. (1995) found that low calcium status was associated with susceptibility to premature softening of whole kiwifruit as well as with the localised loss of firmness involved in the development of soft patches. Fruit used in the current work were, therefore, analyzed for calcium to determine whether or not it may be linked to fruit susceptibility to soft patch development due to compression forces.

3.2 MATERIALS AND METHODS

3.2.1 Fruit

Fruit were harvested from 8 Bay of Plenty orchards in early May 1992. Fruit of 33 count size (0.107-0.116 kg) were picked randomly over all vines within 1 block for each orchard and placed into pocket packs within single layer trays. Fruit were sampled during the commercial harvest period from commercial properties. All fruit sampled from a given orchard were randomised before allocation of compression treatments. Total fruit number in the experiment was 9412.

3.2.2 Experimental design

Fruit were given 1 of 2 compression treatments; *compression* (pipes full of fruit stored vertically) or *control* (pipes full of fruit stored horizontally). Fruit were held in 1500 mm long, 80 mm diameter, round polyvinylchloride pipe. During the period when fruit were not in compression treatments, they were kept in single layer trays with polyliners, stored in the same conditions as fruit being held in pipes. Compression treatments were applied in factorial combination with the following 5 times of application:

- *AH* (during the 96 h immediately after harvest from the 4 May to 7 May before transportation).
- *DT* (during transportation by truck to Massey University (450 km) on 7 May).
- *EC* (early in coolstorage, 8 May to 31 July (12 weeks) at 0°C).
- *LC* (late in coolstorage, 31 July to 4 December (18 weeks) at 0°C).
- *SL* (during simulated shelf-life, 4 December to 11 December (1 week) at 20°C).

Pipes were cut in half, lengthways, with interlocking flaps at 3 positions at equal distance along the pipe to help hold the 2 sides in constant juxtaposition. One pipe half was first lined lengthways with 50 mm wide strips of bubble plastic (5 mm diameter bubbles) to prevent lateral

movement of individual fruit out of alignment. All 33 fruit from a tray were uniformly placed flat side by flat side on top of the bubble plastic starting from 1 end of the pipe half (Fig. 3.1). Two strips of bubble plastic were placed over the fruit, the matching pipe half was attached, ends were capped and pipes were taped to hold both sides rigidly together. During each of the storage treatment periods, compression pipes were secured vertically in a frame whilst control pipes were maintained horizontal in the same environment. Fruit positions within compression treatments were identified by number (1 - 33 from the bottom to top). Polyliners were placed into all trays for the EC and LC storage periods. For each storage treatment, 4 pipes were stored vertically (compression) and 3 pipes horizontally (control) for every orchard line. Upon fruit removal from pipes into trays, contact sites between fruit were gently marked with a felt-tipped, water-based marker pen. Theoretically, control fruit had no force exerted on them. However, trichomes on fruit became flattened by the contact between adjacent fruit due to the initial force when loading fruit into pipes and minor movement during handling. This was how the contact site on control fruit was located.

3.2.3 Assessment

At harvest, a random sample of 33 fruit from each orchard line had firmness and soluble solids contents measured using an Effegi penetrometer (0-118 N with a 7.9 mm diameter head, mounted in a drill press), and an Atago hand-held refractometer (0 to 20%) at ambient temperature (firmness ranged from 95 to 82 N and soluble solids content from 7.0 to 8.2%). Firmness measurements were made at the fruit surface mid-way along the longitudinal axis at a site where the skin tissue had been removed.

After 30 weeks, all fruit except SL treatment fruit were assessed when the average firmness had reached c. 10 N. Fruit were assessed immediately after removal from coolstorage, except for SL fruit. The SL fruit were assessed after 31 weeks total storage due to an additional 1 week storage at 20°C. The fruit surface to be assessed was classified in 3 ways:

contact site (the central area on the flat side of fruit which had been touching adjacent fruit due to positioning in pipes), fruit surface *outside the contact site*, and, combining these 2, over the *total area of the fruit*. Soft patches were identified by feeling the entire fruit surface without visual examination. Their perimeters were then marked and surface areas (mm^2) quantified using a transparency marked with circles of different areas. Soft patches were identified as being either at the contact site (located between pen marks on flat side of fruit) or outside of it. Patches that overlapped both areas were scored as being present within the contact site.

For each of the 3 fruit surface categories, areas of all individual patches were summed to provide an aggregated value per fruit. A fruit was classified as a reject for a given fruit surface category if the summed soft patch area, A^{sp} , exceeded 100 mm^2 . Firmness was measured using an Effegi penetrometer (0-39 N, set up as above) on an area from which the skin tissue had been removed. One firmness reading per fruit was taken on the pared side of a fruit, 90° from the area in contact with other fruit, when viewed down the longitudinal axis. Firmness readings were made on tissue devoid of soft patches.

3.2.4 Mineral analysis

Calcium content was determined on the 4 trays of compression treatment fruit from the AH, 96 h storage treatment only, for 6 orchard lines. Each sample of 132 fruit was divided into 3 groups according to fruit position within a pipe giving *bottom* (fruit positions 1 to 10), *middle* (fruit positions 11 to 20), and *top* (fruit positions 21 to 33) groups. Within each group, fruit were divided into 3 soft patch categories according to location of soft patches on the fruit: *healthy* (no soft patches on fruit at all); SP_{contact} (soft patches present on fruit at the contact site, regardless of their presence elsewhere), and SP_{outside} (soft patches on fruit, but not at the contact site).

For a given orchard line, all fruit within each of the 9 sub-samples thus formed, were combined and homogenised. Approximately 0.3 g of homogenate was analyzed on a fresh weight basis according to the method

described in Section 6.2.5.

3.2.5 Data analysis

Data were subjected to analysis of variance using the general linear models procedure of SAS (SAS Institute 1988) to examine effects of compression, storage period, fruit positions within pipes, and orchard line with tests for appropriate interactions and orthogonal contrasts. Analysis of proportions was carried out using the frequency procedure in SAS (SAS Institute 1988). All means presented were averaged over all treatments unless otherwise stated.

3.3 RESULTS

3.3.1 Compression effects on area of soft patches

Soft patches due to compression were usually associated with water-soaking at the contact site. Averaged across storage treatments and orchard lines, mean A^{sp} and percentage rejects of compressed fruit were 4 times greater at the contact site and 2 times bigger for the entire fruit surface compared to control fruit (Table 3.1). However, compression treated fruit had a smaller mean area and fewer rejects than controls for soft patches occurring on fruit surface outside the contact site (Table 3.1).

3.3.2 Storage effects on area of soft patches

For all storage treatments, compression resulted in greater A^{sp} at the contact site and over the total fruit surface compared to controls (Table 3.2). Of all storage treatments, SL fruit had the highest mean A^{sp} for the contact site, and total fruit surface (both contrasts $P < 0.0001$). Compressed fruit had twice the percentage of fruit rejected for soft patches at the contact site of those from controls for the first 4 storage treatments, whilst they had 6 times as high a percentage for SL (25% compared to 4% for controls; data not shown). Fruit given the LC treatment had the lowest mean A^{sp} for total fruit area. Mean A^{sp} outside the contact site on SL fruit was greatest in control

fruit; the other storage treatments had similar values (Table 3.2).

3.3.3 Variation in area of soft patches under different compression loads

For LC and SL storage treatments, fruit at different pipe positions differed in mean A^{sp} at the contact site between compression and control pipes (Figs. 3.2A,B; $P < 0.01$ and 0.0001 , respectively). The value for A^{sp} outside the contact site did not differ for different pipe positions between compression and control pipes. A^{sp} for the total fruit surface for fruit at different pipe positions differed between compression and control pipes for LC and SL storage treatments (data not shown; $P < 0.05$ and 0.01 , respectively).

Variation in A^{sp} between fruit at different pipe positions found in compression pipes for LC and SL was not seen in equivalent fruit stored in control pipes. Thus compressed fruit from the lowest pipe positions had higher A^{sp} than those from comparable positions in control pipes.

3.3.4 Variation in area of soft patches between orchard lines

Average value for A^{sp} occurring at the contact site and on the whole fruit surface differed between orchard lines (30 to 76 mm², respectively; $P < 0.01$; SED = 11 and 43 to 118, respectively; $P < 0.0001$; SED = 15).

Similarly, percentage rejects due to soft patches at the contact site and total fruit area varied amongst orchard lines (7 to 17%, respectively; $P < 0.001$ and 10 to 22%, respectively; $P < 0.001$). Soft patches on the fruit outside the contact site varied between orchard lines ranging in mean area from 12 to 61 mm², respectively ($P < 0.0001$; SED = 9) and in percentage rejects from 10 to 15% ($P < 0.001$).

3.3.5 Firmness

With all storage treatments fruit exposed to compression always had greater contact areas between fruit than those in pipes stored horizontally with no compression. Overall, after 30 weeks storage and an additional 1 week for SL fruit there was no mean firmness difference between the compressed and

control fruit, with average firmness being $9.4 \text{ N} \pm 0.12$ (80 df (experimental unit = 1 tray of 33 fruit)).

Firmness differed amongst storage treatments ($P < 0.0001$), but the size of the SED (0.39) indicated that all storage treatments had a similar average firmness, except for SL fruit (4.5 N) which was less than half the firmness of the other treatments (ranging from 10.2 to 10.9 N).

Fruit at similar pipe positions differed in their average firmness between compression treatments ($P < 0.05$) for LC and SL storage treatments. This difference was mainly due to compression fruit at the lowest pipe positions having a reduced firmness compared to equivalent fruit in control pipes (Fig. 3.3A,B, respectively). On average, firmness after 30 weeks coolstorage differed between orchard lines ($P < 0.0001$), ranging from 6.8 to 12.2 N (SED = 0.49).

Initial firmness of orchard lines at harvest had no correlation with any variables measured on fruit after 30 weeks storage (final firmness, calcium, A^{sp} ; data not shown). However, after 30 weeks storage overall mean firmness levels for different orchard lines were negatively correlated with mean A^{sp} occurring on the fruit surface outside of the contact site and over the total fruit surface (Fig. 3.4A,B, respectively). There was only a slight (non-significant) decrease in A^{sp} at the contact site with increasing firmness of orchard lines of fruit (data not shown). Mean A^{sp} at the contact site for compression fruit increased as firmness of corresponding control fruit decreased for different orchard lines (Fig. 3.5).

3.3.6 Calcium

SP_{outside} fruit contained less calcium than the SP_{contact} and healthy fruit (5.9, 6.5, and 7.3 mmol/kg, respectively; $P < 0.05$; SED = 0.78). Calcium contents did not differ amongst the 3 fruit positional pipe groupings of bottom, middle, and top, and there were no interactions of these with soft patch categories.

3.4 DISCUSSION

3.4.1 Compression

Given that compressed fruit in this study on average had 4 times the amount of soft patch damage compared to control fruit it is clear that compression has the potential to substantially affect quality of kiwifruit. From harvest to retail sale, kiwifruit are susceptible to develop soft patches due to compression and it appears that fruit become more vulnerable as their firmness decreases. The slope of the regression line in Fig. 3.2B indicates that an additional 130 mm² of A^{sp} could result from piling fruit 10 deep for a week at 20°C. Whilst this slope is not particularly steep, it indicates that a depth of only 5 or 6 fruit may be required to render a fruit a reject using the threshold soft patch area criterion of 100 mm². Low fruit firmness (10 N), coupled with exposure to simulated shelf-life temperatures (20°C), appeared to greatly enhance the rate at which soft patches developed in response to compression damage (Table 3.2). This was demonstrated by the greater mean A^{sp} for the SL treatment than the LC storage treatment (Fig. 3.2). It appears that the amount of damage due to compression depends on a number of key factors which influence the initiation and development of soft patches. These factors appear to include: firmness (the softer the fruit, the less resistance to compression force), temperature (warmer flesh would be linked to more rapid deterioration of flesh tissue), time (longer duration would exacerbate fruit stress), and size of the compression force (greater force would lead to more extensive damage).

For kiwifruit exposed to compression at simulated shelf-life temperature, there was a slight reduction in firmness and a marked increase in A^{sp} compared to controls (Fig. 3.3; Table 3.2). As the kiwifruit ripened, fruit were more susceptible to compression damage and had greater soft patch development under compression; a similar observation was made by Hopkirk (1985). Increases in temperature have been shown to increase the rate of fruit softening through ripening, and also, to cause a physical drop in firmness to an extent that depends on the fruit's firmness-temperature

coefficient (Jeffery & Banks 1994). Kiwifruit with a firmness of 20 N may decrease in firmness by 35% within 24 h of removal from coolstorage to 20°C. Presumably, this direct effect of temperature could substantially increase fruit susceptibility to compression. This should be of concern to those involved in displaying kiwifruit for retail sale at ambient temperature, as it suggests there is potential for causing soft patches by compression as a result of poor display practices.

Kiwifruit of similar initial firmness were used for the AH and DT storage treatments. AH fruit were compressed for 96 h and had a larger mean soft patch area than DT fruit, compressed for c. 10 h. Therefore, the use of wooden bins to collect kiwifruit in appears not only make fruit vulnerable to compression damage, but the level of damage would be proportional to the length of time fruit are held in bins. The storage of kiwifruit in wooden bins at harvest can initiate the development soft patches, which may later develop into a rejectable size of 100 mm² during coolstorage. However, a soft patch of any size can detract from the overall fruit quality if premature fermentation and development of off-flavours or water-soaking of the soft patch tissue occurs.

The lower percentage of overall rejects from the LC, compared to the AH, DT, and EC storage treatments was probably because LC fruit were assessed immediately after treatment. In contrast, fruit from the earlier 3 storage treatments were stored for a number of weeks in single layer trays after compression treatment. There would, therefore, have been less time for soft patches at the contact site to develop at 0°C on LC fruit than on fruit from the 3 earlier treatments. In fruit in which compression loadings were exaggerated by shocks associated with transportation, as little as 10 h were needed for compression to initiate damage to harvested kiwifruit (cf. DT storage treatment). Once initiated, this damage then developed into soft patches during subsequent coolstorage. Cell walls in freshly harvested kiwifruit may fracture under the influence of a compression force in a similar way to harvested fruit when impacted (Section 4.3.1). Instead of major cell wall fractures, prolonged compression force may cause more

numerous but less visible, smaller cell wall fractures. During subsequent storage, such cell wall fractures could cause the premature initiation of tissue softening and the development of a soft patch.

3.4.2 Control fruit

Overall mean values for total A^{sp} per fruit for control fruit were at least half those of fruit given the compression treatment, indicating that soft patches resulted from physiological causes as well as from physical stresses. Predisposition to such physiological damage could have developed before harvest, which would help to explain the variation in the incidence of soft patches on fruit from different orchard lines.

A^{sp} for the total fruit surface for fruit at different pipe positions in the LC and SL storage treatments differed between compression and control pipes due largely to a difference in A^{sp} at the contact site. Fruit in the compression treatment appeared to have smaller A^{sp} occurring on the fruit surface outside the contact site relative to the equivalent value for control fruit. Under the influence of compression, fruit developed larger soft patches and a greater contact area between adjacent fruit compared to the contact area between control fruit (Fig. 3.1). Therefore, compression treatment fruit had less fruit surface area to be assessed as being outside the contact site than control fruit. Control fruit had a smaller fruit surface inside the contact site on which soft patches could be found. Therefore, any soft patches just outside of the contact site on control fruit would probably have been within the contact site on compressed fruit.

3.4.3 Firmness

Except for SL treatment, none of the compression and storage treatments affected overall mean firmness after storage, showing that compression did not necessarily have an effect on whole fruit softening. This result is similar to that of Hopkirk & Finch (1989) for impact damage of kiwifruit, who found that fruit firmness was unaffected by physical damage at harvest when they were put into long term coolstorage at 0°C after being impacted.

However, compression did have an effect on firmness of fruit across the different pipe positions for the later 2 storage treatments. Average firmness of individual fruit at lower pipe positions was reduced compared to control fruit (Figs. 3.3A,B). Surprisingly, fruit from high pipe positions in the compression pipes (low compression load), appeared to be actually firmer than the no compression fruit at equivalent positions. This might be compared to the result reported by Davie (1992), who found that fruit which had been exposed to mechanical damage associated with grading at harvest, had a slightly higher average firmness than fruit that had no physical handling. It may be that physical stress associated with small compression forces caused an increase in fruit firmness, though there is no clear mechanism by which such an effect might be expected to develop. However, it is also possible that small temperature differentials (unmeasured) between the bulk of the fruit stack in the store and the exposed length of the vertical pipes protruding above the stack were responsible for these differences in firmness. The exposed pipe would have been exposed to greater air flow which may have depressed temperature and thereby slowed the rate of fruit softening (Lallu et al. 1992; Amos et al. 1993).

The orchard line with fruit which remained firmest after being coolstored had the lowest mean A^{sp} (Fig. 3.4). However, given the large number of factors which may affect soft patch development, fruit firmness could only be expected to be a loose indicator of a fruit's susceptibility to development of soft patches. Factors that cause the initiation of soft patches due to physiological factors such as a lack of calcium usually affect the overall rate of fruit softening (Section 6.3.1). However, soft patches initiated due to physical forces at harvest only affect the damaged tissue and not the whole fruit, so the soft patch develops independently of overall fruit softening (Section 4.3.1). The firmness at harvest of these fruit was not a predictor of the line's susceptibility to compression damage.

3.4.4 Calcium

Kiwifruit with soft patches only on areas outside of the contact site (e.g., of physiological origin) were low in fruit calcium. This finding is consistent with the suggestion of Banks et al. (1995) that fruit low in calcium may have a tendency to develop soft patches due to physiological causes. Fruit with soft patches at the contact site had lower calcium concentrations than those of normal fruit without soft patches, though at significantly differing levels. The physical damage resulting from forces acting on fruit may be resisted to an extent that depends on the level of calcium working in combination with other factor(s), since calcium is thought to affect turgor pressure, cell wall strength, and resistance of pectate in the middle lamella to degradation (Glenn 1987; Harker & Hallet 1994).

3.5 CONCLUSIONS

Compression caused physical damage to localised areas on the fruit surface which resulted in soft patches. This damage occurred regardless of whether the compression was applied for 96 h immediately after harvest or during extended periods of coolstorage. The effects were greatest when compression was applied to ripe fruit during a week's shelf-life simulation at 20°C. It appears that kiwifruit can be susceptible to compression damage at any point during the postharvest life of the fruit, though damage due to compression generally becomes manifest as soft patches rather than as a decline in overall fruit firmness. Susceptibility to soft patches and severity of damage were linked inversely to fruit firmness after storage and fruit calcium status, information that indicates some potential strategies for reducing current levels of fruit loss to soft patches. The findings indicate that it would be worthwhile for the kiwifruit industry to consider the influence of compression from harvest through to retail display on the potential for decline in quality related to soft patch development.

3.6 ACKNOWLEDGEMENTS

We thank the New Zealand Kiwifruit Marketing Board for financial support.

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3.8 TABLES

Table 3.1 Mean A^{sp} and percentage rejects (averaged over orchard lines and storage periods) of kiwifruit with and without compression at: (i) contact site between fruit; (ii) fruit surface outside the contact site; and (iii) total area of fruit.

		Compression treatment		SED	P
		Compression	Control		
(i)	A^{sp} (mm ²)	81	19	5	< 0.0001
	Rejects (%)	15	4		< 0.001
(ii)	A^{sp} (mm ²)	22	36	4	< 0.01
	Rejects (%)	5	7		< 0.001
(iii)	A^{sp} (mm ²)	103	55	7	< 0.0001
	Rejects (%)	18	10		< 0.001

Table 3.2 Mean A^{sp} (mm²; averaged over orchard lines with and without compression during storage in pipes) at: (i) contact site between fruit; (ii) remainder of fruit surface; and (iii) total area of kiwifruit.

		Storage treatments					SED	P
A_{sp} (mm ²)		AH	DT	EC	LC	SL		
(i)	Control	19	22	19	6	29	12	< 0.0001
	Compression	55	36	72	45	199		
(ii)	Control	31	25	31	28	67	9	< 0.01
	Compression	23	33	17	11	27		
(iii)	Control	49	46	50	35	96	17	< 0.0001
	Compression	78	69	89	56	226		

Storage treatments were: AH (compression during the 96 h immediately after harvest, before transportation); DT (during transportation by truck to Massey University (450 km)); EC (early in coolstorage, initial compression for first 12 weeks at 0°C); LC (late in coolstorage, last 18 weeks at 0°C); and then SL (compression only during simulated shelf-life for 1 week at 20°C). SED is for comparing any pair of means within the section.

3.9 FIGURES

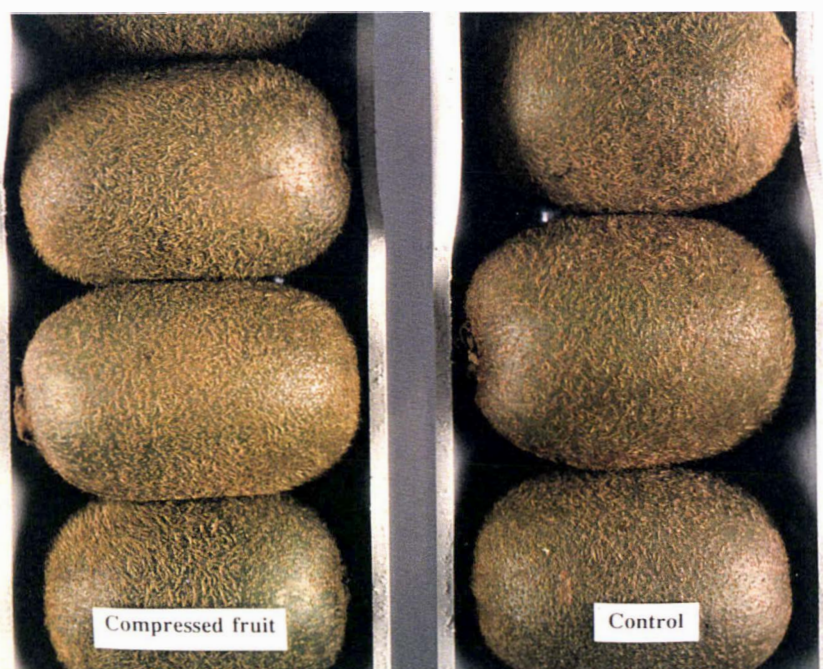


Fig. 3.1 Experimental arrangement of fruit placed in pipes which exposed them to compression for a particular storage period due to the weight of fruit above them. In the 'no compression' treatments, pipes were stored horizontally.

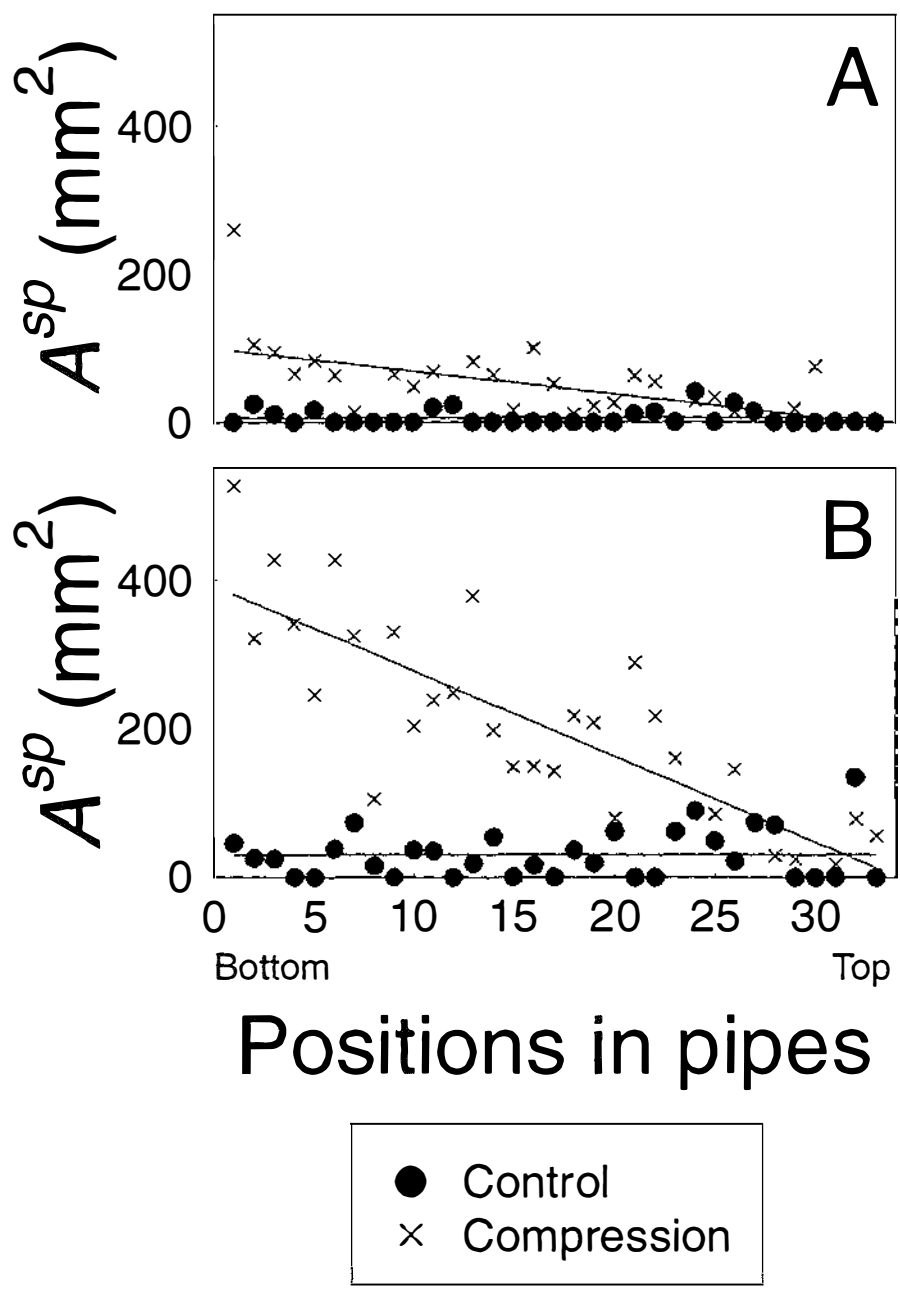


Fig. 3.2 Mean A^{sp} at the contact site of individual fruit at different positions (p) in vertically (compression treatment) and horizontally (control) stored pipes during: **A**, LC (late coolstorage); and **B**, SL (simulated shelf-life) storage periods averaged over orchard lines. Fruit were assessed after a total storage period of 30 weeks at 0°C. Lines fitted to data for the compression treated fruit were: **A**, $A^{sp} = 98 \pm 41.1 - (3.1 \pm 0.75) p$; $r^2 = 0.35$; and **B**, $A^{sp} = 392 \pm 74.9 - (11 \pm 1.4) p$; $r^2 = 0.70$. Symbols represent means of 32 fruit.

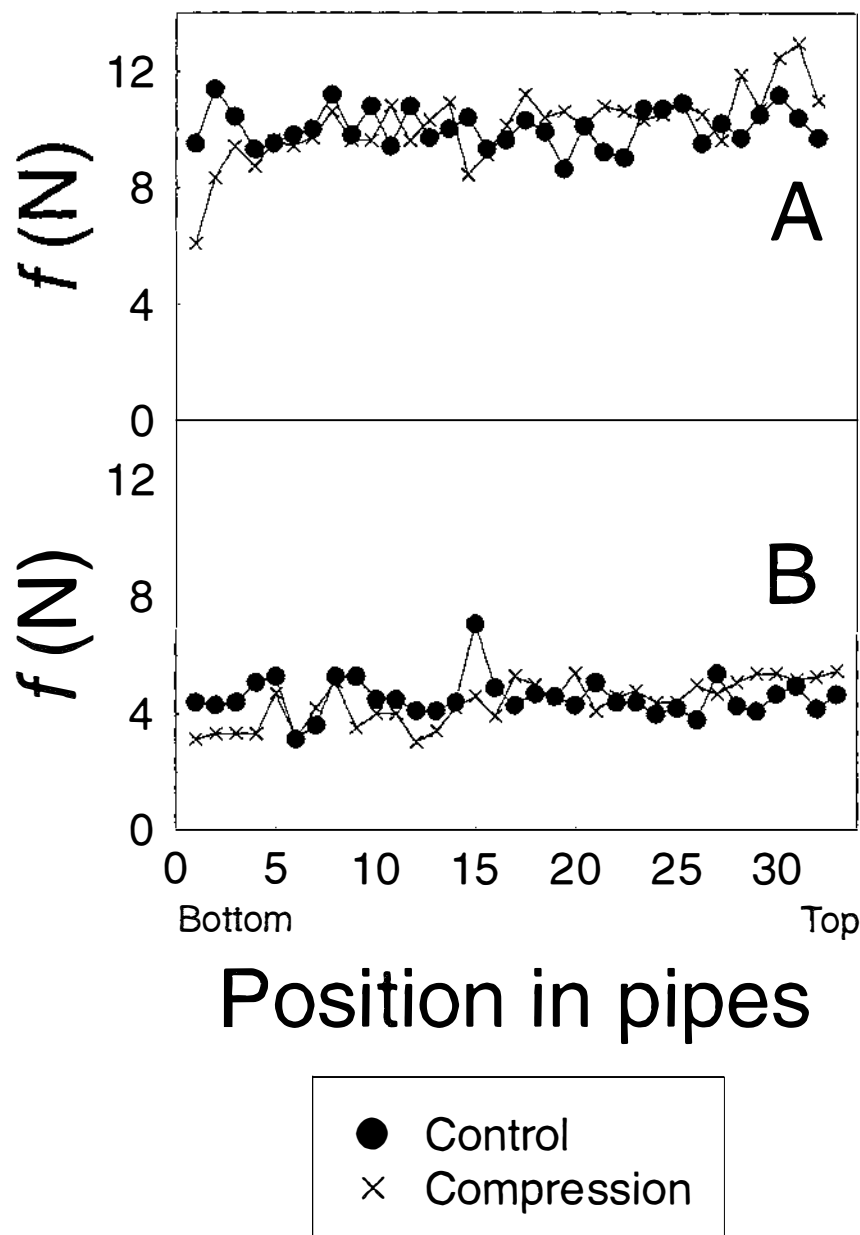


Fig. 3.3 Firmness (f) of individual fruit at different positions in pipes for compression treatments for: A, LC (late coolstorage); and B, SL (simulated shelf-life) storage treatments averaged over orchard lines assessed after a total storage period of 30 weeks at 0°C. Symbols represent means of 32 fruit.

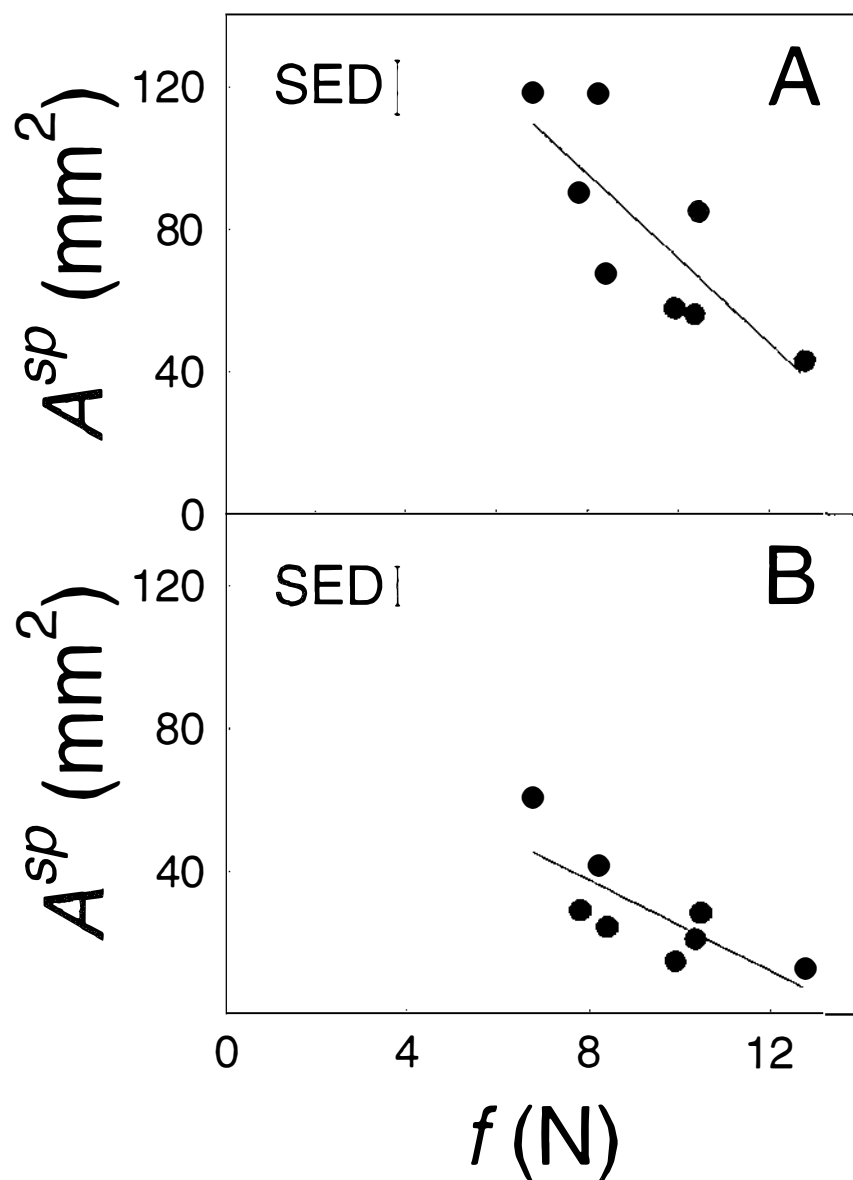


Fig. 3.4 Relationship between A^{sp} of different orchard lines of fruit and their firmness (f) for: **A**, the entire fruit surface; and **B**, the area outside contact site, averaged across compression and storage treatments assessed after a total storage period of 30 weeks at 0°C (fitted equations are $A^{sp} = 190 \pm 18.4 - (12 \pm 3.6) f$; $r^2 = 0.64$ and $A^{sp} = 89 \pm 6.4 - (6 \pm 2.1) f$; $r^2 = 0.61$, respectively). Symbols represent means of 330 fruit.

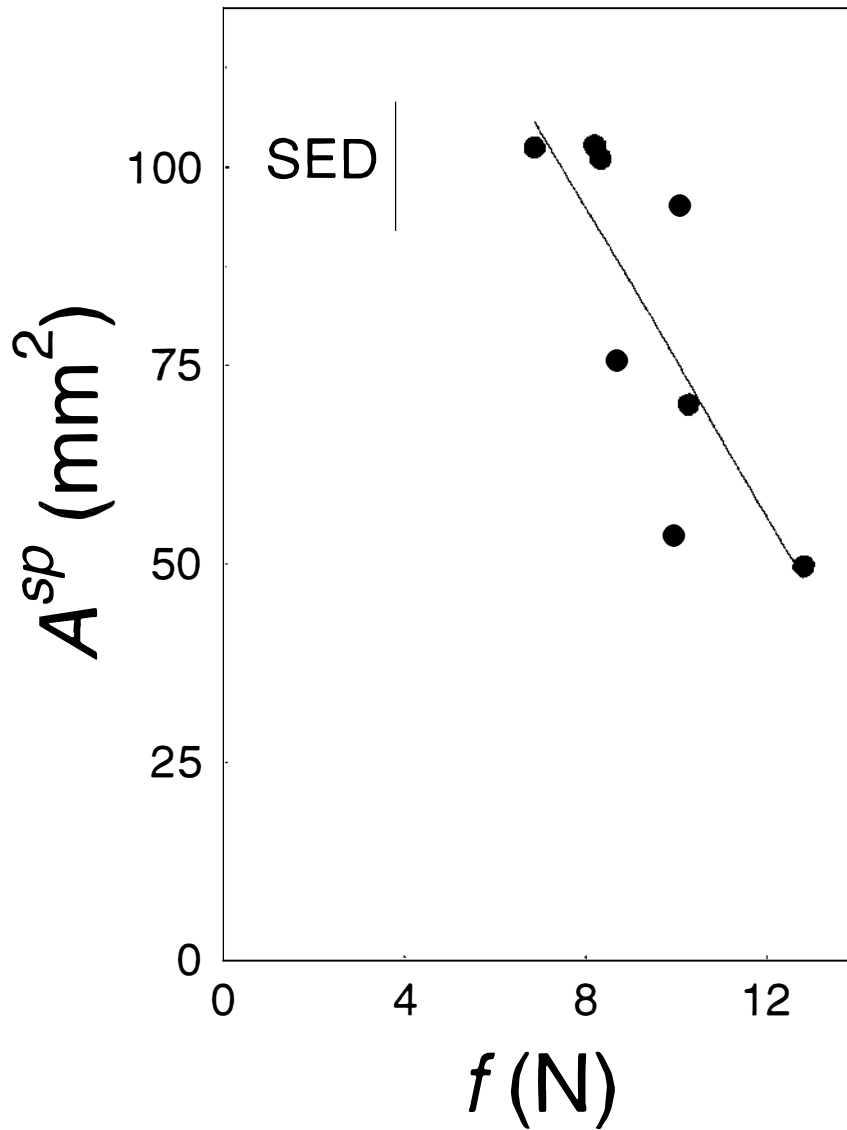


Fig. 3.5 Relationship between mean A^{sp} at the contact site of fruit exposed to compression and firmness (f) of non-compressed controls for orchard lines assessed after a total storage period of 30 weeks at 0°C (fitted equation is $A^{sp} = 173 \pm 14.6 - (10 \pm 3.1)f$; $r^2 = 0.62$). Symbols represent means of 165 fruit.

Impact damage in kiwifruit

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4.i Abstract Two laboratory studies on impact damage investigated the relationship between severity of impact with an indenter of constant mass, on kiwifruit (*Actinidia deliciosa*) at harvest and during storage, on the area of soft patches (localised soft areas) which developed at the impact site after at least 19 weeks storage at 0°C (coolstorage). Rejects due to soft patches greater than 100 mm² at the impact site increased from 0 through 5 to 90% as impacts equivalent to dropping a 0.11 kg kiwifruit from 0 through 0.075 to 1.6 m at harvest (all levels of applied impact had an effect). After coolstorage, fruit given a week's simulated shelf-life at 20°C almost doubled the area of soft patches at the impact site on fruit impacted at harvest and increased percentage of soft patch rejects by almost 33%. For fruit impacted during coolstorage, soft patches at the impact site that developed after storage consistently increased in average size with increasing length of time in storage prior to impact. This corresponded to their decrease in firmness at the time of impact. After coolstorage, non-impacted control fruit had a greater firmness than fruit impacted during coolstorage. Susceptibility to soft patches due to impacts during coolstorage increased with decline in firmness, which has implications for delayed handling of fruit after harvest associated with prolonged bulk storage. Impact had no effect on development of soft patches outside of the impact site on the remaining fruit surface.

Soft patches due to impacts would be likely to have a serious negative effect in consumer perception of kiwifruit quality. Growers and packhouse operators should systematically identify potential opportunities for impact in the postharvest handling system and attempt to eliminate them.

4.ii Keywords kiwifruit; *Actinidia deliciosa*; soft patch; firmness; impact; handling damage; coolstorage

4.1 INTRODUCTION

Kiwifruit (*Actinidia deliciosa* (A.Chev) C.F. Liang et A.R. Ferguson 'Hayward') have a high firmness at harvest and yet are still prone to injury caused by impact forces occurring during postharvest handling (Hopkirk & Finch 1989). Impact is a potential cause of premature ripening in kiwifruit (Finch & Hopkirk 1987; Hopkirk & Finch 1989; Mencarelli et al. 1996). Finch & Hopkirk (1987) recommended that fruit dropped more than 0.1 m should be discarded due to the potential of the impacted fruit to produce ethylene and initiate ripening of other fruit. During the 1994/95 kiwifruit season 5.2 million dollars was lost to the New Zealand kiwifruit industry due to prematurely soft fruit (G. Sampson pers. comm.). After long term storage at 0°C (coolstorage), kiwifruit may be rejected at condition checking prior to export because they are prematurely soft. Fruit can be rejected because the whole fruit firmness value is below the export threshold for the relevant time period (10 N from September onwards; New Zealand Kiwifruit Marketing Board (NZKMB) 1996). Kiwifruit may also have localised areas below the export threshold (often referred to as *soft patches*; NZKMB 1996) on an otherwise healthy fruit with adequate firmness for export.

Finch & Hopkirk (1987), Hopkirk & Finch (1989), and Mencarelli et al. (1996) found that bruising enhanced water loss and stimulated production of ethylene by kiwifruit, especially at high temperatures, which was a potent promoter of fruit softening. Mencarelli et al. (1996) found that impact energy caused superficial injury to the fruit skin and this would then stimulate ethylene production by kiwifruit (Massantini et al. 1995). Impacted tissue on freshly harvested fruit can become water-soaked as fruit soften (Finch & Hopkirk 1987). Kiwifruit were most susceptible to impact damage at harvest, with susceptibility reducing with softening. However, these same studies indicated that effects of impacts on softening of fruit placed immediately in coolstorage were minimal. Finch & Hopkirk (1987) found that visible damage was greatest on kiwifruit impacted soon after harvest, with maximum development of visible symptoms occurring when the fruit softened to less than 10 N.

It has recently been shown (Banks et al. 1992) that, after extended coolstorage, fruit harvested with no mechanical damage had a lower incidence of soft patches than those harvested through the normal handling system. However, there were no differences in the rate of decline in firmness between these groups of fruit, an observation which is consistent with the findings by Finch & Hopkirk (1987). The loss in fruit quality was associated with individual fruit becoming prematurely soft in localised areas of the fruit surface, rather than through an increased rate of whole fruit softening. Impacts associated with harvesting and packhouse handling systems were implicated in these effects. In addition, it is known that severity of soft patch symptoms is influenced by storage temperature, but there are likely to be other preharvest and postharvest factor(s) involved in soft patch development (Lallu et al. 1992). The present study determined the importance of standardised impacts on the storage behaviour and incidence of soft patches on kiwifruit from different orchards. The potential for kiwifruit to become increasingly susceptible to impacts as firmness decreased due to softening during coolstorage was also investigated.

4.2 MATERIALS AND METHODS

4.2.1 Fruit

Fruit were harvested from 8 properties in the Bay of Plenty in early May 1992 (Experiment 1) or from 3 properties in South Auckland in mid May 1993 (Experiment 2). In both experiments fruit were sampled during the commercial harvest period, from commercial orchards. For both experiments, count 33 or 39 size fruit (0.107-0.116 kg and 0.087-0.098 kg, respectively; Experiments 1 and 2, respectively) were taken over a number of vines within 1 block from each orchard and gently placed into single layer trays. Fruit were held at 20°C in trays without polyliners until impacted (Experiment 1) or were placed into coolstorage until being impacted (Experiment 2). After impact, fruit were coolstored again with polyliners put into the trays. All fruit from each orchard were randomised

before allocation to impact treatments.

4.2.2 Experiment 1: effect of impact energy

Fruit were given 1 of 8 treatments, each with a different impact energy from the indenter (a 0.16 kg hockey ball) dropped from a different height: 0 m (control, no impact), 0.05, 0.08, 0.13, 0.22, 0.36, 0.60, and 1.00 m on the 13 May immediately after harvest. Using the following equation (Schoorl & Holt 1981), the corresponding impact energies (E^I , J) were 0, 0.08, 0.12, 0.20, 0.35, 0.57, 0.94, and 1.6 J:

$$E^I = m \cdot g \cdot h^I \quad [4.1]$$

where m was the mass (kg), g was the gravitational constant (m/s^2), and h^I was the drop height (m). For each orchard line, 4 trays of fruit were used and the 8 treatments were replicated 4 times per tray, giving 16 fruit per treatment per orchard line. Every fruit had an identification sticker placed adjacent to the impact site near the middle of the wide and flat side of each fruit. Fruit to be impacted were removed from trays and placed firmly onto a 0.05 m deep bag of flour placed on a flat support. This prevented lateral movement and minimised damage to the opposite side of the fruit during impact, by spreading the load over a large area. A 0.10 m diameter PVC plastic pipe, 1.2 m high was placed vertically over a fruit. The pipe had a series of pairs of holes drilled horizontally through the middle of the pipe at the required treatment heights above the bottom of the pipe. A rod was placed through the appropriate pair of holes to support the indenter, which subsequently fell the required height onto the fruit when the rod was removed quickly. The pipe had three 0.01 m wide and 0.1 m high longitudinal gaps around its base to allow air forced down the pipe by the hockey ball to leave the pipe without building up pressure and decelerating the ball. Trays of impacted fruit were stored at ambient temperature next to a packhouse shed under protected covering for 48 h. Polyliners were then placed into trays, and fruit were then transported to Massey University by

truck on 15 May and placed in coolstorage at 0°C on 16 May. After 19 weeks in coolstorage 2 of the 4 trays per orchard line were assessed immediately on removal. The other 2 trays were given a simulated shelf-life treatment of 1 week at 20°C.

4.2.3 Experiment 2: effect of storage on response to impact

Thirty eight fruit of 38 count were given 1 of 7 treatments which comprised impact with a 0.16 kg hockey ball dropped from a 0.60 m height (0.94 J) at 1 of 6 different dates after harvest: initially prior to storage and subsequently during coolstorage (1, 4, 9, 13, 16, 21, weeks) and a control (no impact to fruit). Firmness was measured on an additional sample of 38 fruit at each of the 6 impact dates.

Thirteen trays from each of 3 orchard lines (used as experimental blocks) were transported to Massey University before any treatments were applied. These were then randomised evenly over 13 single layer cardboard trays containing count 39 plastic moulded pocket packs. All fruit were labelled on a sticker placed adjacent to an intended impact site (centre of the wide, flat side). On 28 May 1993, 1 week after harvest, 1 tray of fruit was assessed for firmness (see below) and fruit from another tray were impacted. Of the remaining 11 trays of fruit not treated, 5 trays were used for remaining impact dates during storage, 1 tray was used as non-impacted control and 5 trays were used for firmness measurements, one at each impact treatments during storage. The impacted tray of fruit and the remaining 11 trays of fruit were further randomised evenly over 12 trays so all letters were represented in a tray. At each impact time during storage, fruit to be impacted were removed from a tray and impacted using the technique described in Experiment 1, then placed back into the same tray position they had been taken from. Polyliners were placed into trays which were then placed into coolstorage at 0°C by orchard line as blocks. All further impacting and firmness measurements were carried out at 0°C.

4.2.4 Assessment

Experiment 1 and 2 fruit were assessed after 19 or 27 weeks of coolstorage, respectively (once the average firmness of the experimental fruit fell to c. 16 or 13 N, respectively). Fruit were assessed immediately after removal from a coolstorage temperature of 0°C, except for simulated shelf-life fruit which were held at 20°C for an additional week. All fruit were assessed for both soft patches and firmness. Soft patches were identified by feeling the entire fruit surface without visual examination. Once a soft patch was found, its perimeter was marked and its surface area (mm²) quantified using a transparent sheet marked with circles of different areas. Areas of all individual patches per fruit were summed to provide an aggregated value. A fruit was classified as a reject if the mean A^I (soft patch area at the impact site, mm²), mean A^E (soft patch area on fruit surface excluding the impact site, mm²), or the mean soft patch area over the total fruit surface ($A^T = A^I + A^E$) exceeded 100 mm². Firmness was measured using Effegi penetrometers (0-118 N or 0-39 N) mounted in a drill press with a 7.9 mm head after fruit skin was removed. One firmness reading per fruit was taken on the side of a fruit, 90° from the area impacted, (when viewed down the longitudinal axis) on tissue devoid of soft patches. The firmness of the soft patch itself was not measured. Soft patches were categorised into 2 groups: soft patches at the impact site, and soft patches occurring on the fruit surface excluding the impact site. On a sample of 30 fruit from Experiment 1, a median slice was cut through the impact site and the slice stained with iodine solution to detect the presence of starch (Mencarelli et al. 1996).

4.2.5 Data analysis

Effects of orchard lines for Experiment 1, simulated shelf-life and blocks for Experiment 2, and drop height, date of impact, and appropriate interactions for both experiments were explored by analysis of variance using the general linear models procedure of SAS (SAS Institute 1988). The standard error of the difference for means was calculated for treatments and relevant interactions. Analysis of proportions was carried out using the frequency

procedure in SAS (SAS Institute 1988). Change in firmness (f) in Newtons of Experiment 2 fruit against time (t) in weeks was characterised by:

$$f = \frac{a}{t^b} \quad [4.2]$$

where a (N weeks) and b were parameters. Change in (A^I) of Experiment 2 fruit against firmness at time of impact was characterised by an analogous function of firmness:

$$A^I = \frac{c}{f^d} \quad [4.3]$$

where c (mm² N) and d were parameters of the equation. All values expressed are means for stated treatments averaged over other factors unless otherwise stated.

4.3 RESULTS

4.3.1 Experiment 1: effect of impact energy

Impact treatments had no effect on whole fruit firmness after 19 weeks or after a further 1 week simulated shelf-life. The averaged firmness after the simulated shelf-life period (10.0 N) was less than that of fruit immediately assessed after removal from coolstorage (16.2 N; $P < 0.0001$; $SED = 0.32$). Lines of fruit from different orchards averaged over both assessment times, varied in firmness after storage at 0°C ($P < 0.0001$), with means ranging from 15.0 to 10.2 N ($SED = 0.64$).

Impacted fruit had 43% more rejects due to soft patches at the impact site compared to control fruit ($P < 0.001$). A week's simulated shelf-life treatment caused the mean A^I at the impact site to be on average 60% greater than that on fruit assessed immediately after removal from

coolstorage ($P < 0.0001$; Fig. 4.1A). Impacting was associated with whitening of fruit flesh under the skin at the area of impact with fracture lines radiating towards the core. This whitened tissue stained blue-black with iodine solution (Fig. 4.2). Values of A^I at the impact site were also different amongst orchard lines of fruit which ranged from 73 to 121 mm² ($P < 0.05$; SED = 13). The proportion of rejected fruit due to soft patches at the impact site increased consistently up to 1 J impact energy (Fig. 4.3). Interestingly, 12% of fruit did not develop soft patches larger than 100 mm² at the highest impact energy. These fruit were all from a single orchard line. It was the only orchard line to have no fruit with rejectable soft patches on the fruit surface excluding the impact site. Across all orchard lines, a week's simulated shelf-life treatment increased the proportion of fruit rejectable due to soft patches at the impact site by a third (from 32 to 43%; $P < 0.001$) over all impact energies.

The mean A^E , soft patch area on fruit surface excluding the impact site differed marginally amongst drop heights ($P < 0.05$), but there was no consistent relationship with drop height (data not shown). A week's simulated shelf-life treatment caused nearly a 4 fold increase in the mean A^E (from 7 to 27 mm²; $P < 0.01$; SED = 7). There was no interaction between effects of impact and simulated shelf-life treatments on A^E . Impact treatments and simulated shelf-life treatments had similar level of A^E rejects (data not shown).

A week's shelf-life treatment caused the mean A^T occurring across all impact treatments to be on average nearly twice that of fruit assessed immediately after removal from coolstore ($P < 0.001$; Fig. 4.1B). The amount of difference between simulated shelf-life treatments increased with greater drop heights ($P < 0.0001$). Mean A^T varied amongst orchard lines of fruit (from 89 to 149 mm²; $P < 0.05$; SED = 26). The percentage of fruit rejectable because of total soft patch area increased consistently with increasing impact energy (Fig. 4.3; $P < 0.0001$). Simulated shelf-life treatment increased the proportion of fruit rejectable due to total area of soft patches compared to those immediately ex-coolstore (46 and 34%,

respectively; $P < 0.001$). The percentage of rejectable fruit due to total area of soft patches was similar for all orchard lines.

4.3.2 Experiment 2: effect of storage on response to impact

Firmness of fruit measured at the different times at which impacts were applied followed a curvilinear decline (Fig. 4.4A). Values for a and b for Eq. 4.2 (change in firmness against time) were 39.3 ± 0.91 N weeks and 0.32 ± 0.015 , respectively. After 27 weeks coolstorage at 0°C , firmness of fruit not impacted (control) was higher than the average value of all impacted fruit across impact dates (14.0 and 13.0 N, respectively; orthogonal contrast $P < 0.05$; $\text{SED} = 0.30$). After coolstorage, mean firmness values for fruit impacted on the different dates were similar. Orchard lines varied in firmness, with means ranging from 11.0 to 15.4 N ($P < 0.0001$; $\text{SED} = 0.27$).

Mean A' for control (28 mm^2) was considerably smaller than the range of values for impact treatments (192 to 254 mm^2 ; orthogonal contrast $P < 0.0001$; $\text{SED} = 11$) which consistently increased with time in coolstorage before impact (Fig. 4.4B), though the proportional increase was only about 30%. The largest mean A' resulted from impacting the softest fruit (Fig. 4.5). Values for c and d for Eq. 4.3 (change in A' against firmness at time of impact) were $4.7 \pm 0.95 \text{ mm}^2 \text{ N}$ and 0.25 ± 0.066 , respectively. Orchard lines varied in A' ($P < 0.01$; $\text{SED} = 7$), with means ranging from 179 to 204 mm^2). Virtually all impacted fruit were rejects due to area of soft patches at the impact site, whereas controls had only 12% ($P < 0.001$).

Mean values for A^E , ranged from 78 to 132 mm^2 ($P < 0.05$; $\text{SED} = 21$) but were not consistently affected by time in coolstorage before being impacted (data not shown). Mean A^E values for orchard lines ranged from 40 to 210 mm^2 ($P < 0.0001$; $\text{SED} = 23$). Percentage rejects due to area of soft patches outside the impact site did not vary across impact dates (data not shown), whereas means for orchard lines means varied from 9 to 33% ($P < 0.001$).

Mean total area of soft patches (A^T) ranged from 280 to 370 mm² across impacts at different dates but were only 130 mm² for controls ($P < 0.0001$; SED = 30). Mean value for A^T for different orchard lines ranged from 220 to 420 mm² ($P < 0.0001$; SED = 20). As with rejects due to soft patches at the impact site, rejects due to total soft patches did not differ amongst the different dates of impact because all of them had rejects $\geq 99\%$. However, A^T of controls caused only 21% of fruit to be rejected ($P < 0.001$) and for A^T orchard lines did not vary (data not shown).

4.4 DISCUSSION

Impacts applied to kiwifruit at harvest did not have an effect on whole fruit firmness when assessed after 19 weeks storage at 0°C. If there was a localised stimulation of ethylene production caused by these impacts, it did not affect softening of the rest of the fruit. Ethylene production of impacted fruit may be negligible at 0°C, unlike the elevated ethylene production and premature softening of impacted fruit stored at 20°C (Finch & Hopkirk 1987). If impact to fruit at harvest did stimulate premature ethylene production in fruit, it was not evident as an effect on fruit firmness after the week's shelf-life simulation at 20°C. Although, if whole fruit firmness after storage was not affected, impacts at harvest still caused some damage to tissue that was seen as flesh whitening, which stained blue-black with iodine solution. This indicated that starch had failed to become converted to sugar (Fig. 4.2) as surrounding tissue had ripened. This was probably because the impact ruptured a proportion of cells in the bruised tissue, inhibiting enzymatic breakdown of starch that would be associated with normal ripening in non-damaged cells. Damage resulting from impacts at harvest, therefore, appears to be expressed in the form of soft patches and not as a reduction in overall fruit firmness.

Date of impact during coolstorage did not have any effect on the level of firmness reached by impacted fruit after storage. Fruit impacted after 1 week in storage and stored a further 26 weeks had similar firmness to fruit impacted after 21 weeks storage and stored for 6 weeks. On the

other-hand, fruit impacted during storage were 0.5 N softer on average than control fruit after storage. The reduction appeared to be consistent regardless of the time of impact during storage. In contrast, fruit impacted at harvest had a similar firmness to control fruit after coolstorage. From these data, it seems likely that fruit graded after long term storage may only have a slight reduction in overall firmness due to grading.

Soft patch size would be expected to relate to how much the indenter was able to deform the fruit surface during impact, with softer fruit yielding to a greater extent than firmer fruit. Firmness, therefore, was expected to be an indicator of fruit susceptibility to soft patches caused by impact damage, with the potential for damage increasing as fruit soften. However, note that A' went up by only 25% in fruit for which firmness had gone down by two thirds: firmness may not be that critical an issue in soft patch development. On the other hand, patches in Experiment 1 increased in size by 80% during a week's shelf-life simulation. This further increased the proportion of fruit which became rejectable on the basis of area of soft patches. Soft patches that may be of tolerable size in coolstorage, could grow to become unacceptable by the time they are presented for retail sale or are consumed.

Exposure of fruit to controlled impacts revealed that a 0.08 J impact on a freshly harvested fruit (equivalent to dropping a 0.11 kg fruit from 75 mm) caused c. 5% of impacted fruit to become rejectable on the basis of area of soft patches at the impact site. Impacts of this magnitude would be commonplace in the existing handling system for kiwifruit in New Zealand, such as the release of fruit from a picking bag into a wooden bin or a drop on grading equipment. There was a continuous increase in the proportion of rejects as impact energy increased above zero. Therefore, rather than identifying a maximum permissible drop height, it would seem sensible to put effort into achieving close to nil impact energies throughout the entire postharvest handling system. The fact that a proportion of fruit from one orchard line were remarkably resistant to impact damage signalled that there may be preharvest influences on susceptibility to mechanical damage. Further work to elucidate these effects would be worthwhile.

Soft patches also develop as a result of factor(s) other than physical damage. These types of soft patches are thought to be caused by physiological factor(s), such as chilling injury and lack of calcium, which have been linked to similar softening disorders (Lallu et al. 1992; Banks et al. 1995).

4.5 CONCLUSIONS

This study has shown that impacts typical of the magnitude of those which kiwifruit experience during handling after harvest can result in development of soft patches which would make them unacceptable for export. This would result in direct revenue loss to growers through rejection of fruit at condition checking. Sources of impacts during harvest and handling of fruit could, therefore, usefully be identified and eliminated as outlined by Bollen & Dela Rue (1990).

The size of soft patches resulting from standardised impact increased consistently with decreasing firmness at time of impact though to a smaller proportional extent than the difference in firmness. Fruit impacted at harvest had a similar firmness to control fruit after long term coolstorage, whereas averaged firmness of fruit impacted during storage were lower than control fruit firmness after long term storage at 0°C. There was a strong relationship between impact energy and A^I , soft patch area development at the impact site. All impact energy treatments resulted in some incidence of soft patches and, therefore, rejects. This information demonstrated that all reductions in impacts in the harvesting system are likely to be rewarded by lowered incidence of soft patch rejects. Attention in the handling of kiwifruit should focus on operators' effective elimination of all impacts rather than reduction to some notional threshold level.

4.6 ACKNOWLEDGEMENTS

We thank the New Zealand Kiwifruit Marketing Board for financial support.

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4.8 FIGURES

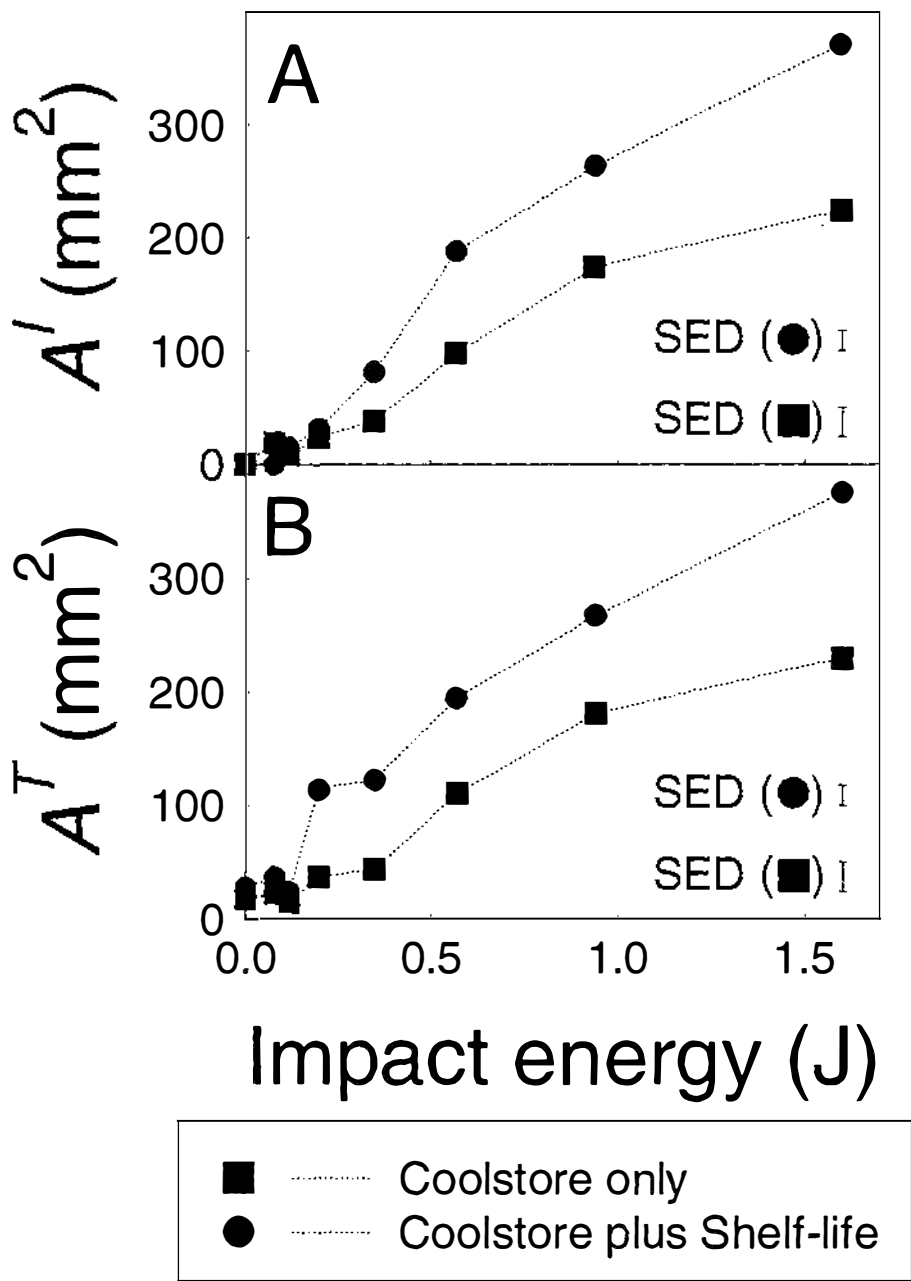


Fig. 4.1 A, Mean A' (area of soft patches at the impact site); and B, mean A^T (area of soft patches on the total fruit surface), plotted against impact energies for impacts onto kiwifruit from 0 through 0.08 to 1.6 J at harvest. Fruit were assessed after 19 weeks at 0°C, with or without simulated shelf-life (SED = 18 and 26, respectively) averaged over orchard lines. Symbols represent the means of 128 fruit.



Fig. 4.2 Impact (1.6 J) at harvest to fruit with damage symptoms (whitening of flesh; right hand fruit) that stained blue-black (left hand fruit) in the presence of iodine due to unconverted starch after 27 weeks coolstorage at 0°C.

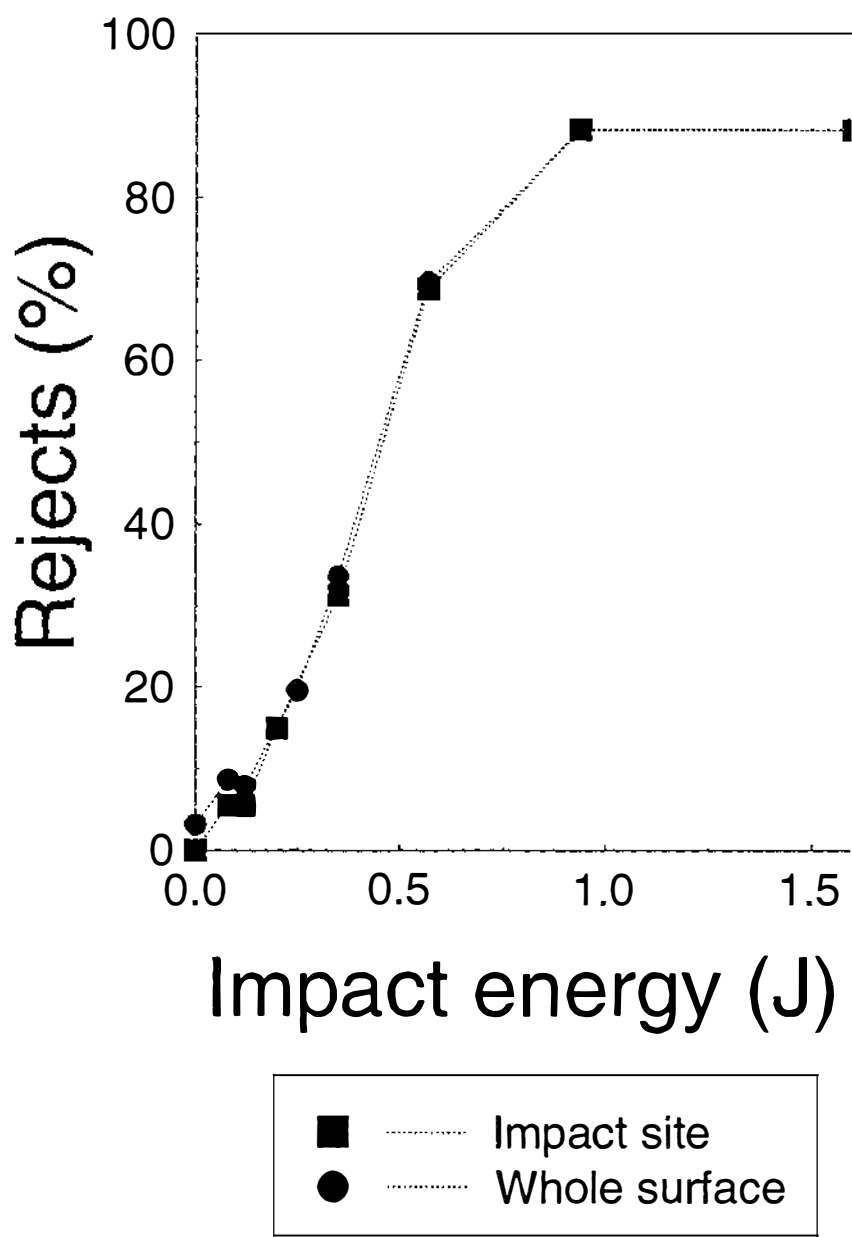


Fig. 4.3 Mean percentage of kiwifruit rejectable because of area of soft patches at the impact site and over the total fruit surface, following impacts with different impact energies applied at harvest and assessed after 19 weeks storage at 0°C (averaged over orchard lines and simulated shelf-life treatment). Symbols represent the means of 256 fruit.

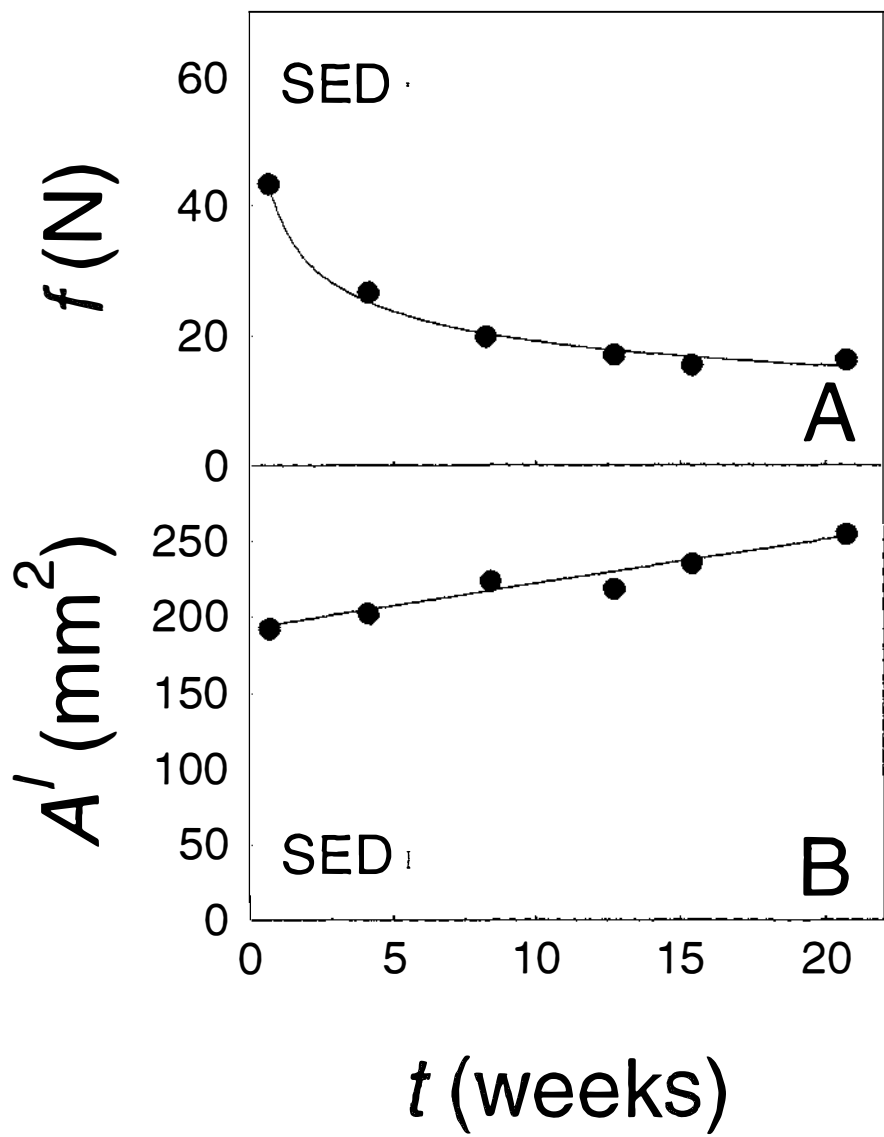


Fig. 4.4 Change in: **A**, firmness (f); and **B**, mean A' assessed after 27 weeks storage at 0°C as functions of time of impact (t ; impact energies 0.94 J ; $r^2 = 0.93$; fitted equation for A' is $A = 192 \pm 2.9 + (2.9 \pm 0.39) t$. Symbols represent the means of 38 and 114 fruit for f and A' , respectively.

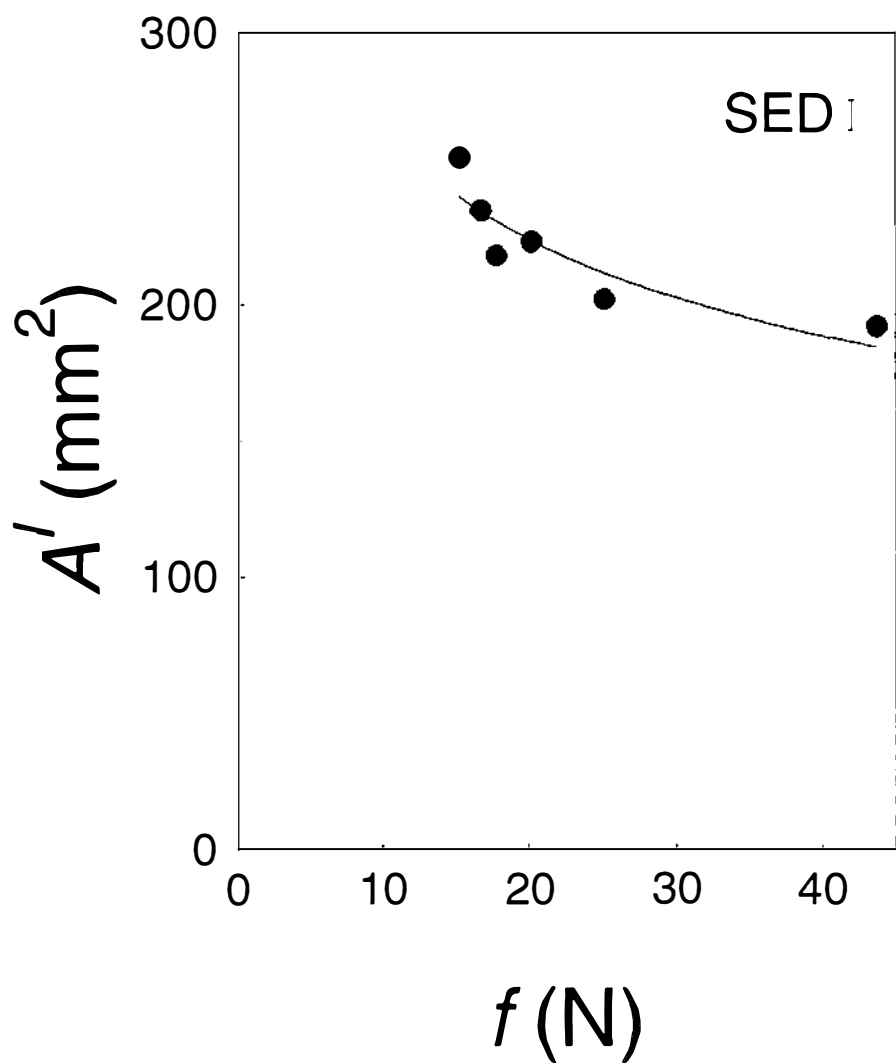


Fig. 4.5 Mean A' (area of soft patches at the impact site) assessed after 27 weeks storage at 0°C, plotted against mean firmness (f) of fruit when impact during coolstorage. Symbols represent the means of 38 and 114 fruit for f and A' , respectively.

Soft patch development in kiwifruit: effects of grading damage and packaging

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5.i Abstract In one experiment, kiwifruit (*Actinidia deliciosa*) were passed across 1 of 6 different commercial grading machines, which ranged in their handling of fruit from gentle to severe, or left as untreated controls. After 19 weeks storage at 0°C, graded fruit had double the proportion of rejects (fruit rejected because of localised soft area on the fruit surface had an area of more than 100 mm² (soft patch) of that found in controls. There was evidence of an association between the severity of handling fruit received during grading, and the area of soft patches on graded fruit. Improving grading equipment used in the kiwifruit industry should, therefore, reduce the incidence of damaged fruit and associated fruit losses.

In a second experiment, kiwifruit were stored in cardboard or wooden single layer trays or tri-packs, and assessed after 18 weeks storage at 0°C. Soft patch rejects were about twice as high in single layer trays as in tri-packs (10% cf. 5%), indicating that tri-packs may be more suitable than single layer trays for long term storage of kiwifruit. However, fruit at the bottom of a tri-pack, where compression loads were greatest, had more soft patch rejects than fruit in upper layers. Soft patch development was greatest in the softest fruit. Effects of compression in bulk packs or wooden bins on soft patch development should be investigated. There was no variation in whole fruit firmness due to grading or type of packaging used.

5.ii Keywords kiwifruit; *Actinidia deliciosa*; soft patch; firmness; graders; grading; packaging; coolstorage

5.1 INTRODUCTION

Returns to New Zealand kiwifruit (*Actinidia deliciosa* (A.Chev.) C.F. Liang et A.R. Ferguson 'Hayward') growers on exports of kiwifruit are affected by fruit that become prematurely soft. Soft patches on the surface of kiwifruit can develop as a result of handling damage such as impact or compression (Finch & Hopkirk 1987) or due to physiological factors such as low calcium concentrations in fruit (Banks et al. 1995).

Bollen & Dela Rue (1990) have identified a number of sites on equipment commercially used for grading kiwifruit such as impacts and drops, at which significant mechanical damage could occur to the fruit. Massantini et al. (1995) showed that brushes used on grading equipment caused surface wounds to fruit. These wounds were thought to stimulate ethylene production, which promotes fruit ripening (Pratt & Reid 1974). In preliminary studies, Banks et al. (1992) showed that kiwifruit harvested by hand with negligible mechanical damage had a lower incidence of soft patches after prolonged storage at 0°C than those harvested and handled through the normal postharvest system. Impacts associated with the harvesting and packhouse handling systems were implicated in this difference. However, there were no differences in the rate of decline in firmness between these groups of fruit, an observation which is consistent with the findings by Finch & Hopkirk (1987) for fruit stored at 0°C.

Severity of soft patch symptoms is influenced by storage temperature, but other preharvest and postharvest factor(s) may also be involved (Lallu et al. 1992). Banks et al. (1992) found that the bottom of tri-packs had twice the incidence of soft patches of those in the top layer. In these packs, fruit at the bottom were exposed to small compression forces over many weeks of storage due to the fruit above them. This indicated a role for compression in the development of soft patches on fruit in tri-packs. On the other hand, fruit exiting grading equipment and falling into the

bottom of tri-packs dropped a greater distance than fruit delivered subsequently to the upper layers. Therefore, fruit in the bottom layers received higher impact energies than fruit in higher subsequent layers. They also received more impacts than those in upper layers because, in addition to their own impacts into the base of the package, they were involved in the impacts of other fruit falling in on top of them. The severity of damage received may also depend on whether fruit impact against the tri-pack base or other fruit.

It is clear that mechanical damage occurring during postharvest handling and storage could potentially be a serious cause of poor kiwifruit quality. The aims of the current study were to determine what influence commercial graders have on softening behaviour and incidence of soft patches on kiwifruit from different orchards, and to quantify differences in firmness and soft patches on fruit coolstored in different packaging.

5.2 MATERIALS AND METHODS

5.2.1 Fruit

Count 33 size kiwifruit (0.107-0.116 kg) were harvested from a number of vines in a single block on each of 8 commercial properties in the Bay of Plenty on 11 and 12 May 1992. Fruit were sampled during the commercial harvest period. Once fruit were picked from the vine they were placed carefully into pocket packs held in single layer trays.

5.2.2 Experiment 1: grading

Three trays of fruit per orchard line were used for each of 7 treatments (control or graded on 1 of 6 different graders) in a randomised complete block design, using orchard lines as blocks and trays of fruit as experimental units (total of 168 trays). All fruit from a given orchard line were randomised and separately labelled with a sticker to identify orchard line of origin. For each treatment grader, all fruit from the 8 orchard lines were randomised together on the sorting table before entry to the grader. Once

fruit had passed over a grader (on 13 or 14 May) they were repacked randomly into single layer trays, then placed at random onto a pallet under cover, at ambient temperature, until transportation. Each grader was allocated a subjective rating, according to its perceived severity of handling fruit which passed over it (taking into account such factors as drop heights, number and slope of ramps and objects that fruit impacted against). A scale of 0 to 10 was used as an aid to interpreting damage incurred by different graders (0 = no grading (control), 10 = most severe handling).

5.2.3 Experiment 2: packaging

Fruit harvested directly from the vine without being graded, were randomised, and placed carefully into packaging to give 1 of 5 treatments: *card* (cardboard single layer trays), *wood* (wooden single layer trays), *tp^T* (top layer of a tri-pack), *tp^M* (middle layer of tri-pack), and *tp^B* (bottom layer of tri-pack). Three single layer tray replicates were used for each of 8 orchard lines for the card and wood treatments; the equivalent of 3 single trays of fruit were combined to make up just 1 tri-pack for each of the 8 orchard lines. Orchard lines were used as blocks. Each tri-pack fruit was labelled to identify which layer it was allocated to. All packed fruit were stored randomly on a pallet under cover at ambient temperature until transportation.

5.2.4 Transportation and storage

Prior to transportation, polyliners were placed into trays of fruit from Experiment 1 and the filled treatment packs in Experiment 2, and loaded at random onto separate pallets. Fruit were then transported by truck to Massey University on 15 May overnight (a distance of 450 km). All packs were placed in coolstorage at 0°C on 16 May after sorting into the 2 experimental sets and reloading packs from Experiment 1 at random onto a separate pallet. Experiment 2 packs were stacked randomly onto shelves in the coolstore by treatment packaging within blocks (orchard lines).

5.2.5 Assessment

All fruit were assessed after either 19 or 18 weeks coolstorage (once average firmness reached c. 17 or 16 N; Experiments 1 and 2, respectively). Fruit were assessed immediately after removal from coolstorage. Soft patches were identified by feeling the entire fruit surface without visual examination. Their perimeters were then marked and surface areas (mm^2) quantified using a transparency marked with circles of different areas. Areas of all individual patches were summed to provide an aggregated value per fruit. A fruit was classified as a reject if its total soft patch area (A^{sp}) exceeded 100 mm^2 . Kiwifruit firmness was measured using 1 of 2 Effegi penetrometers (0-118 N or 0-39 N) with a 7.9 mm diameter head, each mounted in a drill press. Skin tissue was removed before the firmness measurement was taken. Firmness readings were made at the fruit surface on tissue devoid of soft patches midway along the longitudinal axis of the kiwifruit.

5.2.6 Data analysis

Data were subjected to analysis of variance using the general linear models procedure of SAS (SAS Institute 1988) to examine effects of grader or packaging treatment, blocks (orchard line), with tests for appropriate interactions and orthogonal contrasts. Analysis of proportions was carried out using the frequency procedure in SAS (SAS Institute 1988). All means expressed averaged over other treatments and blocks (orchard lines) unless otherwise stated.

5.3 RESULTS

5.3.1 Experiment 1: grading

Mean firmness after coolstorage did not differ between graded and control fruit (overall average = $17.4 \text{ N} \pm 0.25$; 61 df). Firmness varied between orchard lines ($P < 0.0001$) ranging from 14.5 to 21.2 N (SED = 0.52).

Graded fruit had twice the proportion of fruit rejectable on the basis

of A^{sp} compared with non-graded controls (4 and 2%, respectively; $P < 0.001$). However, the differences in proportion of fruit rejected due to A^{sp} after grading due to different graders were significant only at the $P < 0.1$ level. Nevertheless, there was an increase in the proportion of fruit rejected on the basis of A^{sp} for increased severity of grading ($r^2 = 0.95$; Fig. 5.1). The graders which were perceived to have most gentle handling resulted in fruit with the least percentage rejects. The proportion of fruit rejected on the basis of A^{sp} differed significantly among orchard lines and ranged from 1 to 9% ($P < 0.001$).

5.3.2 Experiment 2: packaging

After coolstorage, fruit firmness was not significantly influenced by the different types of packaging used in this trial. Mean firmness over the 5 different packaging types was $16.5 \text{ N} \pm 0.40$ (72 df). Fruit firmness varied among orchard lines ($P < 0.0001$), ranging from 14.1 to 18.8 N (SED = 0.10).

In contrast, mean A^{sp} on fruit from single layer trays was twice that of fruit from tri-packs (Fig. 5.2A; $P < 0.01$). Soft patch rejects were twice as high (a little over 10%) in both card and wood treatments compared with tri-packs (Fig. 5.2B; $P < 0.001$). Within tri-packs, rejects were greater in the bottom layer (tp^B) than in the middle (tp^M) or top (tp^T) layers. Fruit varied in their mean A^{sp} ($P < 0.05$; SED = 9) for individual orchard lines; A^{sp} ranged from 5 to 45 mm^2 . Averaged across all types of packaging, the incidence of soft patch rejects varied between 5 and 18% in fruit from different orchards. Mean A^{sp} consistently decreased with increasing mean fruit firmness assessed after 18 weeks of storage (Fig. 5.3).

5.4 DISCUSSION

After coolstorage, there was no decrease in whole fruit firmness associated with grading. Such treatments have previously even resulted in a slight improvement in retention of whole fruit firmness after storage due to grading immediately after harvest (Davie 1992; Banks et al. 1992).

Variation in whole fruit firmness amongst orchard lines is a well known phenomenon in the industry, and has previously been attributed to a wide range of preharvest factors (Hopkirk & Clark 1992) including mineral nutrition (Banks et al. 1995).

The consequences of mechanical damage occurring on grading equipment were seen as an increased A^{sp} on the graded fruit. That differences amongst the graders in their proportion of rejects were only significant at $P < 0.1$ level may have been due to the limited numbers of fruit used in Experiment 1. However, overall, graded fruit had more fruit affected by soft patches than the controls, the extent of which depended upon the severity of handling received by the fruit on each grader (Fig. 5.1).

It was quite possibly largely fortuitous that there was such a close relationship between levels of rejects and perceived severity of grading, given the absence of a clear model for linking the diverse nature of individual events as fruit traversed the grader with fruit damage.

Nevertheless, the relationship is consistent with work by Bollen & Dela Rue (1990) which indicated the potential for grading equipment to cause mechanical damage to kiwifruit. Conversely, graders which handled fruit gently had A^{sp} values similar to the controls. Coupled with other findings linking severity of impact with levels of rejects (Section 4.3.1), these data clearly indicate the potential for ameliorating grader damage to kiwifruit by improving grader design and management of grader operation to avoid high velocity impacts. Use of the Instrumented Sphere techniques described by Pang et al. (1994) could be used to identify damaging handling sites on graders. There is a clear need for postharvest operators to be made aware of grading equipment problems so they may take the necessary remedial action to reduce fruit damage to minimal levels. Reducing fruit damage can be achieved by preventing damaging impacts against other fruit or handling equipment, cushioning, or padding of hard surfaces, and decelerating fruit travelling down ramps or chutes (Brown et al. 1990).

Packaging treatment type did not affect fruit firmness but there were

marked differences in soft patch development amongst packaging types (Fig. 5.2A). Within the tri-packs, fruit in the bottom layer had a greater incidence of soft patches than the upper 2 layers, possibly as a result of compression or impact damage to fruit in the bottom layer by overlying fruit (Sections 3.3.1, 4.3.1). This was consistent with similar findings made in a previous study (Banks et al. 1992). Further work is required to determine what proportion impact and compression loads contribute to the incidence of soft patches found on commercially harvested and packed kiwifruit after long term coolstorage. This raises another possible origin of soft patches in this work: mechanical damage developed during transportation to the storage site. Fruit exposed to the hard supporting surface of the tray may have been more prone to develop mechanical damage associated with vibration during transportation (Pang et al. 1995; G. Finch pers. comm.). The susceptibility of fruit to damage due to vibration may be determined by how well fruit fit their pocket pack. This effect might have been ameliorated in fruit held more firmly in place by neighbouring fruit, as in the tri-packs, particularly for those fruit resting in other fruit rather than on a hard packaging surface. However, location of soft patches on the surface appeared to be random, rather than concentrated in areas on fruit that were in contact with packaging. This could be consistent with fruit bouncing around within the pack or fruit vibrating against packaging material during transportation.

Orchard lines of fruit from Experiment 2 with high levels of firmness after storage, tended to have lower levels of soft patch rejects and mean area of soft patches (A^{sp} ; Fig. 5.3). This indicated that development of soft patches not due to physical handling at harvest was associated with rapidly softening lines of fruit, an observation which would make it doubly important to ship such lines of fruit early in the storage season. In addition to losing whole fruit firmness rapidly, such fruit also seem prone to localised softening which can be detrimental to the quality of long-stored fruit.

In this study, we have shown that the proportion of fruit affected by soft patches is affected by fruit origins, severity of grading treatment, and

packaging type. In the long term, preharvest and postharvest factor(s) that predispose fruit to be less susceptible to grader damage and storage disorders should be identified to assist growers to produce the type of fruit required by the industry. The potential effects of temperature and compressive loads on bulk coolstorage of kiwifruit and on subsequent soft patch development should be investigated with regard to both the prevention and reduction of fruit losses during long term storage.

5.5 CONCLUSIONS

Mechanical damage incurred on grading equipment affected quality of kiwifruit by inducing development of soft patches rather than by stimulating loss of whole fruit firmness. There was some evidence that the magnitude of this effect was related to the apparent severity of handling on the commercial grading machines. There would seem to be good scope for reducing loss of kiwifruit quality across the entire industry by making improvements to grading equipment. Storage of kiwifruit in different types of packaging had little effect on whole fruit firmness. However, development of soft patches was higher in single layer trays than in tri-packs, perhaps due to differences in transport induced damage between the packaging types. Fruit subjected to additional impact and compressive loads present in the bottom layer of tri-packs developed more soft patches than those in the upper layers. Losses to soft patch development should, therefore, be minimised by gentle grading and careful release into multi-tray packages for protection of fruit during storage and distribution.

5.6 ACKNOWLEDGEMENTS

We thank the New Zealand Kiwifruit Marketing Board for financial support.

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5.8 FIGURES

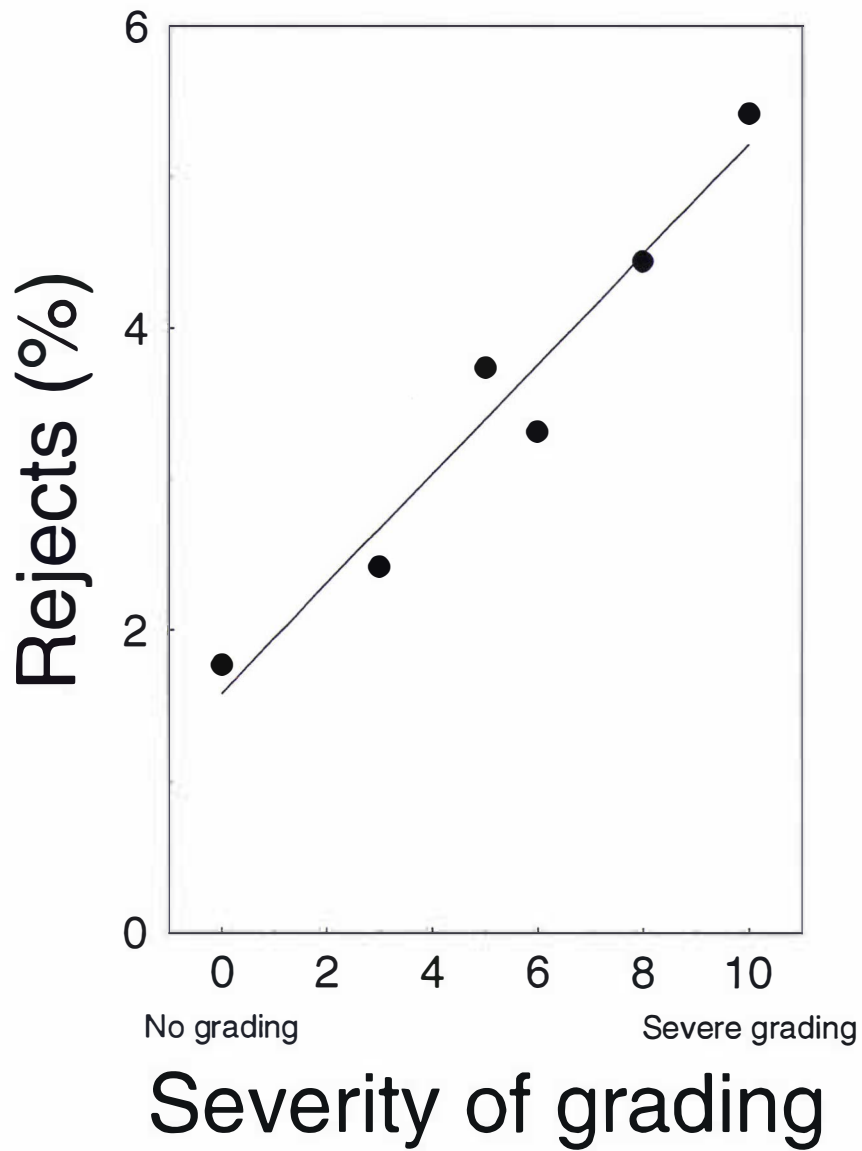


Fig. 5.1 Percentage of rejectable (R_j) fruit on the basis of A^{sp} after 19 weeks in coolstorage following different grader treatments plotted as a function of severity of grading (sg) averaged over orchard lines ($r^2 = 0.95$; equation for fitted line $R_j = 1.6 \pm 0.34 + (0.36 \pm 0.042) sg$; each symbol represents the mean of 792 fruit).

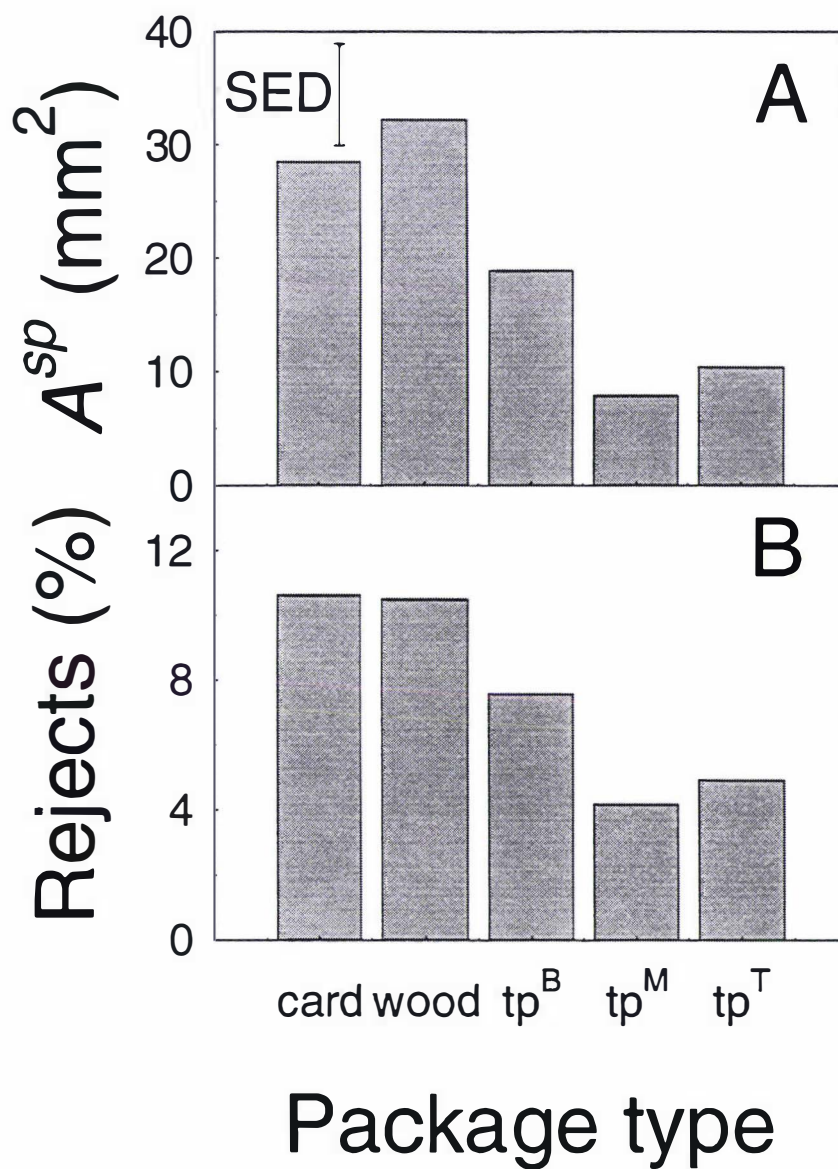


Fig. 5.2 A, Mean A^{sp} ; and B, percentage of rejectable fruit on the basis of A^{sp} for different packaging types after 19 weeks in coolstorage and averaged across 8 orchard lines of fruit (each symbol represents the mean of 792 fruit; cardboard single layer tray (card), wooden single layer tray (wood), tri-pack bottom layer fruit (tp^B), tri-pack middle layer (tp^M), and tri-pack top layer (tp^T)).

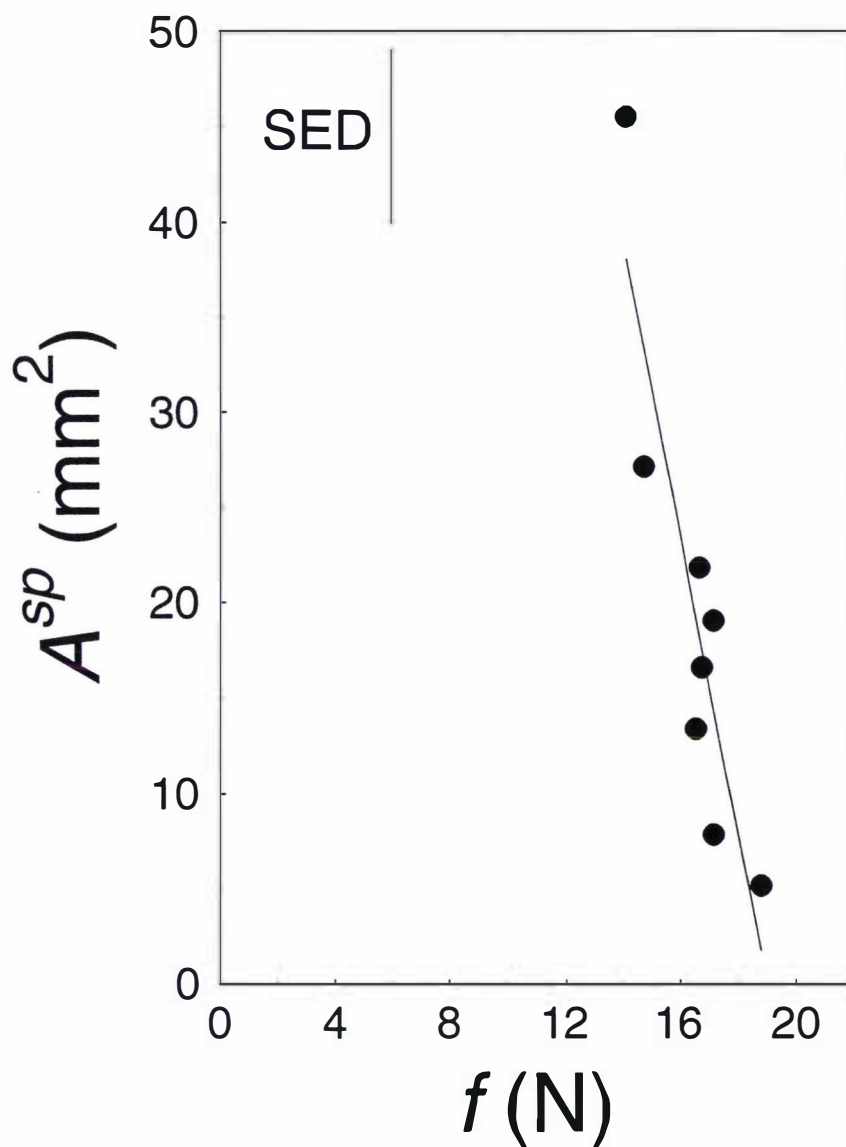


Fig. 5.3 Relationship between mean A^{sp} and whole fruit firmness (f) after 19 weeks coolstorage for individual orchard lines of fruit, averaged across all packaging types ($r^2 = 0.81$; fitted equation is $A^{sp} = 148 \pm 6.0 - (8 \pm 1.6) f$; each symbol represents the mean of 495 fruit).

Grader damage to kiwifruit after controlled atmosphere storage

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6.i Abstract The responses of kiwifruit (*Actinidia deliciosa*) to grader damage with differing levels of fruit firmness or flesh temperature were examined in 2 experiments. Fruit had been bulk-stored in controlled atmosphere (CA) for 20 weeks at 0°C in 0.5 m deep wooden bins. Initial firmness for 20 orchard lines ranged from 17 to 45 N before grading. After an additional 7 weeks air coolstorage at 0°C and 1 week simulated shelf-life at 20°C, final firmness of graded fruit (8.9 N) was slightly less than controls (fruit not graded; 9.5 N). Final firmness was largely unrelated to initial firmness before grading. Regardless of the initial flesh temperature (0°C or 16°C) of kiwifruit when graded, final firmness was the same for all groups of fruit. Fruit graded with a flesh temperature of 0°C had a slightly lower final firmness than ungraded controls. Initial firmness before grading had only a weak correlation with incidence of soft patches (localised soft areas on fruit surface) for graded fruit. Incidence of soft patches on control fruit had a strong association with final firmness. Grading increased the incidence of soft patches by 35%. Flesh temperature at time of grading had no effect on subsequent development of soft patches. Fruit from the bottom layer of a wooden bin had a higher final firmness, and lower incidence of soft patches on average, than fruit from the top layer. Presence of soft patches in control fruit was linked to low calcium, high phosphate concentrations, and low dry matter. The results, therefore, suggest that strategies to reduce incidence of soft patches could include preharvest management of fruit dry matter, calcium, and phosphate contents, and gentle handling to reduce grader damage.

6.ii Keywords kiwifruit; *Actinidia deliciosa*; firmness; soft patch; temperature; controlled atmosphere; grading; coolstorage

6.1 INTRODUCTION

During the 1994 New Zealand kiwifruit (*Actinidia deliciosa* (A.Chev) C.F. Liang et A.R. Ferguson 'Hayward') season, c. 3 million tray equivalents were stored in controlled atmosphere (CA) storage, a technique which is increasing in popularity (Lallu & Manning 1994). Wooden bins filled with picked fruit are placed into CA coolstores at 0°C. CA storage delays fruit softening and, therefore, allows greater flexibility in marketing the crop (McDonald & Harman 1982). New Zealand CA-stored kiwifruit can be graded and packed until the end of October each year (G. Sampson pers. comm.). Fruit sorting after long term CA storage enables removal of prematurely soft fruit. Fruit that become prematurely soft are otherwise packed at harvest in the standard postharvest handling regime for fruit.

Lallu & Manning (1994) suggested that long term CA-stored fruit may not withstand the rigours of grading like their freshly harvested counterparts. Freshly harvested fruit are firmer than long term CA-stored fruit; kiwifruit stored in CA for 20 weeks have an average firmness of c. 45 N compared to 69 N for fruit freshly harvested (McDonald 1990). Kiwifruit grading equipment may expose fruit to potentially damaging impacts and drops (Bollen & Dela Rue 1990). This handling damage is likely to cause localised prematurely soft areas on kiwifruit, termed *soft patches*. Fruit with a firmness below 59 N have been reported to develop elevated ethylene levels after impact (Mitchell 1990), indicating that kiwifruit should not be handled below this firmness. The minimum firmness set by the New Zealand Kiwifruit Marketing Board for grading CA-stored kiwifruit is 15 N (G. Sampson pers. comm.). However, the incidence of soft patches and loss of whole fruit firmness associated with grading CA-stored fruit have not been quantified.

After removal from CA storage at 0°C, fruit would normally be graded immediately with a flesh temperature near 0°C. Grading 'Royal Gala' apples warmed to ambient temperature has been shown to cause less bruising than grading fruit with a flesh temperature at 0°C (Banks et al. 1993), an effect probably associated with a slight drop in firmness caused by

warming (Bourne 1982). Firmness of long-stored kiwifruit can decrease by 35% when warmed from 0°C to 20°C (Jeffery & Banks 1994). This loss in firmness was almost totally recovered once flesh temperature was returned to 0°C. Such a dramatic drop in kiwifruit firmness after warming might be expected to affect their susceptibility to handling damage.

Postharvest calcium dips result in kiwifruit with a reduced softening rate that are firmer than controls upon removal from storage (Hopkirk et al. 1990; Prasad & Spiers 1992). Resnizky & Sive (1993) reported that calcium concentrations in prematurely soft CA-stored kiwifruit were lower than those of sound fruit. Banks et al. (1995) found that the presence of soft patches in kiwifruit were associated with lower levels of calcium and high levels of phosphate in fruit. The ratio of calcium to phosphate concentration was twice as high in healthy fruit as in fruit with soft patches.

This study was conducted to quantify the incidence of soft patches and loss of whole fruit firmness associated with grading of fruit after removal from CA storage. Their incidence of soft patches and overall firmness of fruit graded at different flesh temperatures were investigated. Finally, the study sought to confirm that long term CA stored fruit which received minimal handling (ungraded) and had soft patches, also had low levels of calcium and high levels of phosphate.

6.2 MATERIALS AND METHODS

6.2.1 Fruit

Kiwifruit were sampled from wooden bins (1.2 m long, 1.2 m wide, and 0.5 m deep) on 26 September and 11 October 1994 at a packhouse in the Bay of Plenty, New Zealand. Before sampling, bins containing fruit had been stored for 19 and 21 weeks, respectively in CA storage and a further 2 weeks in air storage. All fruit storage, sampling, and handling were completed in coolstorage at 0°C unless otherwise stated. Fruit sampling and randomisation were done carefully by hand to ensure negligible damage to fruit. Kiwifruit had previously been commercially harvested into wooden

bins and transported to the packhouse for CA storage.

6.2.2 Experimental design

6.2.2.1 Experiment 1

Samples of twelve trays of c. 33 count size fruit were taken from the top layer of each of 20 wooden bins on 26 September and 11 October. Each bin was from a different orchard line or, in 5 cases, the same orchard but with different harvest dates. Fruit sampled on 26 September were stored in polyethylene-lined cartons for 14 days at 0°C in air. Within each sample, fruit were randomised over 12 single layer trays on 11 October. Fruit from 15 orchard lines were removed from coolstore and given grading treatments on 12 October by orchard line. To increase the range of firmness levels involved, fruit from the remaining 5 orchard lines were further softened by keeping them in unlined trays at 20°C with a humidity of 97% for 6 days. They were then re-equilibrated to 0°C for 24 h before the grading treatments were applied.

For each orchard line, 6 trays were allocated to each of 2 treatments: (i) *control* (not graded); or (ii) *graded* (grading immediately after removal from coolstorage) at a commercial packhouse. The grader ran at 7 rods/s with accumulated drop heights totalling 1.6 m. Fruit were systematically passed across the grader by orchard line and collected from one exit line into 'Euro packs' which were loose filled with fruit. Packs were immediately returned to coolstorage and fruit transferred by hand randomly into 33 count moulded plastic pocket packs. These packs when full of fruit were enclosed in a polyliner, and both placed into a single layer tray by orchard line. For subsequent storage, trays were randomly allocated to 1 of 2 pallets.

6.2.2.2 Experiment 2

All treatments used c. 33 count fruit from a single wooden bin for each of 4 orchard lines on 11 October. Fruit were packed carefully by hand into 33 count moulded plastic pocket packs in single layer trays.

For each orchard line, 6 tray lots were used for each of 9 treatments. From a bin, the top and bottom layers of fruit were removed, each layer being randomised over 6 trays and fruit were not graded (*T* and *B*, respectively). The treatments (*T* and *B*) were designed to test the bin positional effect. Remaining fruit between the top and bottom layers in a bin were randomised over 42 trays. Fruit from 6 trays were used in each of 7 additional treatments using the same grader as Experiment 1:

- *C*: control (not graded).
- *G*: graded.
- *G_M*: graded on a modified grader where severity of drops and impacts had been reduced using foam padding.
- *G₁₆*: warmed at 16°C for 24 h and then graded.
- *C₁₆*: as for *G₁₆*, but a control (not graded).
- *G₀*: warmed at 16°C for 24 h then cooled at 0°C for 24 h before grading.
- *C₀*: as for *G₀*, but a control (not graded).

Treatments were timed so that all fruit were removed from 0°C or 16°C storage and immediately graded on 13 October. Fruit were passed across the grader and collected from one exit line into Euro packs. They were then taken into coolstorage where they were transferred by hand into 33 count moulded plastic pocket packs in single layer trays. Polyliners were put into trays before they were packed onto 2 pallets. Trays from 2 orchard lines were placed onto each pallet, being randomised within each orchard line.

6.2.3 Transportation

Fruit from both experiments were transported by truck to Massey University overnight and had reached a flesh temperature of c. 5°C upon arrival. Trays from Experiment 1 were evenly randomised between 2 pallets when placed into coolstorage. Two orchard lines were placed on each of 2 pallets for Experiment 2; trays were blocked by, and randomised within, each orchard line.

6.2.4 Assessment

Initial firmness ($f^{initial}$) was measured on sub-samples comprising 3 or 4 fruit per tray (18 or 24 fruit per treatment) for Experiments 1 and 2, respectively. Two firmness readings were taken immediately on each fruit using a penetrometer (Effegi 0-118 N or 0-39 N with a 7.9 mm head, mounted in a drill press). Firmness readings were taken on areas from which the skin had been removed and which were 90° from each other when viewed down the longitudinal axis. On 21 November, for both experiments, trays had polyliners removed and were then shifted from coolstorage to ambient temperature (20°C) for 1 week to simulate a shelf-life period.

Fruit had a final assessment on 28 November 1995. Soft patches were located by gently feeling the entire surface of the fruit but without visual examination. Soft patch perimeter was then marked and its surface area (mm²) quantified using a transparency marked with circles of different areas. Areas of all individual patches on each fruit were summed to provide an aggregated value. A fruit was classified as a reject if its total soft patch area (A^{sp}) exceeded 100 mm². Final firmness (f^{final}) of fruit was measured using a penetrometer (as above), 1 reading per fruit on areas from which the skin had been removed and which were devoid of soft patches.

6.2.5 Mineral analysis

Kiwifruit in 3 control trays for each orchard line from Experiment 1 were separated into the following classes: *healthy* (sound fruit showing no disorders); *population* (random sample of fruit), and *soft patch* (fruit with soft patches). Fruit were selected from the same positions within each tray for the population class. The remaining fruit in a tray were allocated into either soft patch or healthy fruit class depending on which conditions for a class the fruit fulfilled. For every tray, fruit within each of the 3 classes were divided into 2 sub-samples. Fruit were cut in half down the longitudinal axis so that 1 half could be used for mineral analysis and the other for determination of their dry/fresh weight ratio. Fruit with soft patches were cut in such a way as to have half of the largest soft patch in

each piece of fruit. Samples to be used in mineral analysis were stored together in a freezer (-20°C) until analysis. Defrosted samples of fruit were blended together for determination of their calcium and phosphate concentrations. Two 3 g samples were taken for acid digestion.

Samples of tissue used for calcium analysis were refluxed with concentrated nitric acid (HNO_3 ; 4 mL) in digestion tubes occluded with small funnels at 150°C for 6 h or until the solution cleared, then boiled to dryness at 250°C. The warm residue was redissolved in 5 mL of freshly prepared strontium (Sr^{+2}) and caesium (Cs^+ ; 2.4% w/w for each element) in 8 mM hydrochloric acid (HCl) and stored at 4°C in a dark refrigerator until analysis by atomic adsorption spectrophotometry.

Phosphate was analyzed by a method adapted from that used for soils as described by Saggar et al. (1990). Samples of tissue in sealed 3 mL vials were shaken horizontally for 16 h at 20°C with 2.5 mL of 80% ethanol, with strips (62 × 25 mm) of cation exchange resin (CER, Na^+ form (sodium)) and anion exchange resin (AER, HCO_3^- form (hydrogen carbonate)). Vials were repeatedly flushed with distilled water (H_2O) to remove ethanol ($\text{C}_2\text{H}_5\text{OH}$) and remaining organic matter. Excess water was removed and 1 mL of 1M HCl added to vials and shaken horizontally for 2 h to remove ions from strips into solution. Strips were removed from vials and 1M NaOH and 2 ml of phosphate reagent added. Vials were then placed onto a horizontal stirrer for 1.5 h before absorbance of solution at 712 nm was determined by spectrophotometer. Absorbance of a standard curve was determined for each of 5 runs using dibasic potassium phosphate (K_2HPO_4). Phosphate concentrations were calculated from rearrangement of a non-linear regression relationship derived for absorbance (Abs) against phosphate concentration (cp , $\mu\text{mol/g}$) using SAS (SAS Institute 1988):

$$Abs = k_1(1 - \exp^{-k_2 cp}) \quad [6.1]$$

where k_1 and k_2 were parameters of the equation.

Dry matter contents were calculated as the ratio of dry to fresh

weights. Dry weights were recorded on samples oven-dried for 2 weeks at 80°C.

6.2.6 Data analysis

Data for both experiments were subjected to analysis of variance using the general linear models procedure of SAS (SAS Institute 1988) to examine effects of grading treatments and orchard line differences. Analysis of proportions was carried out using the frequency procedure in SAS (SAS Institute 1988). Presented means were averaged over other treatments and interactions unless otherwise stated.

6.3 RESULTS

6.3.1 Experiment 1

Before grading, mean $f^{initial}$ for orchard lines ranged from 17 to 45 N (SED = 1.5). After grading, 7 weeks further coolstorage, and 1 week simulated shelf-life, graded kiwifruit had a 6% lower mean f^{final} than control (not graded) fruit (Table 6.1). Orchard lines differed in their mean f^{final} (from 6.6 to 11.4 N; $P < 0.0001$; SED = 0.72). Regardless of $f^{initial}$ before grading, fruit from all orchard lines lay within a narrow range of f^{final} values (Fig. 6.1A). Firmness of orchard lines with high $f^{initial}$ values before grading decreased by 75%, whereas orchard lines with low $f^{initial}$ dropped only 12% (Fig. 6.1B).

After coolstorage and a simulated shelf-life period, mean A^{sp} on fruit that had been graded was 35% more than that on controls (Table 6.1). Mean A^{sp} differed substantially across orchard lines having values from 131 to 451 mm² ($P < 0.01$; SED = 45). A^{sp} on graded fruit had only a weak relationship with $f^{initial}$ across orchard lines ($r^2 = 0.055$, data not shown). In contrast A^{sp} on control fruit decreased as f^{final} for control fruit increased across orchard lines (Fig. 6.2; $r^2 = 0.56$). Graded fruit had a 0.4 times greater mean percentage of rejectable fruit on the basis of soft patches than the level for control fruit (Table 6.1). Mean percentage rejects varied across

orchard lines, ranging from 14 to 43% ($P < 0.001$; data not shown).

Fruit from the healthy and population classes had similar mean calcium concentrations; levels in healthy fruit were higher than those in fruit with soft patches (Table 6.2). Calcium concentrations in individual orchard lines varied from 3.3 to 9.5 mmol/kg ($P < 0.0001$; SED = 0.89). Mean phosphate levels for fruit in the soft patch class were higher than fruit in both the population and healthy classes, which were both similar (Table 6.2). Mean phosphate levels for individual orchard lines varied from 3.9 to 8.1 mmol/kg ($P < 0.001$; SED = 0.87). Dry matter contents for fruit classed as healthy or population were similar; both were higher than the value for soft patch classed fruit (Table 6.2). Dry matter content had no correlation to mean fruit calcium or phosphate concentrations across orchard lines (data not shown); nor was there a significant relationship between any of these 3 variables and mean $f^{initial}$, mean f^{final} or change in firmness across orchard lines.

6.3.2 Experiment 2

Mean $f^{initial}$ averaged across orchard lines ranged from 38 to 47 N (SED = 4.4) and was less for warmed treatments (G_{16} and C_{16}) than for those at 0°C ($P < 0.05$; SED = 0.28; Table 6.3). After grading, 7 weeks coolstorage and 1 week simulated shelf-life, mean f^{final} of fruit from the bottom layer (B) was slightly higher than fruit from the top layer (T; $P < 0.05$ for orthogonal contrast; Table 6.3) whereas control (not graded) fruit (C) values for f^{final} were between the top and bottom layer values. The f^{final} of control (C) fruit was significantly higher than the grading and modified grading treatments (G, G_M), at 0°C but not for fruit warmed at 16°C for 24 h or an additional 24h at 0°C before being graded or not graded (G_{16} , C_{16} , G_0 , C_0). Graded fruit (G) and fruit graded with the modified grader (G_M) had similarly low mean values for f^{final} . They were similar to values for the other grading treatments and their respective grading controls. Warming or re-cooling fruit, grading or not grading did not affect f^{final} (treatments G_{16} , C_{16} , G_0 , and C_0 , respectively; Table 6.3). Overall the difference in f^{final} between

Experiment 2 treatments were small relative to the drop which occurred through the simulated shelf-life period. Orchard lines varied in mean f^{final} averaged across grading treatments, ranging from 10.2 to 14.8 N ($P < 0.001$; $SED = 0.19$).

Mean A^{sp} for fruit from the bottom layer (B) of the bin was smaller than that on fruit from the top layer on average (T; $P < 0.001$ for orthogonal contrast; Table 6.3). Control (C) fruit had greater A^{sp} than fruit from the bottom layer (B) and less than fruit from the top layer (T). Fruit from all remaining treatments were similar to each other and to the controls (C), regardless of flesh temperature, grader modification or even presence or absence of grading (ranging from 92 to 71 mm²). Orchard lines varied in mean A^{sp} ranging from 60 to 110 mm² ($P < 0.01$; $SED = 12$).

Levels of rejects were related to area of soft patches (Table 6.3). Fruit from the top layer (T) had the highest level of rejects (24%) whilst bottom layer fruit (B) had the lowest at 9% ($P < 0.001$). The C treatment fruit had 16% rejects on average and remaining temperature and grading treatments had fruit ranged from 14 to 18% overall with no significant differences. Orchard lines differed in mean percentage rejects from 10 to 19% ($P < 0.001$).

6.4 DISCUSSION

In Experiment 1, reduction in whole fruit firmness associated with grading was statistically significant but contributed only 3% of the overall difference between $f^{initial}$ and f^{final} . All fruit softened to a similar f^{final} value, regardless of $f^{initial}$ before grading. In commercial practice the extent of such a change would be likely to be substantially linked to the temperature regime fruit experience between removal from CA and presentation to the consumer. However, there was still almost a 2-fold range of f^{final} amongst orchard lines essentially unrelated to $f^{initial}$, that presumably was related to other orchard factor(s).

In Experiment 2, grading (G), modified grading (G_M), and re-cooled graded (G_0) treatments reduced firmness consistent with handling effects

observed in Experiment 1. Some of the drop in $f^{initial}$ associated with fruit warming was recovered once fruit were re-cooled to 0°C, consistent with the firmness-temperature coefficient concept outlined for kiwifruit by Jeffery & Banks (1994).

In Experiment 1, grading increased the incidence of soft patches, presumably because of damage that fruit incurred during the grading process (Table 6.1). Amongst control fruit at final assessment, there was a strong relationship between soft patches and f^{final} (Fig. 6.2), perhaps because both of these are linked to a final stage of senescence in the fruit. However, the incidence of soft patches that developed on these fruit was not consistently associated across orchard lines with fruit attributes that might be measured in advance, such as $f^{initial}$, calcium, phosphate, or dry matter. Soft patches caused by handling damage presumably arise through different mechanisms from those due to the localised expression of fruit senescence, which were physiological in origin. Orchard lines closest to whole fruit senescence would, therefore, be expected to have the greatest A^{sp} arising from physiological origins. Soft patches occurring due to handling damage would develop over and above those arising from these causes.

In contrast, grading was not an important factor contributing to soft patch development in Experiment 2 (Table 6.3). These effects appeared to be dominated by the very substantial variation in A^{sp} and firmness associated with position in the bin from which fruit were sampled. There was a consistent increase in A^{sp} in fruit, by c. 200%, from the bottom to the top of the bin. This may have been due to vibration damage which incurred before storage, as fruit in the upper layers of a bulk bins can be exposed to severe vibration damage during transportation (Pang et al. 1995). Vibration of kiwifruit against the bin sides or other fruit may cause superficial injury to the fruit surface which can then lead to water loss, stimulate ethylene production, and subsequent loss of firmness (Mencarelli et al. 1996). An alternative explanation relates to water loss during storage. The fruit in this study were stored in wooden bins without plastic liners enclosing the fruit to reduce water loss during CA storage. Top layer fruit may have been

exposed to a greater air movement than those fruit further inside the bin (cf. fruit on the bottom layer). Therefore, top layer fruit may have had a greater water loss, as it was observed that top layer fruit in some other bins in the coolstore had shrivelled. Kiwifruit stored in high relative humidity have previously been shown to be firmer than fruit stored at lower relative humidity (McDonald & Harman 1982). Thus, the positional variation in firmness and soft patches may have been related to relative rates of water loss during storage. As a further alternative, fruit at the top of the bin may have been colder than those at the bottom, again because of their greater exposure to an air movement and because of temperature gradients within the coolstore associated with external sources of heat (Amos et al. 1993). This would not be consistent with the variation in firmness, as lower temperatures have previously been shown to retard loss of whole fruit firmness (Lallu et al. 1992), but they have also been shown to exacerbate development of low temperature breakdown. The lower temperature that the top layer fruit were exposed to may have influenced the development of soft patches. Variation in firmness and soft patches incidence may, therefore, have related to gradients within the bin due to previous physical damage, or relative humidity or temperature differences through the bins. Excluding the top and bottom layers, any potential variation due to fruit position in the bin would have been spread over all treatments once fruit were randomised, making it more difficult to detect the more minor effects of grading.

Soft patch affected fruit from Experiment 1 had lower calcium and higher phosphate than population or healthy classed fruit (Table 6.2), underlining the potential for a role of composition at harvest in determining fruit susceptibility to soft patches. However, when averaged across all fruit within an orchard line, behaviour of a line in Experiment 1 with regard to premature softening of the whole fruit, soft patches, or LTB, bore no relationship to its composition. Indeed, the differences in fruit mineral contents of fruit with or without soft patches within a line were minor compared to the differences between grower lines. Firstly, this emphasises the value of the paired samples approach used in Table 6.2 in removing line

to line variation from the statistical comparison and facilitating detection of differences which otherwise would have been masked. This resolves the apparent conflict between those workers who have previously found differences in storage behaviour linked to mineral composition and those who have been unable to find such relationships, presumably because the latter did not use designs which removed line to line variation from the comparison (e.g., Resnizky & Sive (1993) found a low correlation between calcium level at harvest and kiwifruit softening). Secondly, it is clear that any effects of the absolute levels of these minerals must to a large extent be dominated by contributions to storage behaviour associated with other fruit attributes, as yet unidentified. Dry matter content was low for the soft patch fruit suggesting that, during fruit development, factor(s) which affect accumulation of photoassimilates such as fruit position on the vine (Hopkirk et al. 1990), could affect the risk of soft patch development. Thus, low calcium content and dry matter status coupled with high phosphate status appear to be indicators that individual fruit may be at risk of developing storage disorders. However, in the absence of a non-destructive test for these attributes, this information provides explanation of why, rather than a management tool by which, fruit may be rejected after harvest. On the other hand, recent evidence (Section 7.3.1.3) has shown that positive enhancement of kiwifruit calcium status can reduce soft patch development, thereby providing growers with a means by which they can reduce such problems.

6.5 CONCLUSIONS

Grading of CA-stored fruit caused a drop in whole fruit firmness and increased A^{sp} . These effects were small compared to variability amongst orchards and variability associated with position in bins from which fruit were sampled. There was no evidence to suggest that fruit from soft lines of fruit suffered more grading damage than those from firmer lines. Within a grower's line, high levels of soft patches in non-graded fruit were associated with low dry matter and calcium contents, and high phosphate concentrations. However, none of these attributes was dominant in

determining soft patch incidence, as there were large variations in their levels between lines that were not reflected in soft patch incidence.

Manipulation of preharvest factor(s) that influence these variables might be a useful supplement to improved postharvest handling procedures as an approach to trying to reduce soft patch incidence but further work should first be conducted to establish if there are other fruit attributes that are better predictors of storage behaviour.

6.6 ACKNOWLEDGEMENTS

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6.8 TABLES

Table 6.1 Overall mean final firmness (f^{final}), area of soft patches (A^{sp}), and percentage of rejects caused by the presence of soft patches for graded and control (not graded) kiwifruit after storage in CA at 0°C for Experiment 1. After grading, fruit were further stored for 7 weeks air coolstorage and 1 week simulated shelf-life; data are averaged over orchard lines (experimental unit = collection of 6 trays from 1 grading treatment).

	Treatments		SED	P
	Control	Graded		
f^{final} (N)	9.5	8.9	0.23	< 0.05
Soft patch area (mm ²)	210	290	21	< 0.001
Soft patch rejects (%)	22	31	-	< 0.001

Table 6.2 Mean calcium, phosphate, and dry matter contents of healthy, population (random sample), and soft patch affected kiwifruit averaged over orchard lines for control fruit in Experiment 1 (experimental unit = 2 subsamples from 33 fruit in 1 control (not graded) tray from 1 orchard line).

	Fruit class			SED	P
	Healthy	Population	Soft Patch		
Calcium (mmol/kg)	7.4	7.1	6.5	0.35	< 0.05
Phosphate (mmol/kg)	5.4	5.3	6.2	0.34	< 0.05
Dry/fresh weight ratio	0.136	0.135	0.129	0.0017	< 0.001

Table 6.3 Mean $f^{initial}$ (before grading) and f^{final} (after being graded) of kiwifruit, stored for 7 weeks at 0°C and 1 week at 20°C, A^{sp} (area of soft patches) and rejects for grading treatments in Experiment 2. Fruit had previously been stored for 20 weeks in CA storage and then 2 weeks air storage at 0°C. Each $f^{initial}$ observation is the mean of 72 fruit. Each f^{final} , A^{sp} , and Rejects observation is the mean of 792 fruit. Treatments were T: top layer of bin; B: bottom layer of bin; C: control; G: graded; G_M : modified grader; G_{16} : fruit at 16°C, graded; C_{16} : fruit at 16°C, control; G_0 : fruit at 0°C, graded; C_0 : fruit at 0°C, control.

Treatments	$f^{initial}$ (N)	f^{final} (N)	A^{sp} (mm ²)	Rejects (%)
Bin position				
T	46	11.6	144	24
B	46	12.2	43	9
Graded (0°C)				
C	45	11.9	86	16
G	43	11.2	84	14
G_M	43	11.2	92	18
Warm graded (0,16°C)				
G_{16}	36	11.6	71	14
C_{16}	38	11.4	74	16
Re-cooled graded (0,16,0°C)				
G_0	44	11.4	80	15
C_0	44	11.3	73	15
SED (all treatments)	4.4	0.28	18	

6.9 FIGURES

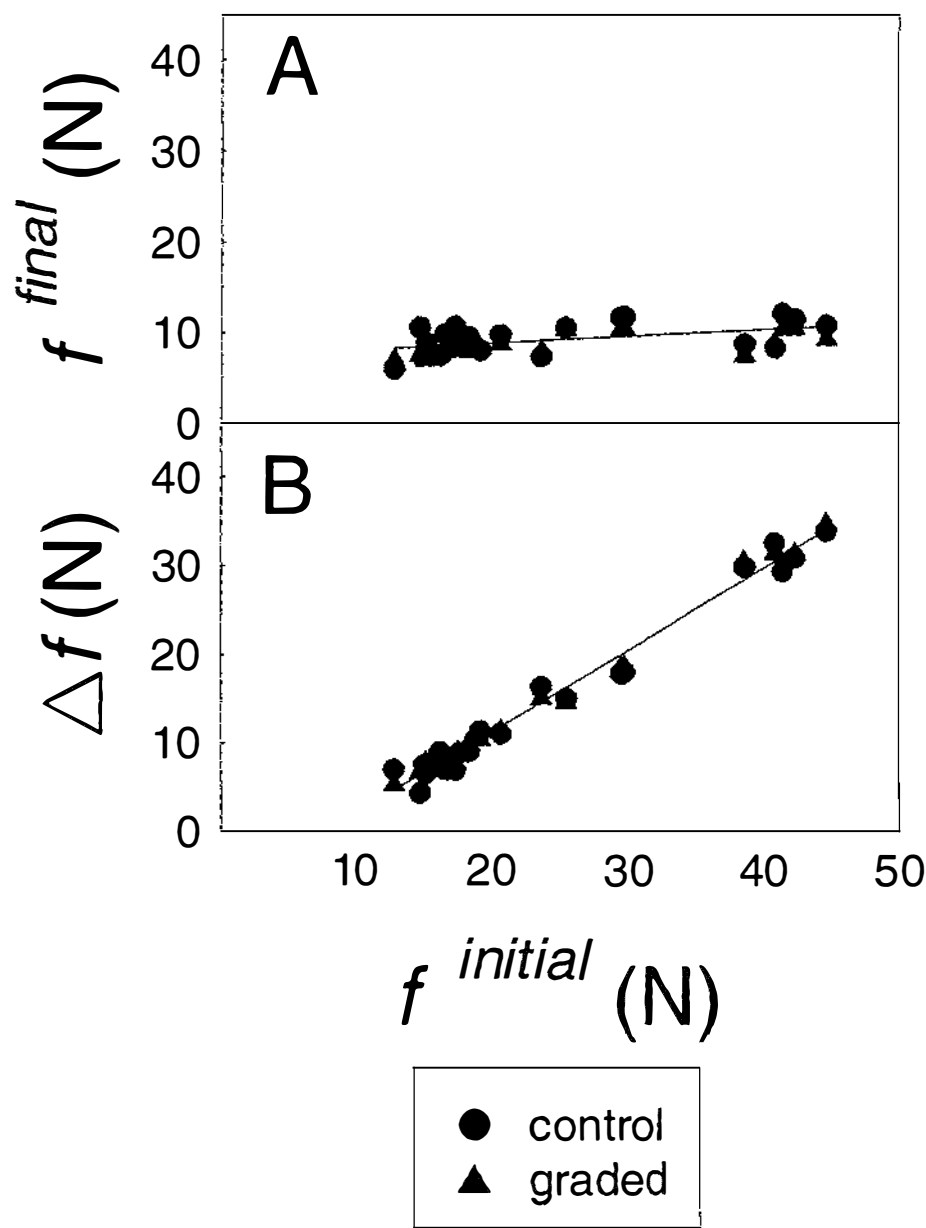


Fig. 6.1 A, Relationship between final firmness (f^{final}) and initial firmness ($f^{initial}$) of graded and control (not graded) kiwifruit after 7 weeks at 0°C and 1 week 20°C storage; and B, difference between $f^{initial}$ and f^{final} values (Δf) for graded and control fruit against $f^{initial}$ averaged across fruit within orchard lines for Experiment 1 (equations for fitted lines for: A, $f^{final} = 7.3 \pm 1.29 + (0.074 \pm 0.0193) f^{initial}$; $r^2 = 0.28$; and B, $\Delta f = -7.3 \pm 1.29 + (0.93 \pm 0.019) f^{initial}$; $r^2 = 0.98$; Symbols represent means of 33 fruit). Fruit had previously been stored for 20 weeks CA and then 2 weeks air storage at 0°C.

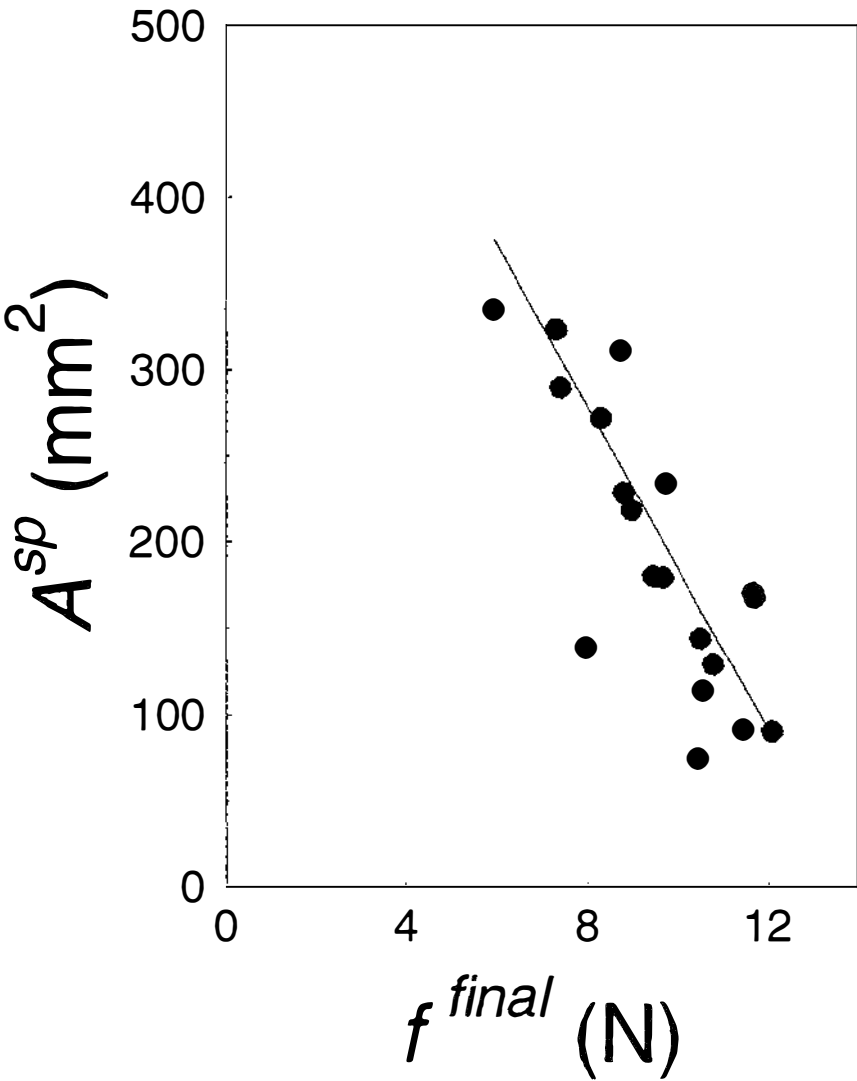


Fig. 6.2 Mean A^{sp} of control (not graded) kiwifruit plotted against mean f^{final} assessed after 7 weeks at 0°C and 1 week at 20°C for orchard lines for Experiment 1 (equation for fitted line $A^{sp} = 614.4 \pm 62 - (47.0 \pm 0.97) f$; $r^2 = 0.56$; symbols represent means of 33 fruit). Fruit had previously been stored for 20 weeks CA and then 2 weeks air storage at 0°C.

Preharvest manipulation of kiwifruit calcium levels

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7.i Abstract Treatments with low concentration calcium salt dips (calcium chloride (CaCl_2) or calcium nitrate ($\text{Ca}(\text{NO}_3)_2$), surface painting to fruit, and whole vine spraying of transpirant drying oils, were applied to kiwifruit (*Actinidia deliciosa*) during growth on the vine. Fruit dipped in calcium solutions were harvested at 7.2 and 13.1% soluble solids content, and some fruit from both harvests were impacted with a sphere (impact energy = 0.94 J) to examine fruit susceptibility to impact. After 20 weeks coolstorage at 0°C, dipped fruit had elevated calcium content, and less incidence of soft patches (localised soft areas) than non-dipped control fruit. Firmness of fruit after coolstorage was unaffected by dips. Soft patches in the impact region were not affected by number of calcium dips or fruit maturity. Late harvested fruit had lower calcium concentration and higher firmness level after coolstorage than earlier harvested fruit. In a second study, application of olive oil and sodium carbonate (Na_2CO_3) mixture early during fruit growth increased calcium concentration and firmness of the painted half of individual fruit after coolstorage. However, these fruit developed surface scarring and splitting on the painted surface. In a third study, a drying oil based formulation (Amsec) sprayed onto whole vines increased fruit permeance to water vapour. Permeance of fruit increased with the number of sprays. However, fruit with the highest number of Amsec sprays had the lowest calcium and firmness after coolstorage: whole vine spraying was not effective for enhancing calcium uptake by fruit. Further work on developing practical techniques to increase fruit calcium status should be undertaken.

7.ii Keywords kiwifruit; *Actinidia deliciosa*; preharvest; permeance; harvest; coolstorage; calcium; firmness; soft patches; calcium nitrate; calcium chloride; dipping oil

7.1 INTRODUCTION

The kiwifruit (*Actinidia deliciosa* (A.Chev) C.F. Liang et A.R. Ferguson) is an important export to New Zealand. Unfortunately, fruit are prone to storage disorders such as *soft patches* (localised soft areas; Banks et al. 1992). Several studies link premature softening in kiwifruit to low calcium status (Prasad & Spiers 1992; Banks et al. 1995b). Calcium is an important nutrient and maintenance of relatively high calcium concentration in fruit tissue results in a slower rate of ripening and fruit softening (Ferguson 1984). Lack of calcium has been shown to be linked to increased incidence of disorders such as chilling injury (Wang 1990). Ferguson (1980) reported that kiwifruit had an 8 and 2 fold higher calcium concentration than apples and grapes, respectively. However, despite high average calcium concentrations relative to other crops, individual kiwifruit within a population may be at risk from low calcium status depending on the spread of values within the population (Resnizky & Sive 1993; Banks et al. 1995b). A lack of calcium content in the soil is not necessarily a limiting factor, as application of calcium to soil does not automatically enhance kiwifruit calcium concentrations or improve kiwifruit storage quality (Harker et al. 1990).

Kiwifruit calcium concentration can be increased by direct application of low concentration calcium salt solutions to fruit (Hopkirk et al. 1990; Prasad & Spiers 1992; Gerasopoulos et al. 1996). Hopkirk et al. (1990) and Prasad & Spiers (1992) reported that postharvest dips of calcium chloride (CaCl_2) enhanced fruit calcium contents and slowed softening in storage. For many years, fruit growers have routinely sprayed calcium salt solutions to apples to increase their calcium concentration leading to improved fruit quality (Watkins et al. 1989). Similar sprays applied to kiwifruit in a study by Harker et al. (1990) caused skin damage and did not improve firmness. In contrast, when Gerasopoulos et al. (1996) applied preharvest sprays of CaCl_2 to kiwifruit, the softening rate of fruit in storage at 0°C was slowed relative to controls. Calcium sprays had enhanced the calcium concentration in kiwifruit by at least 200% without reported damage

to fruit. Calcium solutions could be applied as preharvest dips to kiwifruit to improve fruit storage quality, since there is an apparent association between fruit calcium and the incidence of soft patches and firmness (Prasad & Spiers 1992; Resnizky & Sive 1993; Banks et al. 1995b; Gerasopoulos et al. 1996).

Manipulation of mechanisms in kiwifruit regulating calcium uptake may provide an alternative means of enhancing calcium concentration and improving fruit storage quality. Rate of sap movement in xylem is known to influence uptake of calcium into plant parts (Smith et al. 1995). This is partly regulated by transpiration rate. Most uptake of calcium into kiwifruit occurs in the first 8 weeks after anthesis, a phenomenon thought to be linked to substantial reduction in fruit permeance to water vapour (P'_{H_2O}) during or soon after the early period of fruit growth (Clark & Smith 1988). Thereafter, most calcium taken up into plants goes into leaves (54%; Kotze & de Villiers 1989) due to their high transpiration rate, with the remainder translocated to shoots, fruit or accumulation in roots (Stebbins & Dewey 1972). However, Lang & Volz (1993) suggested that meteorological conditions such as exposure to sunlight which stimulate foliar transpiration should also increase calcium concentration in fruit. Antognozzi et al. (1995), and Hopkirk et al. (1990), found that long term coolstored kiwifruit grown in direct sunlight had a higher firmness and calcium concentration than fruit from similar positions that had been shaded. This indicates a role for fruit transpiration in the accumulation of calcium.

Reducing the natural limitations to water loss in developing fruit would enable a higher transpiration rate over a longer period, and would be expected to enhance calcium levels. A sodium carbonate (Na_2CO_3) and olive oil emulsion mixture sprayed onto grapes before harvest resulted in enhanced transpiration, enhanced calcium uptake, and reduced respiration after harvest (During & Oggionni 1986). Commercial production of table grapes and wine sometimes involves use of ethyl esters of fatty acids to enhance water loss. Ethyl oleate has been reported to be an effective material for enhancing dehydration of grapes (Ponting & McBean 1970;

Uhlig et al. 1996). The oil appears to penetrate the waxy layer and increase P'_{H_2O} (Possingham et al. 1967). Drying oils penetrate the cuticular wax and appear to cause changes in the arrangement of the wax components, and skin permeability to water (Uhlig et al. 1996). Commercial drying oil products from Australia such as 'Amsec' and 'Eemulsoyle' contain 40 and 60% ethyl oleate, respectively; Eemulsoyle also contains potassium carbonate (K_2CO_3). Applications of such materials could be expected to increase P'_{H_2O} in developing kiwifruit, thereby enhancing calcium uptake into fruit.

This study was carried out to determine whether deliberate preharvest dipping of kiwifruit with a low concentration calcium salt or application of drying oils would increase calcium content and improve fruit quality after long term coolstorage.

7.2 MATERIALS AND METHODS

7.2.1 Fruit

All kiwifruit treated were obtained from vines growing on wooden T-bar frames in rows planted north to south at the Massey University Fruit Crops Unit orchard, which had been grafted into rootstock (Cruz-Castillo et al. 1991). In Experiments 1 and 2, fruit were thinned to 1 fruit per cluster. Vines for Experiments 3 and 4 were thinned according to standard orchard practice. The experimental population for Experiments 1 and 2 excluded fruit growing in the central and horizontal section of the canopy, and all fruit less than 0.5 m above the ground. Only fruit growing in the middle and upper vertical sections of the canopy were used as means to reduce fruit to fruit variation associated with positional differences.

7.2.2 Experiment 1: calcium dips

The experiment was a randomised complete block design with 4 replications; vines were treated as blocks. Calcium solutions were applied as individual preharvest dips to fruit with a 2 weekly interval between

successive dips. One of 2 dipping solutions (0.05 M CaCl_2 or $\text{Ca}(\text{NO}_3)_2$ in distilled water with Triton x-100 at 0.1% as a wetting agent was applied as a dip to kiwifruit, at 1 of 4 different numbers of applications (0 (control), 2, 4, and 8 dips) starting on the 18 January 1992. Both calcium salts were applied separately to each of 20 randomly selected fruit on a vine for each number of dips, for each of 2 subsequent harvests. Selected fruit were first dipped on the Harvests were completed at 2 levels of fruit maturity on 6 May and 3 June 1992 (7.2% and 13.1% soluble solids content, respectively, as determined on samples of 30 randomly selected fruit using a hand held Atago refractometer, 0-20° Brix). At each harvest, 10 randomly selected fruit per vine for all treatments were given a 0.94 J impact with a hockey ball (0.16 kg) from a height of 0.6 m. The other, non-impacted fruit were left as controls for the impact treatment. All fruit from a single treatment were placed carefully into 33 count moulded plastic pocket packs in single layer trays.

7.2.2.1 Permeance

Values for $P'_{\text{H}_2\text{O}}$ of individual fruit were determined on a random sample of 5 fruit from each treatment per block after the eighth dip had been applied and at both harvests. Fruit were removed from the vine carefully at 8 am with the pedicel still attached. Pedicels were trimmed to 10 mm and petroleum jelly applied to cover the cut surface. Fruit to be measured were placed randomly onto wire racks in a room at 20°C at 49, 40, and 55% relative humidity for the 3 collection times, respectively, in an air stream with a velocity of c. 3 m/s. After 4 h equilibration, fruit weights were determined before and after a 2 h period of weight loss. Wet and dry bulb temperatures were measured using thermistors. Skin temperature was estimated by inserting a thermistor beneath the intact fruit of 3 additional fruit. Skin temperature readings were made at 3 separate sites at equal distances around the equator of each of fruit and averaged. Values for $P'_{\text{H}_2\text{O}}$ were then calculated using Fick's Law (Banks et al. 1995a) and psychrometric relationships (Campbell 1977). Pedicels were then removed and fresh weight determined. All experimental fruit were labelled with a

sticker that had a fruit number and a treatment letter. All labelled fruit from a vine (block) were randomised over three 33 count moulded plastic pocket packs in single layer trays with polyliners. Trays of fruit were placed into coolstorage at 0°C for 24 weeks, being randomised within blocks.

7.2.2.2 *Firmness, soft patches and calcium*

Fruit were assessed immediately after removal from coolstorage. Soft patches were identified by feeling the entire fruit surface without visual examination. Once a soft patch was found, its perimeter was marked and its surface area (mm²) quantified using a transparency marked with circles of different areas. Areas of all individual patches on each fruit were summed to provide an aggregated value. A fruit was classified as a reject if the soft patch area at the impact site (A^I) or total soft patch area on the fruit surface excluding the impact site (A^E) exceeded 100 mm². One firmness reading per fruit was made on tissue devoid of soft patches with the skin tissue removed. Firmness was measured using 1 of 2 Effegi penetrometers (0-118 N and 0-39 N), each mounted in a drill press with a 7.9 mm diameter head. Calcium was determined on batches of median slices from each of 10 randomly selected fruit per treatment per vine (block). Duplicate samples of c. 3 g of homogenised tissue were analyzed on a fresh weight basis for each batch as described previously (Section 6.2.5).

7.2.3 Experiment 2: preliminary drying oil treatment

A surface treatment containing olive oil and sodium carbonate (Na₂CO₃), both at 2% in tap water with Triton-X-100 wetting agent at 0.1% was applied to 30 randomly selected fruit on 6 vines on 14 January 1992. Treatment was applied by brush to half of each fruit surface, giving control and treated halves on each fruit. Fruit were harvested in early May 1992 and stored in 30 count moulded plastic pocket packs in single layer trays with polyliners at 0°C for 23 weeks.

7.2.3.1 *Firmness*

Firmness of fruit was determined immediately upon removal from coolstore

as in Experiment 1 for both treated and control halves.

7.2.3.2 Calcium

Calcium was determined on a median slice from each fruit taken adjacent to the tissue on which firmness was measured. Slices were then cut into appropriate halves. Fruit slices were ranked into 10 batches of 3 fruit according to firmness of their control halves, and each batch divided into control and treated halves. Duplicate sub-samples of each of these 20 samples were analyzed as in Experiment 1.

7.2.4 Experiment 3: screening drying oils

Two commercially available "drying" oils used in the Australian grape industry were applied to the surface of individual fruit to screen their effectiveness for enhancing fruit P'_{H_2O} . 'Amsec' and 'Eemulsoyle' were each used at 6 levels (0, 0.5, 1, 2, 2.5, and 5% v/v in distilled water), and a second non-dipped control was also used. Each treatment was applied by dipping 8 fruit, all removed from 1 vine on 11 January 1993. Fruit were placed onto wire racks at 20°C at 47% relative humidity before P'_{H_2O} was determined as in Experiment 1.

7.2.5 Experiment 4: Amsec oil spray

The experiment comprised 3 blocks (8 vines per block), with treatments being allocated randomly to whole vines within blocks. There were 2 factors: fertilizer (at 2 levels: none or $Ca(NO_3)_2$) application to the soil at the base of vines at full bloom, and 5% Amsec oil sprayed onto whole vines (at 4 levels: 0 (control), 2, 4, or 6 times). Amsec was sprayed at 2 weekly intervals starting 6 weeks after full bloom on 30 November 1993. For each orchard row, a male vine had been planted for every 3 female vines. The male and second female vines were used as guard plants between treatment vines. Whole vines were sprayed with Amsec using a hand pump back-pack sprayer (Solo knapsack). Calcium fertilizer was applied as a calcium treatment to soil surrounding a vine comprising an application of 0.064

kg/m² as Ca(NO₃)₂ based on the nitrogen application rate for kiwifruit (Clarke et al. 1986).

7.2.5.1 Permeance, fresh weight, firmness, soluble solids content and calcium at harvest

After sprays of Amsec, fruit P'_{H_2O} , and fresh weight were measured on a random sample of 10 fruit per block after 2, 4, and 6 spray applications for each level of spraying that had been completed. Values for P'_{H_2O} were determined as in Experiment 1. On 2 May 1994, 2 samples of 10 randomly selected fruit for each of the 8 treatments per block were removed from the vine for assessment, the first was assessed for its firmness and soluble solids content and the second for estimation of P'_{H_2O} and calcium, which were measured as in Experiment 1.

7.2.5.2 Firmness and soft patches after storage

Fruit were harvested on 2 May 1994 by vine, with all fruit from a vine being randomly picked by hand into 30 count plastic moulded pocket packs, in single layer trays with polyliners. Fruit from each vine were stored in separate trays. Trays were placed onto a pallet according to block, and treatment trays randomised within blocks before coolstorage at 0°C. After 26 weeks in coolstorage fruit were assessed immediately after removal from coolstorage for final firmness and soft patches as in Experiment 1. A fruit was classified as a reject if its A^p over the entire fruit surface exceeded 100 mm².

7.2.6 Data analysis

Data were subjected to analysis of variance using the general linear models procedure of SAS (SAS Institute 1988) to examine effects of treatments, appropriate interactions, blocks, and contrasts. Analysis of proportions was carried out using the frequency procedure in SAS (SAS Institute 1988).

Data presented in results are expressed as means averaged over other factors and interactions in each experiment unless otherwise stated.

7.3 RESULTS

7.3.1 Experiment 1: calcium dips

7.3.1.1 Calcium

Calcium dips caused no surface pitting or obvious damage to fruit at harvest, but fruit dipped 8 times with either $\text{Ca}(\text{NO}_3)_2$ or CaCl_2 had a darker brown appearance than fruit having a lesser number of dips. Overall, both types of dip had similar effects on fruit calcium concentrations. Fruit calcium concentration increased linearly with increasing number of dips (Fig. 7.1A; orthogonal contrast $P < 0.05$). Early harvested fruit had a higher fruit calcium concentration than late harvested fruit (12.5 and 7.9 mmol/kg, respectively; $P < 0.01$; SED = 0.61). Early harvested fruit weighed 91 g on average compared to the larger 97 g fruit from the late harvest ($P < 0.001$; SED = 1.3).

7.3.1.2 Firmness

Mean firmness of fruit after 24 weeks coolstorage did not differ amongst number of dips overall ($10.4 \text{ N} \pm 0.14$). Fruit dipped in CaCl_2 had a slightly higher firmness than fruit dipped in $\text{Ca}(\text{NO}_3)_2$ (10.5 and 10.2 N, respectively; $P < 0.05$; SED = 0.14). Firmness of the late harvested fruit was 3 N higher than early harvested fruit (12.0 and 8.8 N, respectively; $P < 0.0001$; SED = 0.14). Fruit harvested late had a higher firmness than fruit harvested early, regardless of the number of times they had been dipped ($P < 0.05$; data not shown). Firmness varied on average amongst blocks from 9.2 to 12.0 N ($P < 0.0001$; SED = 0.20).

Orthogonal contrast of fruit from the impact versus no impact (control) treatments showed that they had the same overall firmness when assessed after long term coolstorage. Impacting fruit at harvest did not affect firmness for fruit treated with different types of calcium salt, number of dips, or time of harvest (data not shown).

7.3.1.3 *Soft patches*

Impact did not affect mean A^E , occurring on the fruit surface excluding the impact site. A^E was approximately halved as the number of dips increased from 0 to 8 (linear orthogonal contrast $P < 0.01$; Fig. 7.1B). Percentage rejects due to soft patches occurring on fruit excluding the impact site were highest for 0 and 2 dips, decreasing for 8 dips ($P < 0.01$; Fig. 7.1C). CaCl_2 dipped fruit had smaller soft patches occurring on fruit excluding the impact site than $\text{Ca}(\text{NO}_3)_2$ dipped fruit (55 and 76 mm^2 , respectively; $P < 0.05$; $\text{SED} = 10$). CaCl_2 dipped fruit also had less rejects than $\text{Ca}(\text{NO}_3)_2$ dipped fruit (13 and 18%, respectively; $P < 0.05$) due to reduction in numbers of soft patches occurring on fruit excluding the impact site. A^E on fruit excluding the impact site varied amongst blocks from 40 to 93 mm^2 ($P < 0.05$).

Fruit impacted at harvest and assessed 24 weeks after coolstorage had nearly a 20 fold greater mean A^I (area of the soft patch at the impact site) than control fruit (200 and 11 mm^2 , respectively; $P < 0.0001$; $\text{SED} = 4$). A^I was similar across number and types of dips, and time of harvest (data not shown). Soft patches at the impact site caused 94% of impacted fruit to be classed as rejects, whereas only 4% of the non-impacted controls were rejected ($P < 0.001$). Fruit from both CaCl_2 and $\text{Ca}(\text{NO}_3)_2$ treatments and both times of harvest had a similar level of rejects due to soft patches at the impact site.

7.3.1.4 *Permeance*

Values for $P'_{\text{H}_2\text{O}}$ after the eighth application for CaCl_2 (648 $\text{nmol/s.m}^2.\text{Pa}$) of dipped fruit were higher than the control fruit (570 $\text{nmol/s.m}^2.\text{Pa}$; $P < 0.01$; $\text{SED} = 28$). $\text{Ca}(\text{NO}_3)_2$ dipped fruit had the same $P'_{\text{H}_2\text{O}}$ as controls. At harvest, there was no difference in $P'_{\text{H}_2\text{O}}$ amongst dipped fruit (data not shown; overall mean value = 40 $\text{nmol/s.m}^2.\text{Pa}$) or controls, but early harvested fruit had a higher $P'_{\text{H}_2\text{O}}$ (45 $\text{nmol/s.m}^2.\text{Pa}$) than late harvested fruit (33 $\text{nmol/s.m}^2.\text{Pa}$; $P < 0.0001$; $\text{SED} = 3$).

7.3.2 Experiment 2: preliminary drying oil treatment

Firmness of the oil emulsion painted half of fruit after 23 weeks at 0°C, was almost double that of the control values (9.1 and 5.4 N; $P < 0.0001$; SED = 0.72). Calcium levels in the painted half of fruit were 25% more than control levels, but only different at the $P < 0.1$ level (8.6 and 7.0 mmol/kg, respectively; SED = 0.82). Darkened scarring developed on the oil painted surface and there was some splitting of the treated surface in a small proportion of the fruit.

7.3.3 Experiment 3: screening drying oils

P'_{H_2O} was higher for Amsec than Eemulsoyle treated fruit and increased in response to oil concentration, ranging from 460 nmol/s.m².Pa (control) to 762 nmol/s.m².Pa (Amsec 5%; complete data not shown; $P < 0.0001$; SED = 26). There was marking on the fruit surface for Eemulsoyle dipped fruit at the 2 highest concentrations.

7.3.4 Experiment 4: Amsec oil spray

7.3.4.1 *Permeance, fresh weight, firmness, soluble solids content and calcium at harvest*

P'_{H_2O} of developing control fruit dropped over the season from 762 nmol/s.m².Pa on 1 January 1994 to 17 nmol/s.m².Pa ($P < 0.0001$; SED = 25) at harvest. There was no difference measured between controls and treated fruit until after the sixth spray treatment. P'_{H_2O} of fruit after 6 sprays and at harvest increased with number of sprays applied (Fig. 7.2A). Fruit firmness at harvest was linearly and negatively related to number of sprays ($P < 0.05$; Fig. 7.2B). This relationship was not maintained after fruit had been coolstored. There was a similar relationship between mean soluble solids content at harvest and number of sprays, with the control having the highest value (orthogonal contrast $P < 0.01$; Fig. 7.2C). Fruit not sprayed with Amsec had the highest mean fruit calcium levels at harvest, with fruit that had received 6 spray applications having the lowest ($P < 0.05$; Fig. 7.2D). Fruit from vines not given the calcium fertilizer treatment (control) had a

higher mean calcium content than fruit from vines with $\text{Ca}(\text{NO}_3)_2$ (8.7 and 7.6 mmol/kg, respectively; $P < 0.05$; $\text{SED} = 0.39$). Fruit harvested from vines not treated with calcium fertilizer (control) had a reduced mean fresh weight across a number of spray applications (0.11 to 0.10 kg; $P < 0.05$; $\text{SED} = 0.030$), whereas fruit from vines given the calcium fertilizer treatment increased in fresh weight across number of spray applications (0.10 to 0.11 kg; $P < 0.05$; $\text{SED} = 0.030$).

7.3.4.2 Firmness and soft patches after storage

After 26 weeks coolstorage at 0°C the number of sprays had no effects on final fruit firmness or A^{sp} (data not shown). Blocks ranged in levels of mean firmness and A^{sp} from 13.4 to 10.7 N ($P < 0.001$) and 154 to 472 mm^2 ($P < 0.01$), respectively. Fruit receiving 2 and 6 sprays had a similar level of mean rejects of c. 30%, whilst 4 and 0 (control) sprays had lower values of 23% and 26% ($P < 0.001$). Fruit from vines given the calcium fertilizer treatment had more rejects than non-fertilized controls (29 and 26%, respectively; $P < 0.05$).

7.4 DISCUSSION

7.4.1 Calcium dips

Treating kiwifruit with preharvest dips of calcium salts lowered the incidence of soft patches after long term coolstorage at 0°C (Fig. 7.1). This was consistent with the findings by Banks et al. (1995b), that soft patches are found on fruit with a low calcium concentration. This evidence supports a causal role for calcium in reducing kiwifruit susceptibility to soft patch development during coolstorage. Adequate calcium levels in kiwifruit appear to prevent premature deterioration of fruit quality similar to preharvest or harvest applications of calcium to apples reduces the incidence of bitter pit (Saure 1996). Given the timing of repeated dips, it appeared that reduction in soft patch development was not dependent on fruit having calcium concentration enhanced during the early stages of fruit growth.

Repeated dipping of fruit had a cumulative effect on the level of calcium in the fruit. The darkening of fruit skin to a brown colour caused by the 8 dip treatment was a potential concern, but given the natural brown colour of kiwifruit, some browning may be acceptable. There was no obvious scarring or pitting to the fruit surface as found by Harker et al. (1990) when preharvest fruit were sprayed with calcium salts. Dipping of fruit would be too labour intensive to be applied in commercial practice, and spraying should be re-investigated as an alternative to identify a treatment that achieves a substantive reduction in soft patch development without causing surface blemish, particularly given the recent success in this regard by Gerasopoulos et al. (1996).

Enhanced calcium status would also have been expected to affect overall fruit firmness as in studies by Prasad & Spiers (1992) and Gerasopoulos et al. (1996), yet this was not the case for dipped fruit in this study. Likewise, there was no link between calcium status and fruit firmness after long term coolstorage in Experiment 4. Increases in calcium levels in kiwifruit required to have an effect on whole fruit softening may be greater than those required to affect fruit susceptibility to development of soft patches.

Both types of calcium dip achieved similar increases in fruit calcium. Both materials would have increased kiwifruit calcium content by direct movement into fruit through the skin. In addition, CaCl_2 enhanced fruit $P'_{\text{H}_2\text{O}}$ and this could have enhanced the fruit calcium uptake still further above the amount taken up directly from the dips (Smith et al. 1995). Enhanced calcium uptake associated with greater $P'_{\text{H}_2\text{O}}$ may result in a more generalised and even distribution of calcium through the fruit than direct application to the fruit surface. Measured firmness was higher for CaCl_2 than $\text{Ca}(\text{NO}_3)_2$ which may have been linked to an effect of this type.

After storage, late harvested fruit with lower calcium concentrations had superior firmness to early harvested fruit, a finding similar to those of Kempler et al. (1992) and Mitchell et al. (1992), indicating that variation in maturity contributed more to final firmness than variation in calcium content

in fruit. The nature of these influences merits further investigation. The drop in calcium concentration was greater than could be explained by associated fruit growth (6.6%) between the 2 harvests and is difficult to explain without proposing remobilisation of calcium (Clarkson 1984). However, as calcium has been shown to be an immobile element once taken into fruit it is probably unlikely that remobilisation of calcium would actually occur.

Soft patches occurring on fruit outside the impact site were physiological in origin while those that developed at the impact site were presumably mostly caused by the impact itself. In contrast to data presented by Banks et al. (1995b), impacts to late harvested fruit appears to indicate that maturation had no discernible effect on level of soft patches arising from standardised impact. Soft patches that developed due to physical damage appeared to bear no relationship to fruit calcium concentrations, whereas those that developed on fruit due to physiological reasons outside the impact site did (Resnizky & Sive 1993; Section 6.3.1).

Impacts (0.94 J) to harvested fruit in this study nearly always resulted in soft patches at the point of impact, but did not affect levels of soft patches that developed outside the impact site. Neither did impact affect overall fruit texture as determined by penetrometer. Thus, impact damage in kiwifruit subsequently stored at 0°C appears to result in localised tissue damage but not to effect textural change generally throughout the fruit. This is consistent with the findings in Section 3.3.1 in which the effects of compression on soft patch development in kiwifruit were shown to be restricted to the contact site between fruit. In addition, 6% of fruit struck by the ball at an impact energy of 0.94 J were not classed as rejects. This is consistent with findings in Section 4.3.1, where a small portion of fruit resisted development of soft patches due to high energy impact.

7.4.2 Preliminary drying oil treatment

Enhanced calcium content of halves of kiwifruit painted with an olive oil

and Na_2CO_3 emulsion was due presumably to an increased transpiration rate during early fruit growth in similar way to that described by During & Oggionni (1986) in grapes. The scarring and splitting caused by this treatment may have been due to a direct chemical effect (e.g., because of the high pH emulsion). Alternatively, the damage may have arisen because of drying out of the epidermal cells on the fruit skin surface. Although these undesirable cosmetic effects would have made the fruit unsuitable for sale, the treatment demonstrated the potential both to increase fruit calcium status and enhance firmness after long term coolstorage, when $P'_{\text{H}_2\text{O}}$ was enhanced with use of a transpiration accelerant. This was consistent with the findings of Hopkirk et al. (1990) that fruit exposed to sunlight have a higher transpiration rate, calcium, and firmness compared to shaded fruit. Presumably, the magnitude of benefit to calcium status achieved by such a treatment would interact with environmental conditions, with largest benefits being expected to be associated with high fruit temperatures and low relative humidity.

7.4.3 Amsec oil spray

Individual dips with Amsec at 5% substantially enhanced transpiration without causing burning of the fruit surface as caused by Eemulsoyle, or the cracking and splitting caused by olive oil and Na_2CO_3 mixture. However, repeated spray applications to whole vines during growth had only a limited effect on fruit $P'_{\text{H}_2\text{O}}$ (Fig. 7.2A). Despite the slight increase in fruit $P'_{\text{H}_2\text{O}}$ with whole vine spraying of Amsec oil, both fruit calcium, firmness, and soluble solids content after coolstorage were depressed (Fig. 7.2), a marked contrast with effects of those obtained when only the fruit were treated with transpiration accelerants. In particular, it was noted that vines sprayed 6 times with Amsec became severely water stressed on hot days. This may have affected the ability of fruit to compete with the rest of the vine for water. Severe water stress may thus have affected mechanisms which promote calcium uptake into fruit (Lang & Volz 1993).

Addition of calcium fertilizer to the soil around vines did not

enhance fruit calcium levels; indeed, total fruit calcium contents were similar in both treatments but, perhaps linked to the greater fruit size in fruit from treated vines, calcium concentration was lower in fruit from vines with calcium fertilizer. The addition of nitrate to the soil at full bloom may have increased the ability of the vine to support fruit growth leading to a dilution of the calcium concentration in fruit. In addition, this treatment may have produced a high nitrogen to calcium ratio (not determined) which has been suggested to adversely effect kiwifruit storage quality (Prasad & Spiers 1992); this would have been consistent with the higher level of rejects seen in fruit from this treatment.

Reject numbers due to A^{SP} for different levels of Amsec spray applications showed no clear trends, and the calcium concentrations did not differ greatly with numbers of spray applications. The relative difference in calcium may have been too small to affect reject numbers.

There was large variation in final firmness and soft patches between blocks in Experiment 4, possibly due to rootstock effects and temperature differentials in the coolstore (Cruz-Castillo et al. 1991; Amos et al. 1993).

7.5 CONCLUSIONS

Calcium has a causative role in reducing kiwifruit susceptibility to soft patches which develop during long term coolstorage. The reduction in the incidence of soft patches in kiwifruit was proportional to the increase in fruit calcium status achieved by preharvest calcium salt dips. On the other hand, fruit harvested more mature developed less soft patches despite lower calcium contents. Study of mechanisms that predispose mature harvested fruit to remain firmer for longer in coolstorage, could be useful in enhancing storage behaviour of kiwifruit. Neither increasing fruit calcium nor harvesting more mature fruit had any effect on the level of damage due to impacts. Application of drying oils to fruit and increasing fruit transpiration during growth only slightly enhanced fruit calcium levels at harvest. Spraying of whole vines had the opposite effect, probably due to adverse affects on water status on the remainder of the vine. It may be difficult to

find an economic method that limits application of oils to fruit only. It therefore seems that benefits from enhanced fruit calcium status will be achieved more readily by sprays with calcium salts than by transpiration accelerants. Whilst negative cosmetic effects of calcium application in this work were minor, further work should be conducted to develop methods and determine levels of concentration of calcium applications that can achieve useful enhancement of fruit calcium status without risk of fruit blemish.

7.6 ACKNOWLEDGEMENTS

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7.8 FIGURES

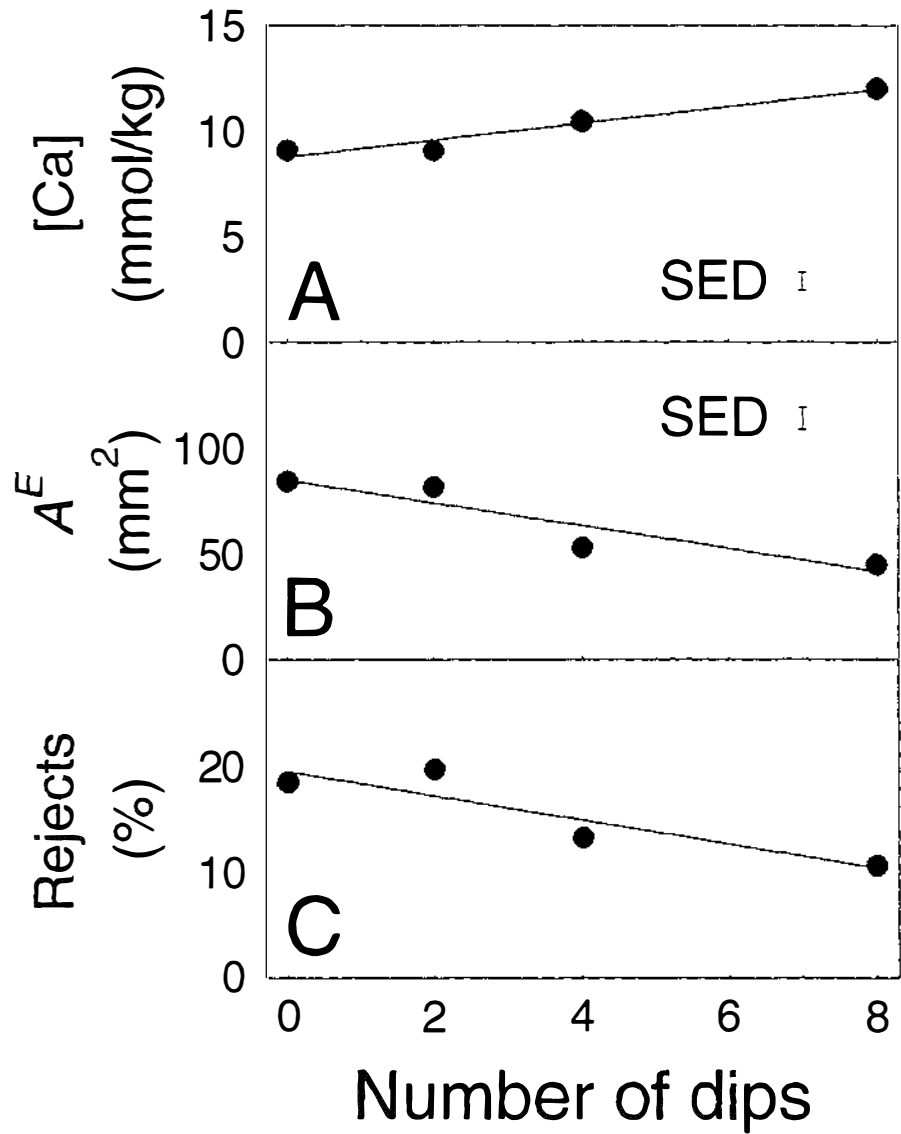


Fig. 7.1 Change in: **A**, mean calcium concentrations ([Ca], mmol/kg, $r^2 = 0.94$, equation of line is $[Ca] = 8.8 \pm 0.41 + (0.40 \pm 0.070) d$); **B**, mean A^E outside the impact site ($r^2 = 0.85$, equation of line is $A^E = 85 \pm 9.5 - (5 \pm 1.6) d$); and **C**, mean rejects (R^E) due to soft patches on fruit outside the impact site ($r^2 = 0.81$, equation of line is $A^E = 20 \pm 2.3 - (1.1 \pm 0.38) d$) for differing number of calcium dips (d) assessed after coolstorage at 0°C for 24 weeks. Each data point is the mean value of 320 fruit.

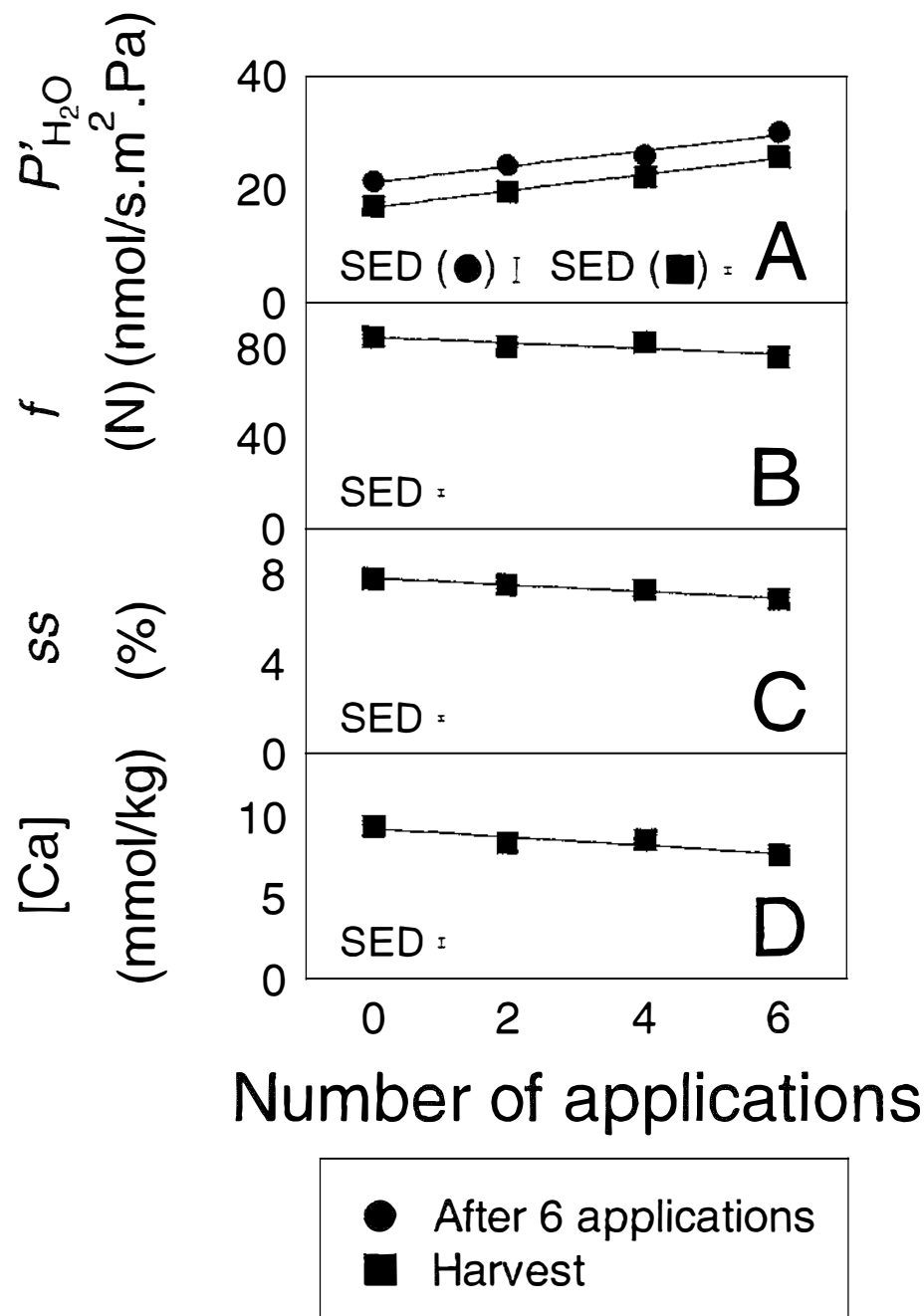


Fig. 7.2 Effects of differing number of oil applications (ap) applied to whole vines: **A**, permeance to water vapour (P'_{H_2O}) after the 6th application (P'_{H_2O} ; $r^2 = 0.97$; equation of fitted line $P'_{H_2O} = 21.2 \pm 0.73 + (1.4 \pm 0.16) ap$) and at harvest (P'_{H_2O} ; $r^2 = 0.99$; equation of fitted line $P'_{H_2O} = 16.8 \pm 0.41 + (1.44 \pm 0.091) ap$), respectively; **B**, firmness at harvest (f ; $r^2 = 0.74$; equation of fitted line is $f = 85 \pm 2.3 - (1.2 \pm 0.52) ap$); **C**, harvest soluble solids content (ss ; $r^2 = 0.98$; equation of fitted line is $ss = 7.81 \pm 0.062 - (0.15 \pm 0.014) ap$); and **D**, mean calcium of harvested fruit ($[Ca]$, mmol/kg; $r^2 = 0.83$; equation of fitted line, $[Ca] = 9.3 \pm 0.38 - (0.26 \pm 0.084) ap$) assessed after 26 weeks at 0°C. Each data point is the mean value of 30 fruit.

Soft patches and low temperature breakdown in kiwifruit: development in coolstorage

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8.i Abstract Kiwifruit (*Actinidia deliciosa*) harvested from different orchard lines, at a range of maturities were stored for 20 weeks at -0.8, 0, or 0.5°C, then assessed for soft patches (localised soft areas on the fruit surface) and internal tissue breakdown linked to long term low temperature storage (low temperature breakdown). Fruit harvested with the most advanced maturity had the lowest incidence of soft patches after coolstorage. Fruit stored at 0.5°C had c. double and triple the area of soft patches found on fruit stored at -0.8 and 0°C, respectively. Soft patch area was negatively correlated with soluble solids content at harvest and calcium concentration for different orchard lines. Fruit with soft patches and low temperature breakdown had lower levels of calcium than healthy fruit. Soft patch development seems likely to be an expression of localised fruit senescence that can lead to whole fruit breakdown and decay. Low temperature breakdown in kiwifruit decreased in severity with more advanced harvest maturity and with warmer storage temperature, supporting the proposition that symptoms of low temperature breakdown are caused by chilling injury during storage. Orchard practices such as enhancing preharvest fruit calcium concentration and selection of fruit with adequate maturity at harvest, should reduce fruit susceptibility to these softening disorders during coolstorage and thereby help reduce the kiwifruit industry's storage losses.

8.ii Keywords kiwifruit; *Actinidia deliciosa*; firmness; soft patch; low temperature breakdown; harvest; maturity; temperature; calcium; coolstorage;

8.1 INTRODUCTION

Premature softening of kiwifruit (*Actinidia deliciosa* (A.Chev) C.F. Liang et A.R. Ferguson) results in loss of potential income to the New Zealand kiwifruit industry each season, and is in part due to localised soft areas on fruit (*soft patches*; Banks et al. 1992). At harvest, kiwifruit typically may have a firmness level of between 69 to 98 N. Kiwifruit are stored commercially at 0°C (coolstorage; McDonald 1990), and can take up to 6 months to fall below a New Zealand Kiwifruit Marketing Board (NZKMB) export firmness threshold of about 10 N (NZKMB 1996).

Rate of softening in storage is influenced by ethylene levels during storage (McDonald 1990), harvest maturity (Kempler et al. 1992), preharvest factor(s) such as calcium concentration (Banks et al. 1995), and the temperature fruit are stored at (Lallu et al. 1992). During storage, individual fruit can soften prematurely and be rejected during condition checking prior to market sale because firmness is below the export threshold (NZKMB 1996). Such premature loss of firmness can happen to the whole fruit, or in a localised area (*soft patch*) on fruit that otherwise have adequate firmness.

Soft patches result from tissue breakdown which may be associated with water-soaking or whitening of sectioned tissue, which are signs of impact at harvest (Section 4.3.1). Physical handling at harvest may expose kiwifruit to damaging impacts or drops (Bollen & Dela Rue 1990; Banks et al. 1992). Once coolstored, prolonged compression of fruit tissue can result in soft patches (Section 3.3.2). In long term coolstorage, such damaged fruit tissue may break down and soften prematurely, and be associated with physiological damage such as chilling injury (Lallu et al. 1992; Banks et al. 1995).

Survey work has found that kiwifruit which develop soft patches have less calcium than their healthy counterparts (Banks et al. 1995). Injuries associated with low storage temperatures in avocados, apples, and peaches are also associated with a lack of calcium (Wang 1990). Low fruit calcium levels cause an increase in the leakiness of cells and deterioration of cellular wall structure in fruit stored at low temperature. These symptoms

are similar to those found in soft patch affected kiwifruit. Therefore, soft patches may be linked to a deficiency of calcium in fruit that increases their susceptibility to breakdown during coolstorage. Postharvest dipping of kiwifruit with calcium has improved fruit quality after long term coolstorage at 0°C (Hopkirk et al. 1990; Prasad & Spiers 1992). Kiwifruit with naturally high levels of calcium might be expected to better resist possible loss of fruit quality related to storage at low temperature.

A commercial coolstore set to 0°C may fluctuate in temperature from -0.5 to 0.5°C (Amos et al. 1993). The highest temperature at which freezing of kiwifruit is likely to occur is -1.5°C (D.C. Marshall *in* Wright & Heatherbell 1967). Kiwifruit would, therefore, be unlikely to freeze in a commercial coolstore due to temperature fluctuations. Nevertheless, some kiwifruit may be predisposed to tissue damage due to prolonged storage at 0°C. Kiwifruit exposed to long term coolstorage at 0°C can develop white flecks and water-soaked tissue radiating from the core (*low temperature breakdown*; LTB), small sunken areas of dead skin tissue (pitting), and darkening of the flesh colour or the core which may become soft and wet (Oogaki et al. 1990; Gorini 1992; Lallu et al. 1992). Lallu et al. (1992) found that some kiwifruit develop internal breakdown after a number of weeks at 0°C, but the incidence was lessened at slightly higher storage temperatures. Chilling injury that results in LTB may, therefore, be affected by temperature fluctuations in coolstore and other preharvest or postharvest factor(s) that predispose fruit to breakdown.

This study was conducted to determine if storage temperature and harvest maturity affected the incidence of soft patches and LTB in kiwifruit after long term coolstorage. The study also sought to confirm the association between incidence of these disorders and low fruit calcium status.

8.2 MATERIALS AND METHODS

8.2.1 Fruit

Samples of commercially grown, harvested, graded and packed kiwifruit (36 count size in single layer trays lined with polyliners; 0.098-0.107 kg) were transported to HortResearch, Mount Albert Research Centre, Auckland. In Experiment 1, fruit were harvested from 3 orchards (orchard lines 1 to 3) in the South Auckland region at 3 different harvest maturities (2 May (*first*), 7 May (*middle*), and 21 May (*last*) 1993). In Experiment 2, fruit were harvested on 7 May, 1993 from a total of 6 orchards in the South Auckland, Gisborne and Bay of Plenty regions.

8.2.2 Experimental Design

In Experiment 1, treatments comprised samples of kiwifruit taken at each of 3 harvest maturities and stored at 1 of 3 temperatures (-0.8, 0, or 0.5°C) in factorial combination. In Experiment 2, treatments comprised 3 temperatures as in Experiment 1. Trays were randomly stacked within an orchard line in each coolstore. An experimental unit comprised 14 trays of fruit.

8.2.3 Assessment

8.2.3.1 Firmness and soluble solids content at harvest

Before any assessments were made on fruit, trays were first removed from coolstorage and left at 20°C for 24 h. At harvest, 1 tray from each treatment for both experiments had all fruit measured for firmness and soluble solids content. Firmness was measured using 1 of 2 Effegi penetrometers (0-118 N or 0-39 N), each with a 7.9 mm diameter head and mounted in a drill press. Two firmness readings per fruit were taken on pared tissue at 90° from each other when viewed down the longitudinal axis. Soluble solids content were measured with a hand-held refractometer (Atago).

8.2.3.2 Firmness, soluble solids content, soft patches and low temperature breakdown after storage

After 20 weeks coolstorage, firmness and soluble solids content were assessed on an additional sample of 20 fruit sampled from 10 trays (2 fruit per tray) for both experiments as above. Fruit in the remaining 3 trays for both experiments were assessed for soft patches and firmness. Soft patches were identified by feeling the entire fruit surface without visual examination. Once a soft patch was found, its perimeter was marked and its surface area (mm^2) quantified using a transparency marked with circles of different areas. Areas of individual patches on each fruit were summed to provide an aggregated value. For Experiment 2, a fruit was classed as a reject if its total soft patch area (A^{sp}) exceeded 100 mm^2 . For both experiments, LTB was subjectively scored by making several cross-sectional cuts from the calyx to the distal end. Fruit were given a score of 0 (no breakdown), through to 4 (severe breakdown through the entire fruit). Fruit were classed as rejects if they had a severity rating of 1 or higher.

8.2.4 Mineral analysis

Calcium concentration was determined on fruit stored at 0°C for all orchard lines in both experiments and for the 3 harvest maturities in Experiment 1. Individual fruit were divided into 4 categories; *healthy* (no soft patches or LTB) *soft patch* (fruit with only soft patches), *LTB* (fruit with only LTB) and, *soft patch+LTB* (fruit with both soft patches and LTB). Fruit in each category were batched by orchard line and harvest maturity. Approximately 3 g of homogenised tissue was analyzed on a fresh weight basis as described previously in Section 6.2.5.

8.2.5 Data analysis

Data were subjected to analysis of variance using the general linear models procedure of SAS (SAS Institute 1988) to examine effects of harvest maturity, storage temperature, orchard lines, and their interactions. Analysis of proportions of LTB was carried out, testing main effects, and interactions

using the frequency procedure of SAS (SAS Institute 1988).

8.3 RESULTS

8.3.1 Experiment 1

8.3.1.1 *Soft patches*

Mean A^{sp} for fruit stored at the highest storage temperature (0.5°C; 163 mm²) was greater than for fruit stored at lower temperatures (0 and -0.8°C, respectively; 109 and 117 mm², respectively ; $P < 0.05$; SED = 19).

Kiwifruit samples from orchard lines 1 and 2 had similar A^{sp} , whereas fruit from orchard line 3 had greater than 3 times the level of soft patches (Table 8.1). Fruit from orchard lines 1 and 2 had variable levels of A^{sp} over the 3 harvest maturities whereas the level of soft patches for orchard 3 dropped consistently with each successive harvest (Fig. 8.1A; $P < 0.0001$). Orchard line 3 had the highest level of soft patches for all orchard lines, at each respective harvest maturity.

8.3.1.2 *Low temperature breakdown*

Fruit from the first harvest (2 May), consistently had the highest rejects due to LTB across all orchard lines. Orchard lines 1 and 2 had substantially less rejects due to LTB than orchard 3 (Fig. 8.1B; $P < 0.001$). LTB was consistently less at the highest temperatures for all orchard lines ($P < 0.05$; Fig. 8.2). Orchard 3 had c. double or more incidence of the rejects due to LTB of the other orchard lines at each storage temperature (Fig. 8.2). Rejects due to LTB in fruit from every storage temperature declined with later harvests (Fig. 8.3; $P < 0.05$). Fruit from the last harvest that were stored at the highest temperature had no LTB rejects.

8.3.1.3 *Firmness*

Orchard lines 1 and 3 had a similar and slightly higher firmness at harvest than those from orchard 2 (Table 8.1). After 20 weeks coolstorage, orchard line firmness ranged from 5.7 N to 7.3 N (Table 8.1). Firmness at harvest

decreased with increasing maturity, dropping from 80.6 to 74.2 N ($P < 0.001$ SED = 1.11). Firmness was similar across harvest dates after 20 weeks coolstorage (6.5 ± 0.30 N), but the first harvested (2 May) fruit were softer than fruit from the last harvest (21 May) at the $P < 0.1$ level. Firmness was considerably lower after 20 weeks storage at the highest temperature (0.5°C ; 5.1 N) than at the lowest temperature (-0.8°C ; 7.6 N; $P < 0.0001$; SED = 0.20).

8.3.1.4 Soluble solids content

At harvest, fruit from orchards 1 and 2 had similar soluble solids content levels, being higher than those for orchard 3 (Table 8.1). After 20 weeks coolstorage, soluble solids content had almost doubled in fruit from all orchards. Levels in fruit from orchards 1 and 2 were still similar to each other, and were higher than those in fruit from orchard 3 (Table 8.1). At harvest, soluble solids content increased with successive harvests, increasing from 7.0 to 8.5% ($P < 0.0001$ SED = 0.37). After 20 weeks coolstorage, soluble solids contents were the same for fruit that had been harvested at different maturities or stored at different temperatures ($13.9 \pm 0.33\%$ in both cases).

8.3.1.5 Calcium

Calcium concentrations were higher in fruit from orchards 1 and 2 than in those from orchard 3 (Table 8.1). There was some indication of variation in calcium status with successive harvests ($P < 0.05$; SED 0.45), although this was not a consistent decline (8.6, 6.8, and 7.6 mmol/kg for the first, second and third harvests, respectively).

8.3.2 Experiment 2

8.3.2.1 Soft patches and low temperature breakdown

Mean A^{sp} varied amongst orchard lines from 35 to 127 mm² ($P < 0.0001$; SED = 11.0). Average values across the different orchard lines ranged from 65, through 37, to 114 mm² for storage temperatures -0.8 , 0, and 0.5°C ,

respectively ($P < 0.0001$; $SED = 7.0$). Mean rejects due to LTB varied with orchard lines ranging from 1 to 5% ($P < 0.001$) and decreased with increasing temperature ranging from 4, through 2, to 1% at -0.8 , 0 , and 0.5°C , respectively ($P < 0.001$).

8.3.2.2 Firmness and soluble solids content

At harvest, mean firmness ranged from 65 to 82 N for the different orchard lines. After 20 weeks coolstorage, firmness of different orchard lines ranged from 5.6 to 7.5 N ($P < 0.05$; $SED = 0.35$). After storage, firmness values for storage temperatures -0.8 , 0 , and 0.5°C were 7.9, 6.8, and 5.2 N, respectively ($P < 0.0001$; $SED = 0.20$). Firmness after coolstorage showed no clear relationship with firmness at harvest ($r^2 = 0.14$; data not shown). A^{sp} averaged over orchard lines was weakly related to increasing firmness after storage ($r^2 = 0.43$; data not shown). Mean soluble solids content at harvest ranged from 6.6 to 8.2% for the different orchard lines ($P < 0.0001$). Soluble solids content differed on average between orchard lines from 12.0 to 15.1% after 20 weeks storage ($P < 0.0001$; $SED = 0.16$) and did not differ across storage temperatures (data not shown).

8.3.2.3 Calcium

Healthy fruit (8.8 mmol/kg) had the highest level of calcium for the different categories (orthogonal contrast for healthy fruit versus those with disorders, $P < 0.001$). Soft patch, LTB, and soft patch+LTB categories (7.6, 7.0, and 7.2 mmol/kg, respectively) had similar values ($SED = 0.52$). Orchard lines ranged in calcium concentration from 6.4 to 8.5 mmol/kg ($P < 0.05$; $SED = 0.64$). A^{sp} of different orchard lines averaged over storage temperatures had a strongly negative association with the product of calcium concentration and soluble solids content at harvest (Fig. 8.4; $r^2 = 0.78$). This relationship was stronger than the product of calcium and final soluble solids content ($r^2 = 0.41$, data not shown).

8.4 DISCUSSION

The most mature fruit at harvest were apparently predisposed to lower incidence of LTB and to a lower level of soft patches (Fig. 8.1A). This was consistent with findings by Kempler et al. (1992), that harvesting mature fruit resulted in better storage behaviour. Fortunately, early harvested fruit are usually exported first. This should help to reduce fruit losses that may otherwise occur if such fruit were given a prolonged coolstorage before export.

Orchard lines with a low level of soluble solids content at harvest and low calcium concentration had a high A^{sp} (Table 8.1; Fig. 8.4). Level of soluble solids content at harvest could provide a potential indicator of an orchard line's susceptibility to soft patch development.

Fruit stored at 0.5°C had the highest A^{sp} , lowest level of LTB, and lowest firmness of all temperature treatments. The fact that these fruit had softened faster than those stored at lower temperatures, is consistent with an earlier finding that at ripening and senescence occurs faster at higher temperature (Lallu et al. 1992). Soft patches may, therefore, be the result of localised natural senescence and breakdown of fruit tissue rather than the result of chilling injury.

In contrast, the negative correlation of LTB with storage temperature (Figs. 8.2 and 8.3) was consistent with the notion that it is a form of chilling injury. The over-riding factor in LTB was storage temperature. Lallu et al. (1992) found that fruit stored at 1°C had a smaller percentage of fruit with LTB than those at 0°C after 20 weeks. To reduce LTB, early harvested fruit could be stored at 1°C instead of 0°C. However, early harvested fruit would probably be exported to markets before LTB would have time to develop.

Some fruit affected with LTB also developed soft patches. Soft patches might be expected to develop if a localised area on the fruit had a low level of calcium, received an impact at harvest, or was compressed during storage, any of which may have physiologically advanced that localised area of tissue towards senescence (Hopkirk & Finch 1989; Banks et al. 1992, 1995).

At harvest, orchard line 3 in Experiment 1 had a lower soluble solids content and after coolstorage, a lower firmness and calcium concentration than other orchard lines (Table 8.1). These factors were associated with the orchard line's high incidence of soft patches and level of LTB (Fig. 8.1). It may be that orchard line's with fruit that soften quickly are also likely to have more soft patches, at any storage temperature, and have a lower calcium and harvest soluble solids content relative to orchard lines that have better storing qualities (Fig. 8.4). Variation in A^{sp} and LTB amongst orchard lines appears to be associated with preharvest differences between those orchards. Identification of preharvest factor(s) that predispose orchard lines to storage disorders, would help in management of the crop to minimise the proportion of crop that had to be rejected once harvested.

Fruit with soft patches or LTB had a lower concentration of calcium relative to healthy fruit. Enhancing calcium concentration of kiwifruit has been shown to reduce soft patch development (Section 7.3.1.3). Any orchard practice that enhances fruit calcium concentration before harvest, might, therefore, be used as a strategy that may developed further as a means to reduce fruit susceptibility to tissue breakdown during coolstorage.

Fruit from the first and last harvests (2 and 21 May, respectively) only had slightly different calcium concentrations but differed substantially in their incidence of disorders. The relationship between A^{sp} , and the product of calcium and soluble solids content (Fig. 8.4) provides tentative evidence for an assessment at harvest to predict the suitability of different lines of fruit for long term storage. It would be worth investigating this issue further to characterise the relationship between levels of critical variables and disorder development. A predictive tool could be developed to determine crop susceptibility to disorders during prolonged coolstorage.

In the longer term, preharvest and harvest methods to enhance fruit storage potential could be developed. For example, positions on the vine that result in fruit with good and bad storing qualities may be identified, thus enabling thinning of fruit with poor storing qualities. Alternatively, positions on the vine that have fruit which mature early could be harvested

first. A second harvest after a time delay could then allow for less mature fruit to develop further and improve their storage potential before they were harvested. If vine positions that lead to fruit with inadequate calcium accumulation could be identified, then the harvest of these fruit could be delayed, to take advantage of good storing qualities that late maturity provides.

8.5 CONCLUSIONS

Whilst LTB could be confidently termed a chilling injury, soft patch development appears to be a response to advanced localised tissue senescence. Fruit with low levels of calcium appeared to have a high susceptibility to soft patches and LTB when put into long term coolstorage. Mature fruit were less prone to LTB and there was an indication of a similar relationship for soft patches. Preharvest and harvest attributes which will enable identification of good and poor storing lines of fruit need to be further characterised. Identification of fruit at risk from these disorders could then be used to manage the export programme. Understanding and manipulation of preharvest and postharvest factors affecting development of soft patches and LTB will aid in the reduction of kiwifruit losses to these two disorders. Early export of orchard lines more susceptible to breakdown would reduce fruit losses and thereby enhance returns to the industry.

8.6 ACKNOWLEDGEMENTS

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8.8 TABLE

Table 8.1 Mean f (firmness) and soluble solids content (ss) at harvest, and after 20 weeks coolstorage mean f , ss , A^{sp} , and Ca^{2+} (calcium concentration) for 3 orchards averaged over 3 storage temperatures and 3 harvest maturities for Experiment 1. Each f and ss value is the mean of 324 fruit. Each A^{sp} value is the mean of 972 fruit. Each Ca^{2+} value is the mean of 36 fruit.

Assessment	Orchards			SED	P
	1	2	3		
At harvest					
<i>f</i> (N)	82.8	65.5	78.9	1.11	< 0.01
<i>ss</i> (%)	7.6	8.3	6.6	0.37	< 0.0001
After storage					
<i>f</i> (N)	7.3	6.7	5.7	0.29	< 0.001
<i>ss</i> (%)	14.5	14.6	12.4	0.46	< 0.0001
<i>A</i> ^{<i>sp</i>} (mm ²)	46	83	259	19	< 0.0001
Ca ²⁺ (mmol/kg)	8.0	7.2	6.4	0.48	< 0.0001

8.9 FIGURES

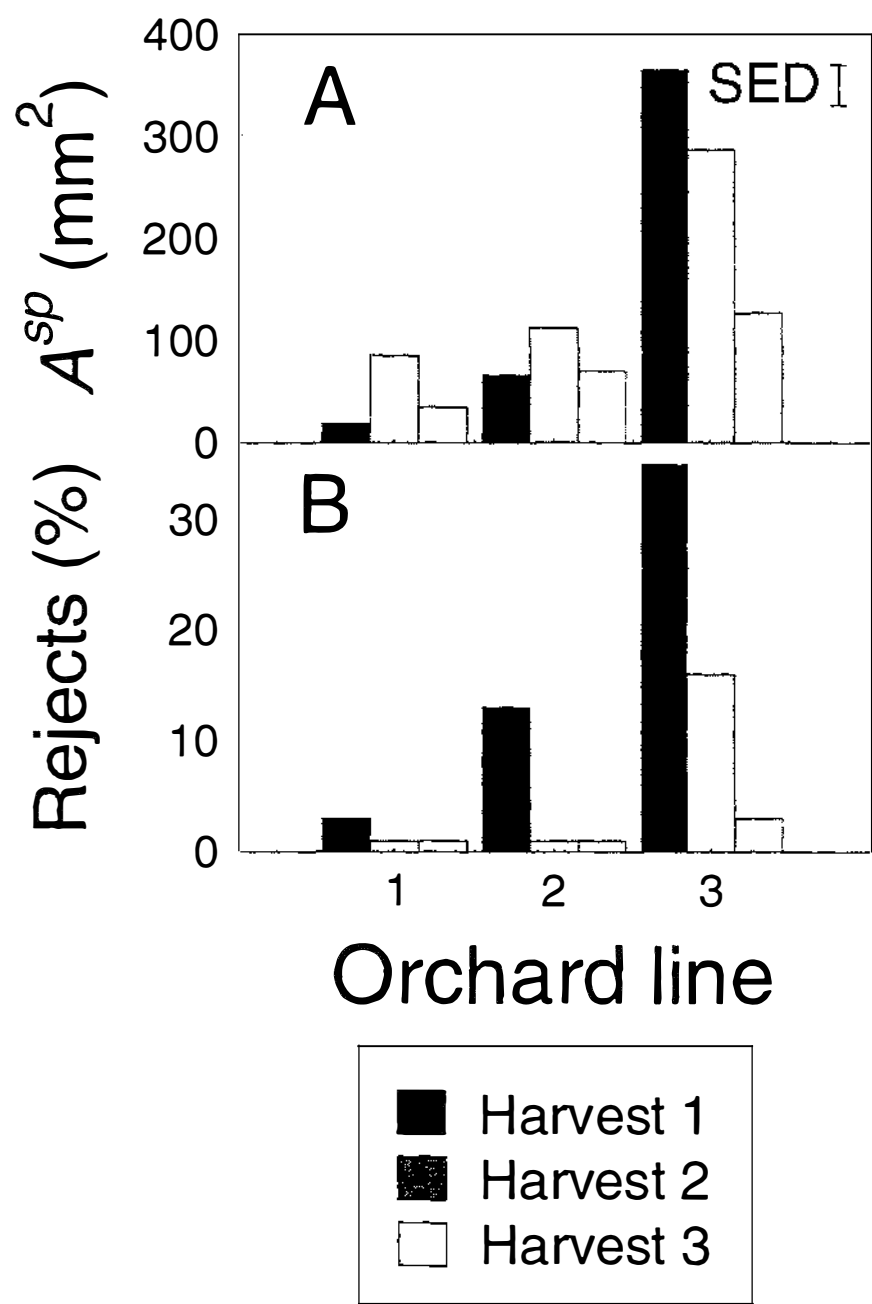


Fig. 8.1 A, A^{sp} ; and B, rejects due to LTB in kiwifruit harvested from 3 orchard lines 3 different times, assessed after 20 weeks storage and averaged over storage temperatures for fruit from Experiment I. Each symbol represents the mean of 324 fruit.

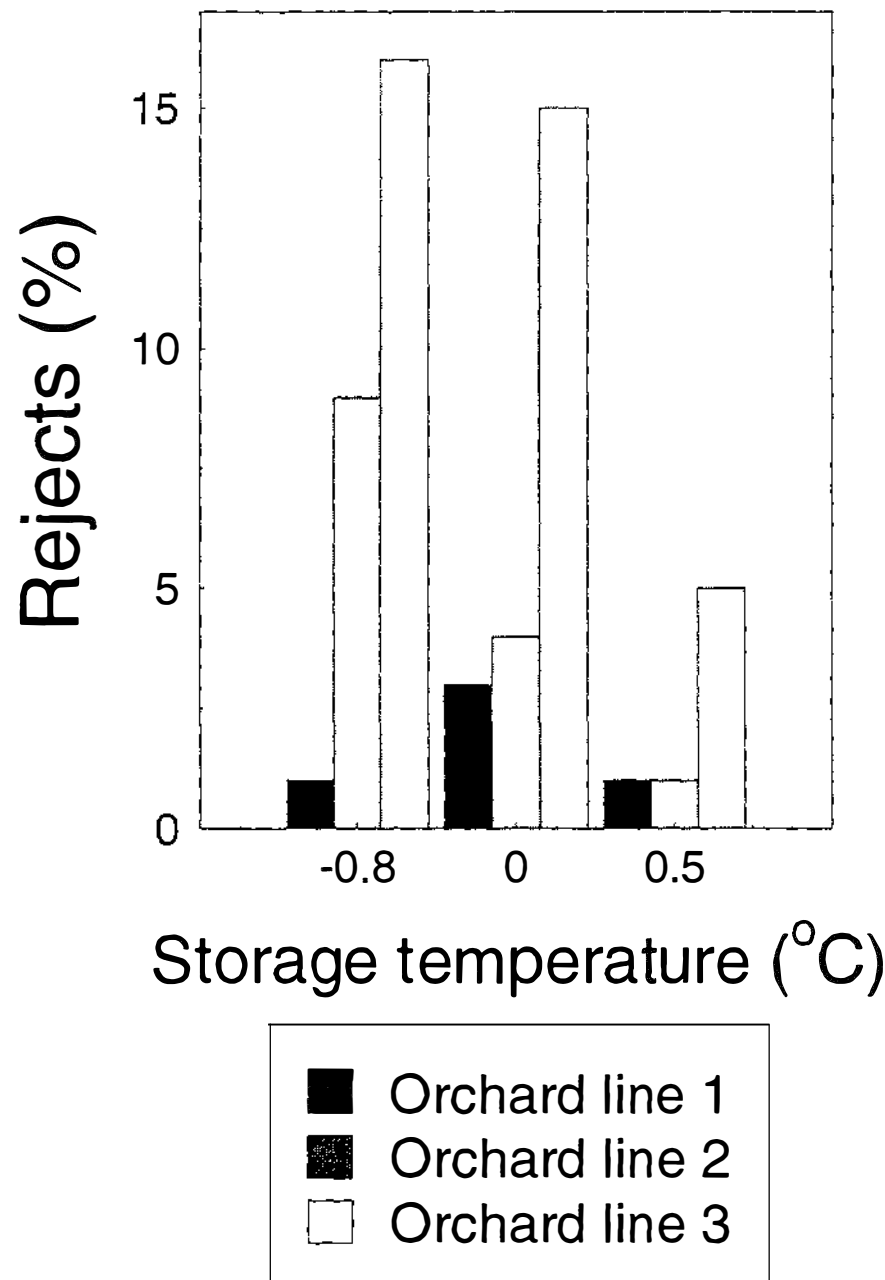


Fig. 8.2 Incidence of rejects due to LTB in kiwifruit for 3 orchard lines in 3 storage temperatures and assessed after 20 weeks storage averaged over time of harvest for fruit from Experiment 1. Each symbol represents the mean of 324 fruit.

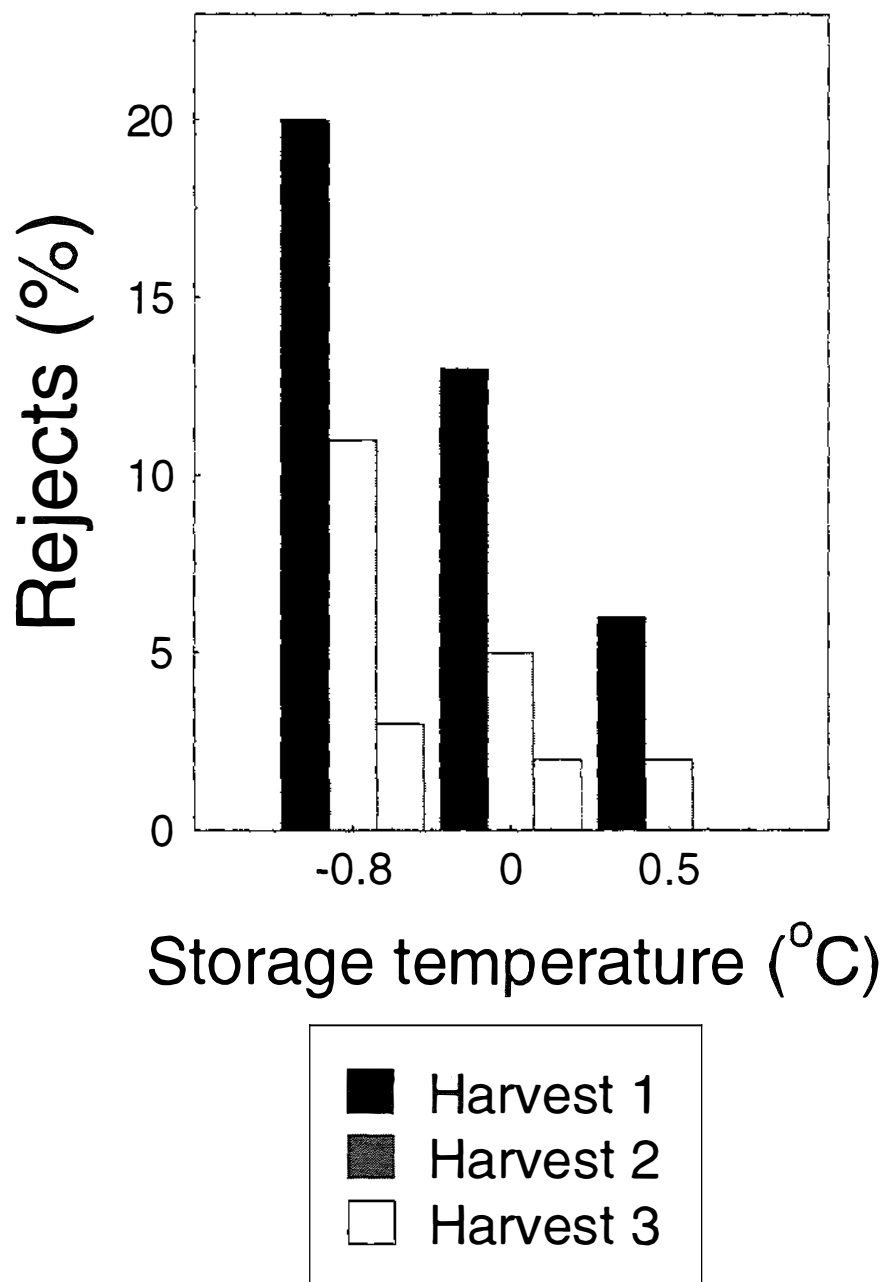


Fig. 8.3 Incidence of rejects due to LTB in kiwifruit stored at 3 temperatures from 3 different times of harvest and assessed after 20 weeks storage averaged over 3 orchard lines for fruit from Experiment 1. Each symbol represents the mean of 324 fruit.

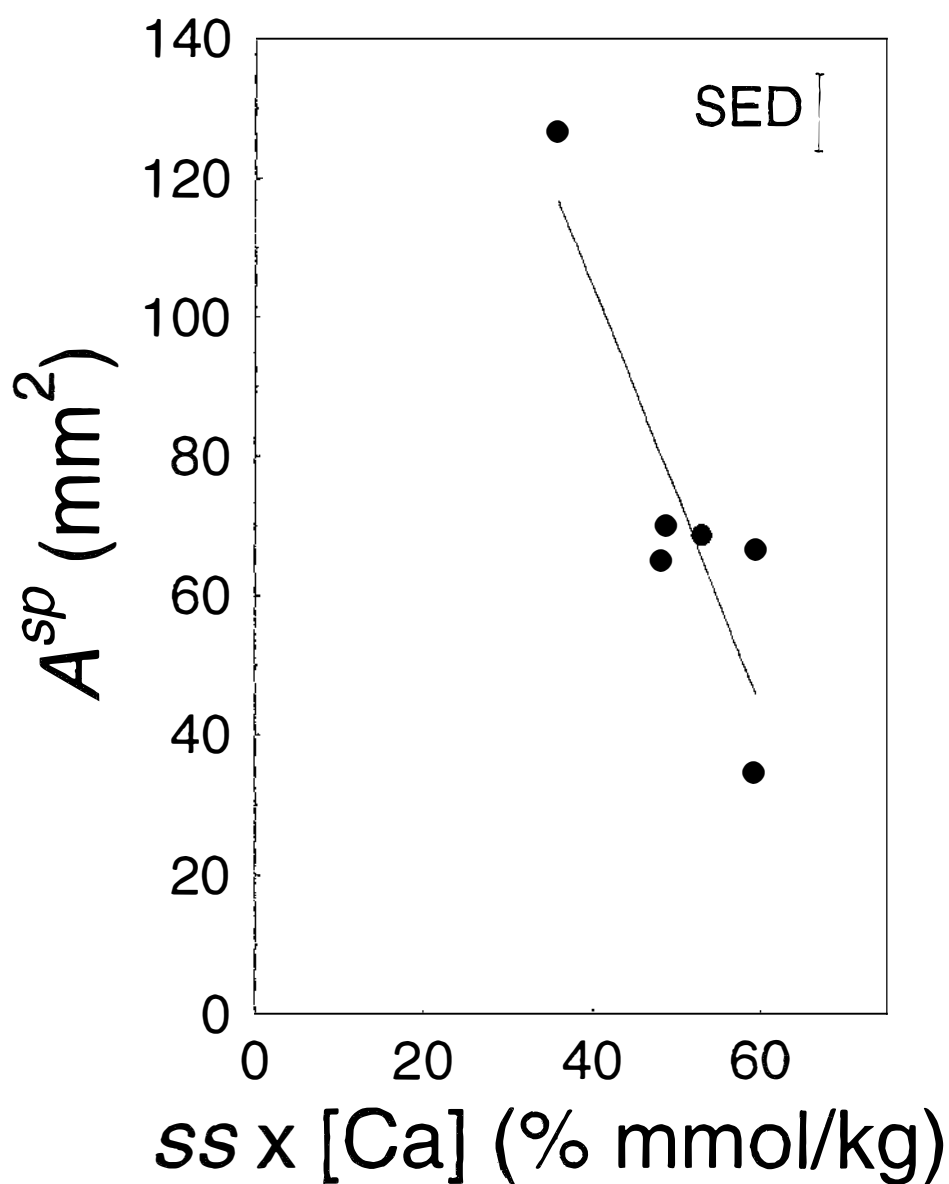


Fig. 8.4 Mean A^{sp} on kiwifruit after 20 weeks storage plotted against the product of harvest soluble solids content (ss) and calcium concentrations ($[Ca]$, mmol/kg) for 6 orchard lines averaged over harvest times and storage temperatures from Experiment 2. Symbols represent means of 108 fruit. Fitted equations for line $A^{sp} = 225 \pm 19 - (3.0 \pm 0.46) ss \times [Ca]$; $r^2 = 0.78$.

General discussion

9.1 INTRODUCTION

The desired goal for the kiwifruit industry is to consistently produce fruit that will have a high eating quality after a long period of storage. Overall fruit quality is an emergent property determined by fruit attributes and, when picked, fruit quality is then also governed by influences present in the handling and storage system. Maintenance of fruit quality during storage is influenced by the handling and storage system which includes picking, grading, packing, transport, cool storage, bulk air or CA storage, export, market, and finally, purchase by the consumer. The handling and storage system exposes fruit to influences such as temperature, time (storage duration), compression, impact, and vibration. Prevention of these influences from being damaging will protect against potential loss of final fruit quality. Nevertheless, these influences do occur to damaging levels in the current handling and storage system. However, particular fruit attributes may make fruit more resistant to these influences. The preharvest period provides the opportunity to influence developing kiwifruit attributes so that a high quality, uniform crop can be harvested and stored for long enough for orderly marketing to occur. Unfortunately, limited knowledge about which are the key fruit attributes and how to effectively manipulate ones already identified restricts what can be achieved.

Potential storage behaviour is defined by fruit structure, composition, and physiology at harvest. If the attributes of fruit associated with good storage behaviour are identified and methods developed to manipulate them in fruit, this would greatly enhance opportunities for growers to produce crops with good storage potential. Similarly if non-destructive means of identifying fruit with good storage potential could be developed from measurements made at harvest time, this would provide scope for segregation of the total crop into lines of uniform quality and storage potential. This would enable those involved in handling and marketing of

the crop to develop new, more effective strategies for maximising revenue. Currently, handling decisions are made at harvest as to how best to prepare kiwifruit for long term storage so the storage potential and quality of fruit is maximised. Harvested fruit can either be graded and packed immediately or bulk stored in wooden bins in either air or CA coolstorage, then graded and packed some time after storage. This provides scope to operate packhouses over a longer time period and grading of fruit some time after harvest enables the removal of fruit which have prematurely softened and/or developed storage disorders during bulk storage. However, it is not clearly understood how the handling and storage system exposes fruit to forces which damage fruit once harvested. During long term storage of kiwifruit, the handling and storage system should protect fruit so quality is maintained, from the time of harvest, to the time it is purchased by a consumer. Identification of circumstances during the harvest or postharvest handling and storage system which expose fruit to damaging forces would enable changes to the current management of fruit to eliminate or minimise damage to fruit.

Premature softening is one of the main causes of decline in perceived fruit quality; it results from inherent limitations in the fruit or external forces such as handling damage. As outlined in Chapter 2, premature softening of kiwifruit may affect localised areas at the fruit surface (soft patches; Fig. 9.1A,B) or the whole fruit (Fig. 9.1C). Kiwifruit stored for extended periods at 0°C may also develop low temperature breakdown (LTB; Fig. 9.1D), which is thought to be a form of chilling injury but not usually associated with premature fruit softening (Lallu et al. 1992). Table 9.1 displays symptoms of, and exacerbating factor(s) associated with, soft patches, premature softening of the whole fruit, or the development of LTB. Factor(s) which initiate and influence the development of the two forms of premature softening and LTB can occur during the preharvest, harvest, and storage phases (Fig. 9.1).

This discussion considers how fruit attributes at harvest affect fruit softening behaviour and how some of these might be manipulated before

harvest to enhance fruit quality after storage. Areas in the handling and storage system that may cause loss of fruit quality are examined and remedies suggested. The discussion explores possible practices which could prevent or reduce loss due to kiwifruit softening prematurely or developing LTB. It then develops a conceptual model of what influences soft patches, premature softening of the entire fruit, and LTB. The significance and implications of the model for scientists and for the commercial handling of kiwifruit are examined. Finally, the areas that could be usefully explored further are discussed.

9.2 KEY FRUIT ATTRIBUTES, HANDLING AND STORAGE

High fruit quality at harvest and after prolonged storage appears to require the following attributes to have developed in fruit after pollination, growth, and maturation: high calcium content, low phosphate content, high dry matter, and high soluble solids content (Table 9.1). Within the handling system, it is necessary to grade, package, store, and transport fruit with minimal damage to fruit. These processes have the potential to expose fruit to damaging forces such as impact, compression, and vibration which result in deterioration of fruit quality (Table 9.1). Within the storage system, temperature and time need to be managed so kiwifruit will still be at peak eating quality when purchased by the consumer (Table 9.1). Kiwifruit is at peak eating ripeness when it has softened to the point when those qualities desired by the consumer have become maximised (Stec et al. 1989). This should be the case for all lines of fruit arriving in the export market even at different times. An understanding of the key fruit attributes, handling and storage forces associated with premature fruit softening and LTB, should enable better management of fruit production and storage to minimise fruit loss.

9.2.1 Calcium

Fruit which developed localised soft patches, softened rapidly, or developed LTB during storage, consistently had a lower calcium content than healthy

fruit (Sections 3.3.6, 6.3.1, 8.3.2.3). Calcium applied to fruit before harvest resulted in fruit that had a lower incidence of soft patches than untreated fruit after storage, consistent with other findings that preharvest calcium applications to fruit will improve their storage behaviour (Sections 2.2.8.1, 7.3.1.3). This suggests a causative association between calcium and premature softening in kiwifruit and that, as in other fruits, calcium plays an important role in maintaining fruit quality. The development of soft patches due to a premature, localisation of flesh softening could occur because a localised area in the pericarp tissue developed low calcium content during early fruit growth relative to the overall pericarp level. Alternatively, low calcium contents throughout the fruit could exacerbate the influence of some other local factor within the tissue that leads to localised tissue breakdown (cf. LTB). In either case, enhancement of fruit calcium content would be expected to reduce softening disorders, particularly if it is uniformly distributed throughout the tissue or targeted towards those areas of the fruit in which calcium is most severely limiting. The importance of getting a high relative increase in fruit calcium content was seen in Section 7.3.1.2, by the lack of effect on overall fruit firmness due to calcium dips. In the study by Gerasopoulos et al. (1996), the calcium content was increased by at least 100% relative to controls whereas, in the study described in Section 7.3.1.2, the maximum increase in calcium was only about 25%. Given the marked response noted by Gerasopoulos et al. (1996), it seems likely that the lack of firmness response due to calcium dips in Section 7.3.1.2 was a reflection of an insufficient enhancement in calcium content, rather than implying that calcium has no role in fruit softening. Calcium sprays are used commercially to prevent tissue breakdown in apples (Section 2.2.8.1). It appears that a similar approach to enhancing calcium contents of kiwifruit could be used to improve storage behaviour, but further work would be required to optimise this process for commercial practice to develop a reliable and consistent method that did not result in skin blemish.

9.2.2 Phosphate

There appears to be evidence to suggest that kiwifruit respond in a similar way to apples, in regard to high phosphate levels being associated with poor fruit quality (Sections 2.2.8.2, 6.3.1; Wooldridge & Olivier 1995). Given the finding in Section 6.3.1, high phosphate content in kiwifruit at harvest may indicate which lines of fruit will be predisposed to softening disorders, such as soft patches. Phosphate levels in kiwifruit may, therefore, prove to be an additional factor that can be used to help determine the storage potential of orchard lines at harvest when deciding how best to manage fruit storage. Interestingly, the combination of low dry matter and high phosphorus in soft patch fruit runs counter to the positive association found between dry matter and phosphorus in kiwifruit in a study by Clark & Smith (1988). As phloem is the main mode of transport for phosphorus and dry matter (carbohydrate) into the fruit, then a combination of low dry matter and high phosphorus may be indicative of some broader physiological imbalance in phloem supplies to developing fruit.

9.2.3 Carbohydrate

Adequate carbohydrate supply may be important for fruit to have a high firmness and not be susceptible to soft patch development (Section 6.3.1). On the other hand, the quality of fruit from vines with heavy crop loads has been reported to be superior to those from vines with light crop loads, in which carbohydrate supply might be expected to be maximised (Hopkirk et al. 1990), an observation which is similar to effects of crop load demonstrated in apples (Ferguson & Watkins 1992). Particular fruit positions on vines may be associated with insufficient accumulation of carbohydrate levels by fruit. If these fruit positions could be identified, this would enable their removal during thinning. Unfortunately, work so far on vine positions and its influence on fruit storage quality, indicates that associations such as these are difficult to determine (Pyke et al. 1996). The dry weight/fresh weight ratio may to some extent be a measure of the quantity of cell wall material within a fruit: thicker cell walls or a larger

number of cells, may better resist disorder development than fruit which have thinner cell walls and fewer cells (Letham 1969; Johnson & Yogaratnam 1978).

9.2.4 Maturity

Considering the large contribution that fruit maturity makes to the softening behaviour of fruit, little seems to be understood on how this occurs or how to manipulate it to improve storage quality of fruit (Section 2.2.6). In fact, the influence of maturity in this current work was found to be far greater than any contribution calcium appeared to make (Sections 7.3.1.1, 7.3.1.2, 8.3.1.3, 8.3.1.5). Incidence of soft patches did not consistently decline with increasing harvest maturity, whereas firmness and incidence of LTB after storage improved with increasing harvest maturity (Section 7.3.1.2; Fig 8.1). Given the effect harvest maturity had on the whole fruit softening and LTB, it had been expected that incidence of soft patches would be influenced in a similar way. Presumably, whole fruit softening and LTB must be governed by different processes from development of soft patches. However, given the association between incidence of soft patches and harvest soluble solids contents (Fig. 8.4), it seems feasible that further work may identify an association between reduced incidence of soft patches in more mature fruit.

9.2.5 Compression

Findings in Section 3.3 were consistent with those by other workers (Section 2.2.7.2), that kiwifruit are susceptible to compression damage from harvest and during all subsequent softening phases. Therefore, all handling and bulk collection of fruit has the potential to expose fruit to compression forces that result in localised premature softening of fruit after long term coolstorage (Sections 2.2.7.2, 3.3.2). Soft patches appear to be induced by long term exposure to forces as low as 2 N ($= 0.11 \text{ kg} \times 2 \text{ fruit} \times 9.81 \text{ m/s}^2$) due to the weight of fruit in the layers above the bottom layer of a 3 layer bulk pack (Section 5.3.2). It appears that the current move towards the bulk storage of kiwifruit within wooden bins is likely to expose fruit to

compression damage which could lead to soft patch development (Section 3.4.1). Considering that even the bottom layer of fruit in a tri-pack developed damage due to compression, the advantages of bulk storage should not be gained at the cost of quality loss due to soft patch development from compression. Given that only short periods of time seem to be required for soft patches to develop due to compression (cf. 96 h compression treatment, Section 3.3.2), and long term storage in stacks of fruit as little as 3 fruit deep cause soft patches (3 layer bulk back, Section 5.3.2), fruit should probably be collected and stored, at and after harvest, in smaller bins. Smaller bins would hold less fruit than standard wooden bins; this would reduce compression damage by decreasing the size of compression forces fruit are exposed to. Given the level of soft patches on fruit stored within wooden bins removed from CA storage (Section 6.3.2), the kiwifruit industry needs to ensure it can accurately separate out fruit which have developed soft patches during storage from other undamaged fruit. Unfortunately, there was no clear relationship between compression damage and rate of whole fruit softening (Section 3.3.5); otherwise it might prove possible to segregate compression damaged fruit on this basis.

The softer fruit become, the more likely there is to be a gradient in soft patch incidence down the bin or within a bulk pack, due to compression (Sections 2.2.7.2, 3.3.2, 3.3.3). This partly reflects how the susceptibility and rate at which the soft patch area develops due to compression increases as fruit soften (Sections 2.2.7.2, 3.3.2, 3.3.3). In general, fruit should be exposed to minimal compression forces during handling and storage.

9.2.6 Impact

Impact to kiwifruit has the potential to cause deterioration in fruit through the initiation of soft patches and, to a lesser extent, a premature softening of the overall fruit. Kiwifruit are vulnerable to impact damage from harvest onwards, with only small impact energies required to damage fruit (cf. 0.08 J, Section 4.3.1). Therefore, the current handling and bulk collection of harvested fruit probably expose fruit to impact forces that result in localised

premature softening of fruit after storage (Sections 4.3.1, 5.3.1). The vulnerability of fruit to impact forces increased with subsequent fruit softening; the softer the fruit, the larger soft patch that developed for an equivalent force (Section 4.3.2). The implications for the industry are serious, given that the stimulation of soft patch development by impacts of as low as 0.08 J indicated that current maximum drop for a kiwifruit as stipulated by NZKMB is considerably too high. If the level incurred at 0.08 J was taken, for a kiwifruit with a mass of 0.11 kg, it can be derived (Eq. 4.1, Section 4.2.2) that the maximum acceptable drop height would be 74 mm, less than a quarter of the current threshold. As with compression, impact to fruit at harvest followed by low temperature storage had no effect on rate of whole fruit softening (Sections 4.3.1, 5.3.1; Finch & Hopkirk 1987). Interestingly, different responses of fruit to impact at harvest or after harvest on rate of fruit softening may be related to the texture differences between such fruit that were found by Finch & Hopkirk (1987; Sections 4.3.1, 4.3.2). Interestingly, the fracture symptoms that kiwifruit express when impacted at harvest, indicates how brittle the fruit tissue is (Section 4.3.1). Freshly harvested fruit could be thought of as being quite fragile and in a sense cell walls 'shatter' upon impact or variation. Once they have softened, the degree to which impact symptoms change reflects how much the flesh has become viscoelastic (Section 4.3.2). In this state, the tissue becomes susceptible to damage through excessive deformation under force, that is, through compression. The change in the nature of fruit flesh from brittle to viscoelastic and the type of force applied (i.e., impact, vibration and compression), would appear to influence when and which damage symptoms develop. The small reduction in whole fruit softening that occurs as a result of impacting fruit that have started to soften appears to reflect how much cell walls have already changed from when fruit were harvested (Section 4.3.2; Harker & Hallet 1994).

Options to make fruit less susceptible to impact forces appear to be limited given that warming fruit or enhancement of fruit calcium contents did not reduce fruit susceptibility to impact damage (Sections 6.3.2, 7.3.1.3).

The most effective way to reduce fruit damage would be to concentrate on improving the handling system (e.g., to have a zero permissible drop height for kiwifruit) rather than attempting to tackle the problem by affecting inherent susceptibility of the fruit to damage.

9.2.7 Vibration

Given that kiwifruit are vulnerable to other forms of mechanical damage at harvest such as compression and impact (Sections 3.3.1, 4.3.1), it seems plausible that vibration could also cause damage to kiwifruit. At harvest, vibration damage could cause many small fractures to cell walls, which would be consistent with the type of injury that impact appears to cause to harvested fruit (Section 4.3.1). In harvested fruit, the tissue is so firm that it appears to be more susceptible to vibration damage than fruit which has softened (Finch & Hopkirk 1987). It has been reported that there can be up to 30 times the level of horizontal vibration at the top of an apple bin, than at the bottom, during transportation (Section 2.2.7.3). Therefore, transportation of bins to the CA store may cause greater vibration forces within the top layers of fruit within a bin. This may explain the greater incidence of soft patches and lower firmness in the top layer of kiwifruit compared to those in the bottom layer within a bin (Section 6.3.2). If vibration can damage kiwifruit at harvest, it seems likely that vibration would also be likely to also damage softening fruit after harvest. Vibration damage might occur to packed fruit during transport such as when trucks corner or go over irregularities in the road surface.

Vibration forces may cause extended stress in localised areas or the fruit surface resulting in weakening of, and damage to, the outer layer of the fruit surface. The enhanced water loss that would be expected to accompany such damage may contribute to premature softening of localised flesh surrounding the damaged skin (Section 2.2.2). Alternatively, damaged tissue may produce more softening enzymes or have reduced ability to resist softening enzymes. Investigations into the potential of kiwifruit to become damaged by vibration are required if it is to be determined how much

potential there is to reduce damage in current handling and storage practices by minimising vibration forces to fruit.

9.2.8 Grading

Grading at harvest caused localised premature softening (Section 5.3.1), which was consistent with the findings by Bollen & Dela Rue (1990). The behaviour of fruit when graded at either harvest or after storage was consistent with the effects of impact and compression on fruit at harvest (Sections 3.3.2, 4.3.1, 5.3.1, 6.3.1). Therefore, it is not surprising that damage due to grading at harvest did not develop until after long term coolstorage, and was localised without appearing to affect whole fruit softening (Section 5.3.1). Clearly, graders have the potential to damage fruit, which appears to be proportional to severity of the forces fruit experience when graded (Sections 2.2.7.4, 5.3.1). Fortunately, steps can be taken to reduce potential damage to fruit due to grading (Brown et al. 1990). Use of padding may reduce potential of fruit to incur a damaging impact against a static surfaces but will not prevent fruit to fruit impacts. The ideal grader would expose fruit to minimal impacts and compression forces. Given the findings in chapter 6, the current trend to grade fruit after a period of storage will make fruit vulnerable to localised tissue damage and to a lesser extent could affects whole fruit firmness (Section 6.3.1). Interestingly, the susceptibility of previously CA-stored fruit to soft patch development appears to be more determined by the severity of handling due to the grader than the initial firmness when graded (Section 6.3.1).

9.2.9 Packaging

It is very important the packaging used to store kiwifruit does not cause a premature loss of fruit quality (Section 5.3.2). Considering how long fruit are stored for within packaging, the degree to which different forms of packaging expose fruit to mechanical forces, and the influence this might have on final fruit quality is not well understood (Section 2.2.7.5). Interestingly, compression not only causes damage to fruit stored in large

wood bins but also within packs with just 3 layers of fruit (Section 5.3.2). The finding is consistent with those described in work previously published by other workers (Section 2.2.7.5). Compression, impact and vibration forces appear to influence fruit storage behaviour depending on the packaging structure and material. Fruit in pocket packs could be exposed to more vibration than fruit held rigidly in bulk packs (Section 5.3.2). Bulk packs could expose fruit to impacts when the pack is being filled. Current and alternative packs or bins used to store fruit need to be evaluated in regard for their potential to prevent fruit exposure to mechanical forces. Packaging that minimises compression, impact, and vibration forces will better maintain fruit quality during the period of time fruit are stored within the packaging. Clearly, the packaging material will only provide protection to a point, and outside forces that act on packaging (e.g. forklift) and, therefore, fruit, need to be managed. Packaging should be adequate to protect stored fruit whether it is moving due to transportation or left in one place.

9.2.10 Water loss

Water loss from kiwifruit needs to be prevented during storage or they may become susceptible to premature softening (Section 2.2.2). The greater incidence of soft patches in the top layer fruit in wooden bins (Section 6.3.2) could have been partly due to water loss but the most likely potential cause was vibration damage. Vibration could have led to small fractures in the fruit skin which promoted water loss from the localised damaged area on the fruit. The enhanced water loss from the localised area may have led to the development of a soft patch. This would be consistent with the finding by Mencarelli et al. (1996) that an impacted kiwifruit had enhanced water loss from the impacted site and associated premature softening of that impacted area on the fruit. Alternatively, air flow across the top of the bin could have contributed to greater water loss from fruit (Section 2.2.2). Whatever initiates water loss from a localised area on a fruit, it appears that the potential for this result in the initiation and development of a soft patch

(Sections 2.2.2, 6.3.2) would be worthy of further investigation. If a strong effect of water loss was found, the development of softening disorders in physically damaged fruit might be reduced by minimisation of water loss during storage e.g., by storage in high humidity air and at low temperature.

9.2.11 Ethylene

Though no measurements of ethylene were made, ethylene probably has only a little contribution to the initiation of soft patches, if any (Sections 2.2.4, 2.4.1). Given the dramatic effects of ethylene on whole fruit softening, if soft patches were associated with elevated rates of ethylene production then this would also be expected to induce the rapid softening of the whole fruit (Section 2.2.4). The effects of ethylene appear to be related to fruit temperature (Section 2.2.4). Fruit that has been damaged at harvest, may then produce ethylene when taken from coolstorage to a higher temperature (Section 2.2.7.1). Potential shelf-life would then be lost due to premature ethylene production by damaged fruit, causing themselves and other healthy fruit to soften prematurely (Section 2.2.4.2).

9.2.12 Temperature

Temperature variation within packs and between pack-types may contribute to differences in fruit quality (Sections 2.2.3.2, 5.3.2). Fruit packed separately in trays may have been at a lower temperature than equivalent fruit in packs which have contact with other fruit in bulk. In Euro packs, fruit to fruit contact and fruit being positioned closer than in single layer trays may cause a greater conservation of heat by nature of a greater volume to surface area ratio within the pack. The temperature differences between pack-types may cause fruit to develop different levels of premature softening and LTB (Sections 5.3.2, 8.3.2.1); the temperature data that would be required to substantiate these ideas were not collected in this work.

The difference in soft patch areas in fruit at 0°C and 0.5°C in Section 8.3 indicates that soft patches were not directly caused by chilling injury, in contrast with LTB. On the other hand, given the higher incidence of soft

patches at -0.8°C than at 0°C it would seem premature to conclude that there is no role at all for low temperature injury in soft patch formation (Section 8.3). Soft patches not caused by physical damage appear to require slow softening at low temperature (e.g. 0°C) for the initiation of the soft patch (Section 8.3). Had the softening occurred at ambient, the soft patch would have been unlikely to become evident due to rapid softening of the fruit flesh associated with ripening. Fruit softening is related to storage temperature, so the rate of development of a soft patch would in part relate to temperature (Sections 3.3.2, 4.3.1; Pratt & Reid 1974). Once a soft patch has been initiated, regardless of it being caused by physical or physiological influences, its rate of development would be faster at a higher temperature (Sections 3.3.2, 4.3.1).

9.2.13 Time

At low temperature, extended time over which kiwifruit soften increases the opportunity for a range of other physiological processes in the fruit to contribute to premature softening and LTB (Table 9.1). The length of the storage duration is an important factor in determining if a fruit would develop soft patches, prematurely softening of the whole fruit, or LTB (Sections 3.3.2, 6.3.1, 8.3.1.1, 8.3.1.2). Fruit exposed to compression late during coolstorage have smaller soft patches than fruit exposed to compression at the start of coolstorage, probably fruit compressed storage would have a shorter period of coolstorage in which soft patches could develop (Section 3.3.2). In general, the longer fruit are stored for, the closer fruit get to senescence and the more likely they are to develop storage disorders, 'symptoms' (i.e., soft patches, LTB) of approaching senescence of fruit.

9.3 CONCEPTUAL MODEL

Ideally, the kiwifruit crop should be managed so there is minimal loss of fruit quality due to soft patches, premature softening of the whole fruit, or development of LTB. To achieve this, it is important to understand what

factors (fruit attribute^s, handling, or storage forces) influence soft patches, premature softening of the whole fruit, or development of LTB. It then needs to be known how these identified factor^s work in isolation or in combination to cause premature softening or LTB. This section outlines a simple conceptual model which integrates current knowledge of factors that influence the initiation and development of soft patches, rapid softening of the whole fruit, and LTB (Fig. 9.1, Table 9.1).

9.3.1 Soft patches

Soft patches appear to be an expression of localised premature senescence of fruit tissue (Sections 3.3, 4.3, 5.3, 6.3, 7.3, 8.3) in response to physiological or physical factors, (Fig. 9.1A,B, Table 9.1A,B). Factors which could predispose fruit to initiate soft patch development appear to mostly occur prior to coolstorage, such as: low calcium content, due to inadequate accumulation during early fruit growth; compression, that results from fruit being on the bottom of a bulk pack or wooden bin; or impact, during grading of fruit (Table 9.1A,B). Incidence of soft patches is influenced by factor(s) such as storage duration and temperature (Table 9.1A,B). The extent to which softening of the whole fruit influences the rate of soft patch development of coolstored fruit partly depends on whether the soft patches are initiated by factor(s) that are physical (physically induced soft patches; Table 9.1A) or physiological (physiologically induced soft patches; Table 9.1B).

It seems likely that soft patches initiated by physical factor(s), develop on what could otherwise be a healthy fruit (Fig. 9.1A, Table 9.1A). Soft patches of this type can be initiated by impact, compression, and, possibly, vibration (Sections 3.3, 4.3, 6.3.2). The size, type, and duration of the physical force, coupled with susceptibility to damage in fruit, would be the key factor(s) determining initiation of a soft patch. The amount of impact damage that occurs to fruit at the time of the initial physical force is bigger with softer fruit (Sections 3.3.2, 4.3.2). It appears that for a given force, the softer the fruit are when damaged, the greater will be the final

soft patch size. Once a soft patch has been initiated due to a physical force, the key factor(s) in its development seem to be storage temperature and duration. Soft patches initiated by physical factor(s) develop at both 0°C and ambient, but development is faster at a higher temperature (Sections 2.2.7.1, 3.3.2, 4.3.1). Physical damage to kiwifruit appears only to affect the localised tissue and not the general fruit, at least for fruit subsequently kept in coolstorage. If physically damaged fruit are stored at 0°C, the localised area of damaged tissue would usually prematurely senesce independently of the whole fruit rate of softening (Sections 2.2.7.1, 3.3, 4.3, 5.3). At higher temperatures, ethylene released by tissues within the damaged fruit appears to stimulate the onset of rapid fruit softening (Mencarelli et al. 1996). For a given impact energy or compression, the greater the storage duration after the initiation of the physical damage, the larger the soft patch is likely to be (Sections 3.3.2, 4.3.2). The ability of fruit to avoid initiation and development of soft patches due to physical damage appears to be independent of its calcium content (Sections 3.3.6, 7.3.1.3). There does not appear to be a consistent relationship across orchard lines between level of soft patches initiated by physical origins due to grading and their whole fruit firmness (Sections 3.3.5, 6.3.1). However, the relationship between soft patch area on impacted fruit and firmness, is not seen on graded fruit possibly as they also included soft patches due to physiological origins. In general, physically induced soft patches are a consequence of the initiation factor(s) (size, type, duration of physical force, and firmness of fruit when damaged), and development factor(s) (storage temperature and period of time between initiation of soft patch and assessment; Fig. 9.1A, Table 9.1A).

Fruit which developed physiologically induced soft patches (fruit which have minimal physical handling), can be thought of as being of an inferior quality due to their preharvest history (Fig 9.1B, Table 9.1B). These fruit develop soft patches when they are near their final stages of softening and would be likely to have a consistent association between the level of soft patches on fruit and their whole fruit firmness (Fig. 5.3). Initiation of physiologically induced soft patches are related to low calcium

content, high phosphate content, and low dry matter, in combination with secondary factors such as long storage duration, a period of storage at low temperature, and advanced fruit softening (Sections 3.3.2, 6.3.1, 8.3). The initiation of physiologically induced soft patches requires risk factors such as those mentioned above, to be present. The softening rate of kiwifruit at ambient temperature is probably too fast for soft patches due to physiological factors to be initiated ahead of fruit collapse after ripening is completed. The slower rate of fruit softening at 0°C presumably allows localised susceptible areas to deteriorate sooner than the surrounding flesh. Once initiated, physiologically induced soft patches required a period of time to develop, with the rate of development being influenced by temperature (Sections 3.3.2, 3.4.2, 4.3.1, 8.3). A lack of calcium leading to initiation and development of soft patches could be similar to development of bitter pit in apples (Saure 1996). Preharvest factors which cause localised areas of the fruit to be low in calcium probably also result in low calcium contents in the surrounding tissue. This would be consistent with the relationships found between level of soft patches resulting from physiological causes on an orchard line of fruit and its calcium content (Fig. 8.4). A population of fruit with an already low mean calcium content could have a larger proportion of fruit with localised areas with a calcium content low enough for soft patches to develop. The kiwifruit flesh surrounding a soft patch due to physical damage would probably have a higher calcium content than the flesh surrounding a physiologically induced soft patch. On this basis, soft patches due to physical factor(s) might be expected to develop in size less markedly than physiologically induced soft patches. However, an alternative would be that healthy fruit with a uniform and average calcium status within the cortex have a variation in some other variable. The change to the variable within a localised portion of the fruit may lower the calcium concentration within this area of the cortex, which in turn initiates a localised soft area. Physiologically induced soft patches have their initiation and development influenced by similar factor(s): low calcium content, high phosphate content, low dry matter, low storage temperature

(e.g., 0°C), long storage duration, and advanced fruit softening (Fig. 9.1B, Table 9.1B).

9.3.2 Premature softening of the whole fruit

Key factor(s) which initiate premature softening of the whole fruit are low calcium, low harvest soluble solids content, ethylene, water loss, and physical damage to fruit (Fig. 9.1C, Table 9.1C). Storage temperature then influences the response of fruit to these factor(s) (Section 2.2.3.2). Storage temperature appears to have the biggest influence on the development of fruit softening (Sections 2.2.3.2, 3.3.5, 4.3.1, 8.3). Therefore, the higher the storage temperature, the smaller the time difference would be between fruit that soften prematurely and healthy fruit, to reach the same final firmness. For fruit held for a long duration at 0°C in coolstorage or a shorter duration at 20°C, there is an association of calcium applications to fruit before harvest and firmness after storage (Section 2.2.8.1). It appears that insufficient calcium levels in fruit at harvest can predispose fruit to soften sooner in coolstorage. This seems to apply to individual fruit and populations of fruit with a low mean calcium content, relative to individual fruit and populations of fruit with a higher mean calcium value. However, it is clear that calcium is one of many other important factors influencing fruit softening in fruit stored for such long periods of time at 0°C (Sections 2.2.8.1, 6.3.1, 7.3.1.2). Calcium does not appear to influence fruit firmness at harvest as much as it does during the final phase of fruit softening. Once fruit start to soften there could be a delay before an association between rate of fruit softening, or fruit firmness, and fruit calcium content can be measured. This may be due to textural and biochemical changes that occur within the fruit during softening that enable the influence that calcium has in fruit softening to become evident (Harker & Hallet 1994). Premature softening in kiwifruit appears to be initiated by the above mentioned factors and the rate at which premature softening will develop seems to depend on storage temperature (Fig. 9.1C, Table 9.1C).

9.3.3 LTB

LTB is the expression of chilling damage to kiwifruit tissue which causes cellular deterioration and membrane leakage (Fig. 9.1D, Table 9.1D). The storage duration required for LTB to develop in a kiwifruit appears to depend more on the storage temperature, than the calcium content and fruit maturity (Section 8.3). A slight variation in temperature around 0.5°C appears to greatly influence the time required for fruit to develop LTB (Section 2.4.2). Fruit which have low soluble solids content and low calcium content appear to be most susceptible to LTB. Mature fruit with adequate calcium contents appear able to prevent or withstand the development of the chilling injury for longer (Sections 8.3.1.2, 8.3.2.3). Fruit with the highest incidence of LTB at the lowest storage temperature also have the highest firmness (Section 8.3). Thus, LTB is initiated by storage at low temperature (near 0°C) for a long period of time, and its development is influenced by low calcium and soluble solids content at harvest (cf. immature fruit; Fig. 9.1D, Table 9.1D)

9.4 IMPLICATIONS OF MODEL

Understanding of which factors influence the initiation and development of soft patches, premature softening of the whole fruit, and LTB in kiwifruit then has implications for research and commercial handling of kiwifruit. This section evaluates what implications the model (Fig 9.1, Section 9.3) has for kiwifruit production and handling from flowering until a fruit is purchased by a consumer (Fig. 9.2).

9.4.1 Flowering

Good pollination results in fruit with a high seed number which in turn influences fruit size (Beever & Hopkirk 1990; Lai et al. 1990). Although increased seed numbers have been shown to enhance calcium uptake and improve storage behaviour in apples (Brookfield et al. 1996), it is not established that good pollination necessarily guarantees good storage behaviour in kiwifruit. It may, therefore, be worth investigating whether

there is potential to reduce premature softening by improved pollination procedures. What contributions these factor(s) make to fruit softening prematurely or the development of LTB is not well understood.

Accumulation of sufficient carbohydrate to fruit appears to be influenced by seed number, time of flowering, pedicel size, and size of ovaries (Lai et al. 1990). Fruit on laterals that have a large number of leaves may have an inadequate carbohydrate supply (Lai et al. 1989) which could predispose these fruit to soft patch development during storage. However, it is not thought to be a lack of leaves which causes fruit to develop low dry matter contents as carbohydrates are thought to translocate over long distances in the vine (Lai et al. 1990). Lai et al. (1990) suggested that factors which cause the accumulation of low dry matter contents in fruit may have occurred before anthesis. If this is the case then the potential to enhance carbohydrate supply during fruit development would appear to be dependent upon understanding and manipulation of factors which influence carbohydrate supply before, or at anthesis. Good storage potential may rely upon good flower development, adequate levels of fruit set, and high seed numbers derived from high efficiency of pollination.

9.4.2 Early fruit growth

Natural accumulation of calcium occurs early, principally during fruit development (Section 2.2.8.1); rates of calcium uptake during this phase are, therefore, essential for adequate accumulation of calcium by fruits.

Transpiration of the flower and developing fruitlets is likely to play a critical role in this accumulation as this would be likely to be a primary driver for uptake from the xylem (Section 2.2.8.1). What prevents sufficient calcium getting into fruit is not clear, though in grapes, this has been attributed to loss of functionality in the xylem (During & Oggionni 1986). In apples, xylem function ceases earlier in 'Cox's Orange Pippin' than 'Royal Gala' (Lang 1990). This causes Cox's apples to have a greater dilution of calcium levels due to subsequent growth fuelled by inflow from the phloem stream. This leads to a lower calcium concentration in Cox's

and is consistent with their high susceptibility to bitter pit (Ferguson & Watkins 1992). Presumably, a similar argument could be applied to kiwifruit: the sooner xylem flow into kiwifruit ceased, the more the accumulated calcium would then be diluted with further growth. Differences between fruit in either duration or rate of xylem flow may determine which fruit develop soft patches and which do not.

Since the driving force for transpiration relates strongly to temperature (Campbell 1977), fruit that develop in shaded positions on the vine might be expected to be amongst those most likely to achieve low calcium status. If fruit in such positions on the vine could be identified then they could be removed during thinning and thereby reduce the proportion of fruit likely to become prematurely soft in the population of harvested fruit. However, the numbers of shaded fruit in shaded positions at the centre of the vine may mean that this would not be an economic option (Pyke et al. 1996). It is important to produce a uniform vine canopy during fruit development.

Differences between fruit in either duration or rate of xylem flow may determine which fruit develop soft patches and which do not. If this is the case, maintenance of calcium uptake may enable sufficient levels of calcium to accumulate in fruit to prevent their premature softening. A successful method that enhanced calcium content of fruit during early growth may provide an assurance of fruit quality during storage and lessen fruit susceptibility to premature softening.

Drying oils applied to fruit during early growth may cause an enhanced rate of calcium uptake by stimulating transpiration-driven influx of xylem sap (Sections 7.3.2, 7.3.4). Application of a drying oil during early fruit growth would take advantage of the stage of growth when fruit are most efficient at accumulating calcium (Section 2.2.8.1). Even if fruit have their natural uptake of calcium prematurely terminated as a result of some other influences, the application of drying oil may enable these fruit to accumulate an adequate supply of calcium beforehand, to prevent premature softening. Enhancement of the process of natural calcium uptake may

enable calcium to reach sites inside fruit which have a greater influence on long term storage quality (e.g. in the pericarp), than direct calcium applications to the fruit surface. It would be interesting to determine whether natural variation in P'_{H_2O} of a fruit causes the calcium content in the fruit to also vary accordingly. Measuring fruit and vine P'_{H_2O} during early fruit growth, and non-destructive monitoring of softening behaviour (Davie et al. 1996) could be used to explore this possibility.

If enhancing the P'_{H_2O} of leaves on a vine decreases fruit calcium content (Section 7.3.4), then potentially a reduction in P'_{H_2O} of leaves might be expected to achieve the opposite result. In this case, application of whole vine anti-transpirants may reduce leaf transpiration rate relative to fruit, and thereby, increase fruit calcium content. Anti-transpirants applied to whole trees have reduced the incidence of bitter pit in apples (Schumacher et al. 1976). Application of anti-transpirants to whole vines may provide an alternative approach to enhance calcium contents in kiwifruit during growth. However, from the data presented in Chapter 7 (Section 7.3.4), it appears that it may be necessary to treat fruit and leaves differently to achieve the desired effect of increasing fruit calcium, a requirement that would be very difficult to meet.

Withholding irrigation during early fruit growth during the day and irrigating at night could be another potential approach to enhance calcium uptake by fruit. This treatment might increase the xylem sap leaving fruit during the day (Lang 1990) as sap was withdrawn from the fruit in response to low water potential in the remainder of the tree. Such sap would have low calcium content (Lang & Volz 1993) whereas the sap drawn back into the fruit at night, as tree water status recovered, would have higher calcium content. This xylem cycling would cause calcium content to increase (Lang & Volz 1993). The effects seen with a olive oil and sodium carbonate (Na_2CO_3) mixture may have been due to an increase in the xylem reversal of the fruit (Section 7.3.2). Greater understanding of xylem function and its termination in fruit is required to assist the development of methods that manipulate fruit mechanisms which influence calcium accumulation into

developing fruit.

An alternative approach to increase calcium would be to augment calcium in the sap during early fruit growth. Although, a lack of calcium to the vine is not thought to be the main limitation to calcium being naturally accumulated into fruit (Section 2.2.8.1), for a given rate of xylem uptake, increasing calcium contents of the xylem should achieve a proportional increase in fruit calcium levels. This might be achieved by a combined use of mulch (to bring feeder roots closer to the surface), coupled with application of a soluble form of calcium fertiliser e.g., gypsum. Withholding irrigation and enhancement of sap calcium would seem to provide some limited options to enhance calcium uptake during early fruit growth and prevent prematurely softening during storage.

9.4.3 Fruit maturation

Direct preharvest applications of calcium could be used as a management tool to enhance calcium status at harvest (Section 7.3.1.1). Direct preharvest applications of calcium could enhance calcium content in fruit which might otherwise fail to develop sufficient calcium levels during their early fruit growth. In previously published work (Section 2.2.8.1) in which fruit calcium content was enhanced, fruit were only assessed for firmness rather than for other softening disorders. However, it would be expected that treatments that resulted in production of firmer fruit would also have a lower incidence of soft patches and LTB (Figs. 3.2, 6.3; Section 8.3). Enhanced calcium content in kiwifruit increased their storage life by 200% (number of weeks for fruit to reach 10 N at 0°C; Gerasopoulos et al. 1996). Direct application of calcium to kiwifruit before harvest (Section 7.3.1.1) indicates that there maybe a causative role for calcium in reducing susceptibility to soft patch development.

Hand dipping fruit before harvest to enhance calcium content would probably not be an effective commercial practice (Section 7.3.1.1). Previously published work by Gerasopoulos et al. (1996), demonstrated that spraying whole vines before harvest may have commercial potential for

enhancing calcium status of kiwifruit, similar to strategies for bitter pit prevention in apples. The number, timing, and concentration of calcium applications need to be investigated in relation to their effects on whole and localised premature softening. Postharvest applications of calcium to harvested fruit may provide an additional means of enhancing fruit calcium (Section 2.2.8.1). This may give some assurance that fruit which otherwise may not accumulate adequate calcium, such as shaded fruit, would have their calcium content enhanced above a threshold that would make them less susceptible to premature softening.

In previously published work (Section 2.2.8.1), there has been no pitting observed on fruit dipped before harvest, whereas, pitting has been found on fruit dipped after harvest and fruit sprayed before harvest (Harker et al. 1990; Hopkirk et al. 1990). It is unclear as to what combination of factors causes fruit to be susceptible to pitting after application of calcium salts. Factors such as calcium salt concentration (Section 2.2.8.1; Harker et al. 1990; Hopkirk et al. 1990), time of application (Section 2.2.8.1; Gerasopoulos et al. 1996), drying conditions (Section 2.2.8.1; Hopkirk et al. 1990; Gerasopoulos et al. 1996), and orchard differences (Section 2.2.8.1; Prasad & Spiers 1992) may all contribute to variation in fruit susceptibility to pitting. Using a low concentration calcium salt solution should largely prevent pitting (Section 7.3.1.1; Prasad & Spiers 1992; Gerasopoulos et al. 1996), but further understanding of factors contributing to pitting is required before preharvest calcium applications could be recommended with confidence.

Another possibility to enhance fruit calcium content may be to manipulate the transpiration rate of maturing fruit. Work on apples by Cline & Hanson (1992) involved reducing the relative humidity around the fruit after the period when most calcium had naturally accumulated into fruit. They suggested that calcium accumulation could have been influenced due to an enhanced fruit transpiration rate, even though it occurred late in the growing season. If the P'_{H_2O} of fruit during later growth can be increased it should be possible to enhance fruit calcium content and improve fruit

storage quality. Unfortunately, an effective method that would enhance the preharvest P'_{H_2O} of fruit, is at present, uncertain (Section 9.4.2).

9.4.4 Harvest

Ideally, fruit attributes at harvest could be used to predict final fruit quality to enable management of the crop so storage losses were minimised. It would also be most helpful in managing the crop to have a maturity index and the ability to predict the storage potential of fruit from an orchard line. However, once fruit have been harvested, any susceptibility to soften prematurely needs to be accommodated by use of handling that prevents or minimises any potential mechanical damage. In the 2 sections below, practices in the current harvest handling system will be evaluated in terms of their potential to cause premature softening of fruit; possible ways to eliminate and prevent this damage will be described.

9.4.4.1 *Fruit attributes*

Harvest maturity gives some general indications about the likely storage performance of orchard lines harvested over a given time period (Sections 7.3.1.2, 8.3.1; Beever & Hopkirk 1990). There is a consistent trend of early harvested fruit softening faster than later harvested fruit (Sections 7.3.1.2, 8.3.1.3). Fortunately, early harvested fruit are exported first, which would minimise fruit loss. Fruit harvested late with high soluble solids content are less likely to soften quickly (Sections 2.2.6, 7.3.1.2, 8.3.1.3), and will have a longer coolstorage period prior to export with minimal loss of fruit due to premature softening. With further investigation, it may be possible to predict the storage performance of an individual orchard line based on the lines harvest maturity, and other key factors that combine with maturity to influence final firmness.

There may be a threshold calcium content that is required for kiwifruit not to be susceptible to premature softening during coolstorage, but such a threshold has not been reported. Interestingly, the fruit with soft patches within each experiment, always had a lower calcium content than

fruit without soft patches (Table 9.2). Soft patch fruit normally had about 12% less calcium content than that of healthy fruit. The calcium content value for soft patch fruit varied between populations which demonstrated how other factors work in combination with calcium to influence fruit quality. However, there appears not to be an absolute level of calcium required to prevent localised premature softening, as mean calcium contents for fruit with soft patches overlapped with values for healthy fruit from other experiments (Table 9.2). This is presumably the reason why the survey by Clark & Smith (1988) did not identify a relationship between storage losses to premature softening and calcium levels. A number of factors initiate and influence the development of soft patches in kiwifruit (Table 9.1A,B). Low calcium and insufficient supply of carbohydrates to kiwifruit could result in fruit with low dry matter content. Shaded fruit may have softened prematurely due to a low calcium content (Section 2.2.8.1), or in combination with low soluble solids content (Section 8.3.1), high phosphate content (Section 6.3.1), and low dry matter content (Section 6.3.1). To what extent calcium works in isolation or in combination with other factors to prevent premature softening is unclear and requires further investigation.

A combined maturity index could enable better management of the kiwifruit harvest by more accurate characterisation of maturity variation between orchard lines and give a basis for identification of lines likely to be susceptible to premature softening (Sections 7.3.1.2, 8.3.1). In commercial apple production, a number of indices can be used to determine maturity such as background colour, soluble solids contents, flesh firmness, harvest date, and starch pattern indices (Watkins et al. 1989; Ferguson & Watkins 1992). Soluble solids contents are used to establish when kiwifruit are mature enough to be commercially harvested (Section 1.1). Starch content (Lallu et al. 1989), firmness (Pratt & Reid 1974; Crisosto et al. 1984), and sugar/acid ratio (Walton & de Jong 1990) might all be used to determine kiwifruit maturity. There is some doubt over how accurate soluble solids content is as a measure of kiwifruit maturity (Lallu et al. 1989; MacRae et

al. 1989). Understanding how harvest indices are related to premature softening should enable development of a predictive model. Other attributes such as calcium content and rate of fruit softening might be used when making decisions about an orchard line's acceptability for export.

When trying to relate the fruit attributes for an orchard line assessed at harvest, with the line's level of whole or localised premature softening after storage, very seldom is a relationship found (Sections 3.3.5, 6.3.1); there is usually too much variation between orchard lines. Using just one of the fruit attributes measured at harvest does not apparently give a clear prediction of a line's potential level of premature softening after harvest (Sections 3.3.5, 6.3.1). Results from Section 8.3.2.3, Fig. 8.4, suggest there may be potential to predict the storage performance of an individual orchard line based on a combined index involving harvest soluble solids content and calcium contents. Kiwifruit are coolstored for a long duration and soften slowly so many factor(s) contribute to final firmness (Table 9.1C). However, a large portion of the final firmness may be linked to variables which can be measured at harvest, such as fruit calcium and soluble solids content (Fig. 8.4). It seems likely that any prediction model could usefully include harvest soluble solids content and fruit calcium concentration. Construction of such a model requires further understanding of how soluble solids content and fruit calcium content work independently, or in association, to influence fruit quality. The association of high dry matter, low phosphate, and high calcium content with healthy fruit after storage (Section 6.3.1) may be useful components in this model. Unfortunately, the data in Section 6.3.1 did not have enough observations to make them suitable for multivariate analysis (Cruz-Castillo et al. 1994) but they do provide a basis for design of further work using the multivariate approach. Studies using such multivariate approaches to characterising the relationships between fruit attributes, storage behaviour, and eating qualities, should provide powerful new insights into better production of kiwifruit.

Late harvested fruit have a higher soluble solids content at harvest than early harvested fruit, a sign of higher fruit maturity (Sections 7.2.2,

8.3.1.4; Beever & Hopkirk 1990), whereas their calcium contents may only differ slightly (Sections 7.3.1.1, 8.3.1.5). The change in fruit soluble solids content between early and late harvested fruit is a measure of the considerable maturity change fruit go through during the harvest period. The amount of time between early and late harvested fruit is small relative to the time taken for kiwifruit to develop from immature to mature fruit (Section 2.1). It seems likely that changes in fruit that enable late harvested fruit to store better than early harvested fruit appear to require fruit attachment to the vine (Section 7.3.1.2). On the other hand, it may be that if early harvested fruit are left at ambient until late harvested fruit are picked, both would have a similar storage potential at 0°C. It is unclear if maturity changes at harvest time to fruit that are attached to the vine are driven by factors that are nutritional or hormonal in nature (Sections 2.1.2, 2.2.6). Understanding of processes which cause late harvested fruit to store better than early harvested fruit could possibly be used to enhance the storage performance of early harvested fruit.

Further work is required to understand how harvest maturity affects kiwifruit susceptibility to soft patch development. Further experimental work using a larger sample size and a greater time duration between harvests may lessen the error variation, which could more clearly show if a relationship exists between harvest maturity and soft patches (Sections 7.3.1.3, 8.3.1.1).

9.4.4.2 *Initial handling when harvested*

The initial handling and bulk collection of harvested fruit has the potential to expose fruit to impacts and compression forces that result in localised premature softening of fruit after storage (Sections 2.2.7, 3.3.2, 4.3.1; 5.3). The actual levels of impact damage that occurs to fruit when they are transferred from the picking bag into a wooden bin, and compression damage which occur as fruit are stored in a wooden bin at the time of harvest, are not known. Variability between fruit in their susceptibility to induction of soft patches by compression masked any gradients there may

have been down the pipes in the study described in Section 3.2.2. Thus, whilst there is clearly a penalty to be paid in terms of fruit quality for exposing fruit to compression, it is difficult to quantify the effect with sufficient accuracy to predict whether alternative bin sizes would be justified.

To what extent using wooden bins at harvest to store and transport fruit exposes them to vibration damage is not known. Practices such as careful driving, maintenance of road surfaces, and air suspension may enable a reduction in the level of vibration fruit transported in bins are exposed to (Section 2.2.7.3). An alternative approach to reduce vibrations to fruit may be to collect fruit in smaller volumes, rather than in bulk using wooden bins. However, decreased fruit volume should reduce compression damage but small volumes of fruit may be even more susceptible to vibration damage as they would have less mass to hold them in place (Schulte Pason et al. 1990). Further work to test this possibility may be worthwhile. Current handling and bulk collection of fruit at time of harvest should be evaluated to determine what incidence of soft patches develop on fruit as a result of vibration damage at harvest.

Exposure to compression and impact forces at harvest and at any time prior to consumption of the fruit, could result in the development of soft patches. There are a number of situations in the current New Zealand kiwifruit industry where fruit are exposed to handling damage, most of which could be prevented. Even small compression and impact energies are enough to cause the development of localised prematurely soft areas on kiwifruit (Sections 3.4.1, 4.3.1, 5.3.2). The New Zealand kiwifruit industry needs to evaluate its fruit management systems to determine the extent to which current practices expose fruit to handling damage which then causes premature softening. Fruit should be prevented from being dropped or hitting other fruit or hard surfaces. All surfaces that moving fruit contact against should have foam padding to absorb the kinetic energy fruit has accumulated due to its travelling. Impact and compression occurring to

kiwifruit in the handling system should be identified and eliminated. As part of this, the kiwifruit industry would benefit from an accurate and economic method or tool that could identify soft patches on kiwifruit. The accuracy with which the incidence of soft patches are being assessed by current condition checking techniques needs to be investigated. To use the overall firmness values for an orchard line when considering if fruit are acceptable for export may not accurately reflect the presence of soft patches due to physical damage or presence of LTB in fruit. The proportions of sampled fruit without soft patches may provide an additional basis for accepting an orchard line for export. If the present condition checking method of briefly holding fruit is changed to feeling the entire surface, this may more accurately detect the presence of soft patches.

9.4.5 Grading

9.4.5.1 At harvest

The severity of damage appears to increase in proportion to increasing fruit velocities and it is likely that damage occurs even at low velocities (Sections 2.2.7.4, 4.3.1). Fruit exiting a grader into a pack are usually fed out of grading machines by belts and ramps with the assistance of gravity, providing opportunity for fruit to be damaged and to soften prematurely (Sections 2.2.7.4, 5.3). Damage due to grading fruit needs to be identified and eliminated. Transfer of sorted fruit after grading into packs should involve fruit being exposed to nil impacts. The instrumented sphere offers a means of evaluating graders for their potential impacts (Section 2.2.7.4). Even an overall subjective assessment of a grader's perceived potential to damage fruit appeared to provide a reasonable indication of the actual damage fruit would sustain during grading (Section 5.3.1). Currently used commercial graders should be quantified for their potential to damage fruit. This could be done by measuring drop heights on graders, and assessment of sites on graders where fruit may potentially increase in their speed of travel, followed by an impacts against static surfaces or other fruit.

9.4.5.2 *After CA storage*

Kiwifruit not graded and packed at harvest are bulk stored in wooden bins in either air or CA storage. Fruit are then graded some time after harvest when they have started to soften (Section 6.1; Fig. 6.1). The final firmness of fruit removed from CA is more influenced by their rapid rate of softening than damage due to grading. Kiwifruit softened rapidly after removal from CA (Fig. 6.1). Understanding of the process which causes rapid softening of whole fruit after removal from a CA atmosphere seems likely to permit a greater influence over fruit rate of softening than any effect mechanical damage would have (Fig. 6.1).

9.4.6 **Packing**

The interaction between packaging and its effect on the long term storage potential of fruit has not been clearly defined in this study (Sections 2.2.7.5, 5.3.2). The factors which cause variation in the incidence of premature softening between different pack-types require further investigation so that packaging aspects of storage practices can be adapted to take advantage of any differences. At the moment, the industry is moving towards bulk storage and grading once fruit have softened, and those which have softened prematurely are removed. The benefits of storing fruit in bulk wooden bins, bulk packs, or in single layer trays depends on the relative costs of the packaging system themselves, and their effect on fruit softening behaviour, the cost of removing soft fruit prior to market sale, and the potential for impact, vibration, or compression to damage fruit in each system. Further work is required into the trade-offs that would be associated with alternative packaging strategies. This may include any variation between packs in their ability to maintain high humidity around the fruit during long term storage to prevent an enhanced fruit softening. Each pack-type may need different management practices to minimise loss of fruit quality during storage. Unfortunately, the benefits of grading softened fruit some time after harvest could be at the cost of the increased susceptibility of fruit to impact damage (Sections 4.3.2, 5.3.1).

9.4.7 Bulk storage

It is not known how much compression damage occurs to kiwifruit stored in wooden bins after the CA atmosphere is removed (Section 6.3.2).

Compression to fruit that are rapidly softening in wooden bins after the CA atmosphere is removed could promote softening of the whole fruit, similar to fruit in the LC and SL treatments (Section 3.3.2). Fruit temperature (Section 2.2.3.2), rate of water loss (Section 2.2.2), and vibration (Section 2.2.7.3) could have been responsible for the observed differences between the top and bottom fruit layers of bins (Section 6.3.2). An alternative approach may be to bulk store fruit in less deep containers.

There was no comparison made with fruit held in bins with or without polyliners to reduce water loss. It is recommended by the NZKMB (1996) that wooden bins have liners during storage to reduce water loss; this should probably be a required practice to prevent loss of firmness due to water loss (Section 2.2.2). However, further work in the relative costs and benefits of such a strategy should be done before a firm requirement could be made.

9.4.8 Coolstorage

Further work is required to understand how temperature influences development of soft patches and LTB in coolstorage, particularly with respect to which phase of fruit softening could be most critical in influencing fruit susceptibility to LTB or soft patch development (Sections 2.2.1, 8.3). If physiological soft patches are a form of localised premature fruit senescence then, once fruit are coolstored, factors such as temperature and time can be used to manage ripening and development of soft patches during coolstorage. This would make it useful to determine how prolonged storage of soft patch fruit at 0°C influences the fruit rate of ethylene production once removed from coolstorage and stored at ambient temperatures.

Fruit with low calcium contents are more susceptible to LTB and soft patches (Section 8.3.2.3). This is consistent with the concept that fruit

which are predisposed to soften quickly, due to low calcium, could also senesce first. Such fruit would possibly be more susceptible to prematurely develop disorders associated with tissue breakdown such as LTB and soft patches. Measuring calcium contents at harvest may enable prediction of orchard lines that will be more susceptible to LTB during storage. As LTB is a form of chilling injury, and is, therefore, temperature dependent (Sections 8.3.1.2, 8.3.2.1; Lallu et al. 1992), it is important to adequately monitor coolstore temperatures to avoid fluctuations below 0°C (Amos et al. 1993). The more temperature falls below 0°C, the greater proportion of fruit would be susceptible to develop LTB (Lallu et al. 1992).

9.4.9 Condition checking

It is important that fruit which have softened excessively during storage are identified and not exported or purchased by the consumer. Condition checking provides opportunity to identify fruit which have soft patches. Condition checking relies mainly on firmness being an accurate measure of overall fruit quality (NZKMB 1996). Mostly, the checking of fruit quality is performed subjectively, by gently clasping the fruit for a second or so, and then making a decision about the whole fruit firmness (NZKMB 1996). Subjective decisions can be confirmed by penetrometer measurements (NZKMB 1996). Accurate detection of soft patches involves feeling the fruit surface and is time consuming (Section 6.2.4). Detection of soft patches by feeling the whole fruit surface may not be an economic option. However, the cost of detecting soft patches needs to be considered against the potential loss of consumer confidence and future sales, due to purchase of kiwifruit with soft patches.

Premature softening resulting from physical handling at harvest is restricted to the localised damaged tissue on the fruit (Sections 3.3.1, 4.3.1, 7.3.1.3). Unless a penetrometer measures at the site of damage, the firmness measurement would suggest that the fruit had a similar firmness to undamaged fruit. The penetrometer appears to be severely restricted in its usefulness for the detection of soft patches (Sections 2.3, 2.4.1). The actual

level of damage occurring at harvest may not be accurately detected by the current condition checking process. Mean firmness for an orchard line may give a good estimate of the likely proportion of fruit with soft patches due to physiological factors (Fig. 6.2). As commercial fruit are likely to be exposed to some level of handling damage this association would be likely to become lost. A quick and accurate non-destructive tool is required to assess for the presence of soft patches in kiwifruit. The 'SoftSense' appears to have the potential to be used on a commercial grading machine at time of condition checking, to identify kiwifruit which have become very soft and, therefore, be likely to have physiological soft patches (Hopkirk et al. 1996). Detection of soft patches would involve assessing a sample of fruit from an orchard line; the number of fruit required in the sample to give an accurate estimate of the incidence of soft patches in an orchard line would need to be determined.

9.4.10 Export

Fruit being exported late in the storage season are often in their final softening phase (Fig. 2.1), and have a high susceptibility to impact and compression damage (Sections 3.3.2, 4.3.2). Fruit texture has changed dramatically from that at harvest (Section 2.2.1), which could allow a greater expression of tissue damage. Dropping or damage to pallets during transportation is likely to result in loss of fruit quality (Section 2.2.7.5). It is very important that staff associated with movement of fruit have the knowledge and skills required to minimise handling damage. No work has been reported on how much handling damage fruit receive during export handling operations, and how much this damage subsequently affected fruit quality. The export part of the distribution chain should be investigated to identify if there is a need to eliminate compression and impacts which might cause fruit to soften prematurely. Workers that are responsible for the movement of packed fruit need to be educated and trained to ensure careful handling of fruit. Companies transporting fruit could be audited to determine if standards agreed to for the handling of fruit are being adhered

to. Every fruit rejected as a result of premature softening represents a cost to the industry and loss of financial return to growers.

9.4.11 Market

Temperature appears to be the main influence on rate of ripening and rate of development of soft patches during the final phase of fruit softening (Sections 2.2.3.2, 3.3.2, 4.3.1). Much of the export of fruit to overseas countries occurs during the northern hemisphere summer when temperatures in overseas markets could be high. Soft patches increase in size as fruit decrease in firmness (Sections 3.3.2, 4.3.1). Shelf-life could be maximised by reducing display temperature to slow rates of softening and soft patch development. Kiwifruit have a high firmness-temperature coefficient (Section 2.2.3.1), so presentation of fruit at a lower temperature would raise fruit firmness. This might be expected to allow fruit to better withstand handling, although, this was not the case for fruit that had been graded after being stored in CA (Section 6.3.2).

After being exported, the pre-history of fruit becomes fully expressed and results in fruit with good or bad sensory qualities (Table 9.3). Localised soft areas have the potential to ferment and produce off-flavours while the surrounding tissue can be similar to that of healthy fruit (Hopkirk 1985; Stec et al. 1989). Soft patches on fruit are likely to have a rapid increase in size when exposed to a shelf-life period at ambient temperature (Sections 3.3.2, 4.3.1). It appears that the higher the temperature, the more rapid soft patch rate of development there would be (Sections 3.3.2, 4.3.1, 8.3.2.1). The increase in the size of a soft patch indicates that progressive nature of the breakdown associated with soft patch development.

When kiwifruit soften prematurely, they are approaching senescence when their quality becomes undesirable to consumers (Sections 3.3.2, 4.3.1). It is very important that if kiwifruit were to be sold in retail outlets already at eating firmness, that market operators appreciate how susceptible to compression damage fruit will be. Based on casual observations, there appears to be much opportunity for improvements in the way fruit are

commercially displayed, that would result in fruit quality being better maintained. Soft fruit should not be stacked very deep when displayed in a retail outlet, to reduce risk of compression (Section 3.4.1). Firm fruit displayed as a stack of fruit or left in bulk packs will develop some level of damage, but this level of damage will be likely to increase in proportion to the amount of load on a fruit and the extent of fruit softening which has taken place (Sections 3.3.3, 4.3.2). Fruit displayed in a shop for purchase may initially have similar firmness and quality. Unfortunately, the longer fruit are at ambient, the more quality will vary (Sections 3.3.2, 3.3.3, 4.3.1). Keeping ripe kiwifruit at a temperature lower than ambient when they are displayed for commercial sale, might ensure that consumers will be able to purchase fruit that have a quality which is more consistent.

Kiwifruit do not change colour as they ripen and only severe water-soaking or depression of fruit surface can visually indicate the presence of soft patches through the skin (Sections 2.2.7, 2.4.1). Prematurely soft fruit stored in a retail display can look similar in appearance to healthy fruit (Sections 2.2.7, 2.4.1). Markets may be able to prevent final fruit senescence and development of large soft patches for longer by keeping fruit at a suitable temperature until purchase and preventing mechanical damage to fruit.

9.4.12 Consumer

Good previous management of the crop would result in consumers being able to purchase from a consistent supply of high quality kiwifruit. Taste is an important measure of fruit quality for consumers (Stec et al. 1989).

Kiwifruit will have a low acceptability with a taste panel if off-flavours are present (Stec et al. 1989). As the firmness of kiwifruit drops, the flavour in kiwifruit changes dramatically. Prematurely soft fruit could have fermented and produced off-flavours. With all the work into disorders and trying to maintain kiwifruit quality there appears to be little published work into what specific qualities the consumer would like an ideal kiwifruit to have. It is not known how accurately whole fruit firmness, as determined by

penetrometer, reflects what the consumer perceives as being acceptable quality. The presence of soft patches may provide a better characterisation of what the consumer perceives as being a serious reduction in fruit quality, than low whole fruit firmness.

9.5 CONCLUSIONS

Kiwifruit become damaged through compression, impact, and vibration at harvest and thereafter, not just when fruit has become soft. The change in condition of the fruit flesh from brittle at harvest to viscoelastic once soft appears to influence when and which damage symptoms develop in response to an applied force. The amount of damage to kiwifruit due to a physical force is more extensive with softer fruit. The effect of physical damage appears to be limited to localised injured tissue with no apparent influence on the overall rate of fruit softening. Premature softening of kiwifruit, due to mechanical damage and low calcium, is probably largely preventable. Changes made to prevent premature softening will reduce fruit loss and enable production of a more uniformly softening, high quality crop.

Calcium concentration in kiwifruit influences their quality during long term storage. Adequate preharvest calcium contents are required for fruit to have low susceptibility to localised premature softening, premature fruit softening of the whole fruit, and low temperature breakdown. Preharvest monitoring of calcium could be used to determine if there is a need to enhance fruit calcium contents. Calcium content of kiwifruit can be enhanced by direct application of a preharvest calcium solution to the fruit surface. However, other fruit attributes are likely to influence final fruit quality in association with calcium. These include phosphate, dry matter, and soluble solids content. Following further research, these attributes may form the basis for a predictive model of fruit softening behaviour after harvest.

The model for the initiation and development of premature fruit senescence during storage, due to localised and whole fruit softening, and low temperature breakdown, could be used as a basis for developing

effective management strategies to prevent deterioration of kiwifruit during storage. Further development of the model for this purpose could include quantitative characterisation of processes that cause the initiation or development quality loss in kiwifruit. The kiwifruit industry needs to evaluate the current handling and storage system for any potential deterioration of fruit quality. The industry can account for key fruit attributes that influence kiwifruit quality, and implement strategies to enhance these attributes to prevent loss of fruit quality (e.g., preharvest calcium applications). Given the limitations of the penetrometer to detect soft patches, and other softening disorders, a new non-destructive instrument is needed to detect such fruit in commercial handling. Researchers need to develop a model to predict storage potential of fruit so appropriate management of fruit inventory can be used to minimise fruit loss.

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9.7 TABLES

Table 9.1 Symptoms and exacerbating factor(s) associated with premature senescence of kiwifruit as a result of: **A**, physically induced soft patches; **B**, physiologically induced soft patches; **C**, rapid softening of whole kiwifruit; or **D**, the development of low temperature breakdown (LTB).

Name	Symptoms	Exacerbating factor(s)
A	Physically induced soft patches (handling damage to fruit)	Initiation:
		<ul style="list-style-type: none"> - Impact at harvest or after harvest (Section 4.3) - Compression at harvest or after harvest (Section 3.3.2) - Grading at harvest or after harvest (Sections 5.3.1, 6.3) - Packaging arrangement (single layer vs bulk; Section 5.3.2) - Vibration during transportation (Sections 2.2.7.3, 6.3.2) - Positional effects within wooden bins and pack type (Sections 5.3.2, 6.3.2) - Fruit firmness (Sections 3.3.2, 4.3.2)
B	Physiologically induced soft patches (no direct physical handling)	Development:
		<ul style="list-style-type: none"> - Storage at 20 or 0°C (Sections 2.2.7.2, 2.4.1) - Storage at 20°C after long term coolstorage (Sections 3.3.2, 4.3.1) - Duration of storage (Sections 3.3.2, 4.3.2)
B	Physiologically induced soft patches (no direct physical handling)	Initiation:
		<ul style="list-style-type: none"> - Low calcium and high phosphate concentration (Sections 2.4.1, 6.3.1) - Low dry matter content (Section 6.3.1) - Long storage duration, low temperature (0°C) and advanced softening (Fig. 5.3; Sections 3.3.2, 6.3.1, 8.3.1.1)
B	Physiologically induced soft patches (no direct physical handling)	Development:
		<ul style="list-style-type: none"> - Storage at 20 or 0°C (Sections 2.2.7.2, 2.4.1) - Storage at 20°C after long term coolstorage (Sections 3.3.2, 4.3.1) - Duration of storage (Sections 3.3.2, 4.3.2)

			<p>Development:</p> <ul style="list-style-type: none"> - Long storage duration at low temperature and advanced softening (0°C; Sections 3.3.2, 4.3.2, 8.3.1) - Low calcium content (Fig. 8.4; Section 6.3.1)) - High phosphate content and low dry matter content (Section 6.3.1)
C	Premature softening of the whole fruit	<ul style="list-style-type: none"> - Rapid rate of fruit ripening leading to premature loss of firmness (Section 1.1) - Premature ethylene production (Section 2.2.4) 	<p>Initiation:</p> <ul style="list-style-type: none"> - Exogenous ethylene (Section 2.2.4.2) - Low calcium concentration (Section 2.2.8.1) - Low harvest soluble solids content (Sections 2.2.6, 7.3.1.2) - Physical damage to fruit stored at 20°C (Section 2.2.7.1) - Grading of softened fruit stored at 0°C (Section 6.3.1) - Compression of softened fruit stored at 0 or 20°C (Sections 2.2.7.2, 3.3.2, 6.3.1). - Vibration during transport (Sections 2.2.7.3, 6.3.1) - Water loss from fruit (Sections 2.2.2, 6.3.2) - Impact to softened fruit (Section 4.3.2) <p>Development:</p> <ul style="list-style-type: none"> - Storage temperature (Section 2.2.3)
D	Low temperature breakdown (LTB)	<ul style="list-style-type: none"> - Water-soaking of outer core and pericarp tissue (Section 2.4.2) - White flecks in outer pericarp tissue (Section 2.4.2) 	<p>Initiation:</p> <ul style="list-style-type: none"> - Chilling injury (Sections 2.4.2; 8.3) - Long storage duration (Section 8.3) <p>Development:</p> <ul style="list-style-type: none"> - Low soluble solids content (Section 8.3) - Low calcium concentration (Section 8.3)

Table 9.2 Mean calcium contents of soft patch or healthy fruit amongst kiwifruit from 3 different populations in 3 different experiments.

Sections	Calcium (mmol/kg)		
	Soft patch	Healthy	SED
5.3.6	6.5	7.3	0.78
6.3.1	6.5	7.4	0.35
8.3.2.3	7.6	8.8	0.52

Table 9.3 Sensory qualities of ripened kiwifruit.

Sensory Qualities	Descriptors	
	Good	Bad
Flavour	Tangy, sweet (Stec et al. 1989)	Sickly, off-flavour (Stec et al. 1989)
Aroma	Slightly sweet (Stec et al. 1989)	Very sweet (Stec et al. 1989)
Visual		Dark green water-soaked tissue (Hopkirk & Finch 1989)
Texture	Firm, soft (Stec et al. 1989)	Mushy, very soft (Stec et al. 1989)

9.8 FIGURES

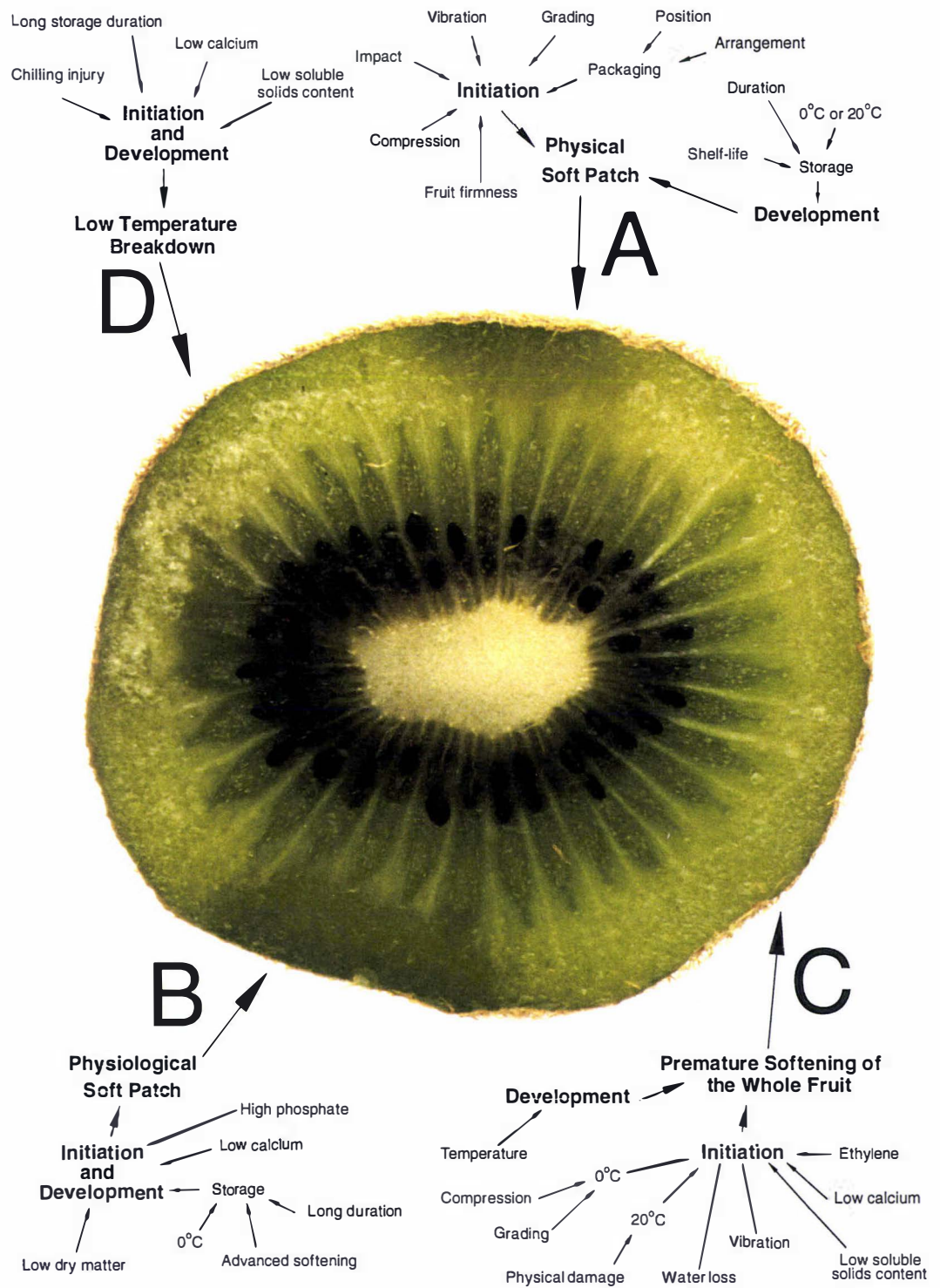
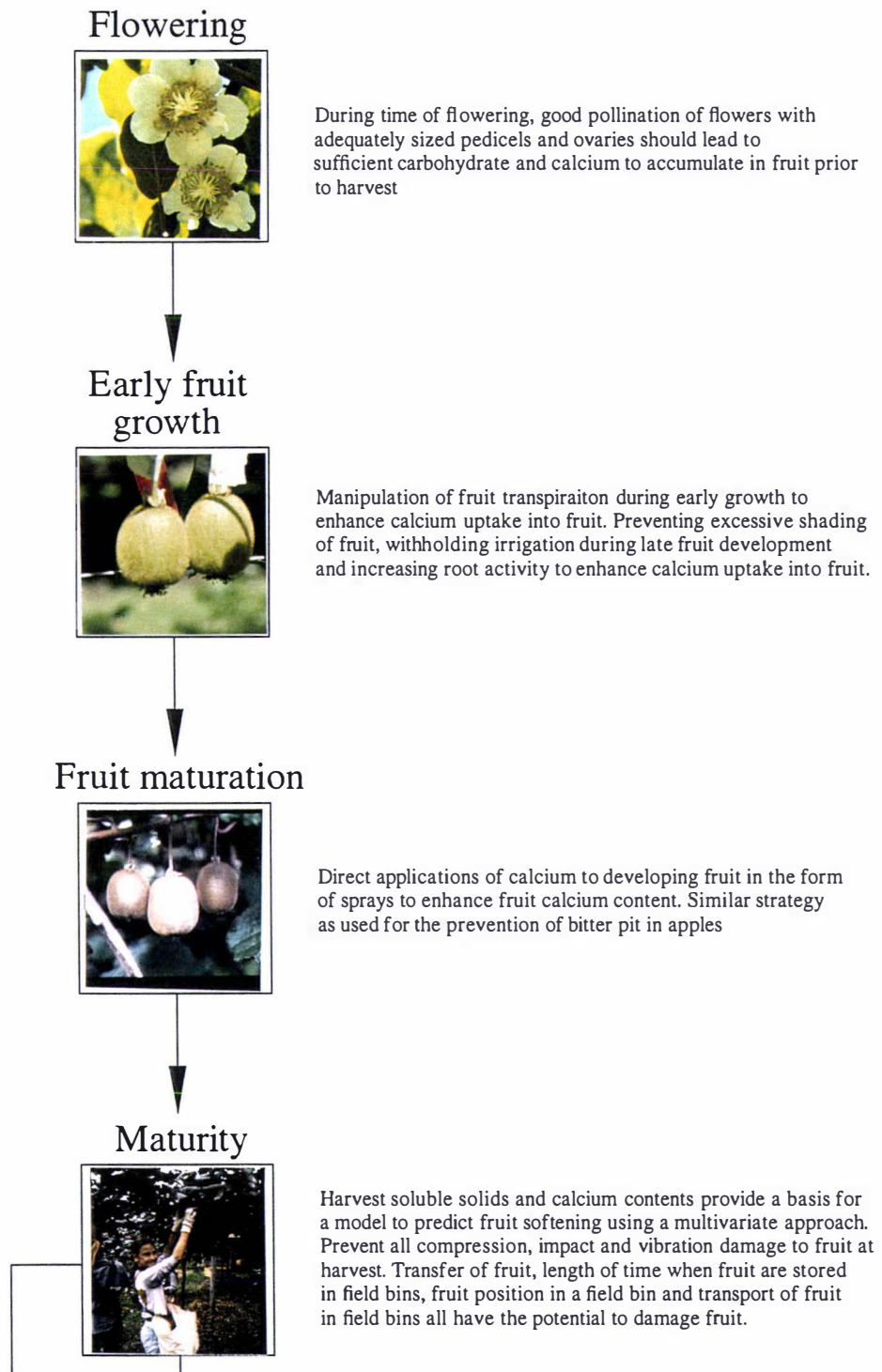
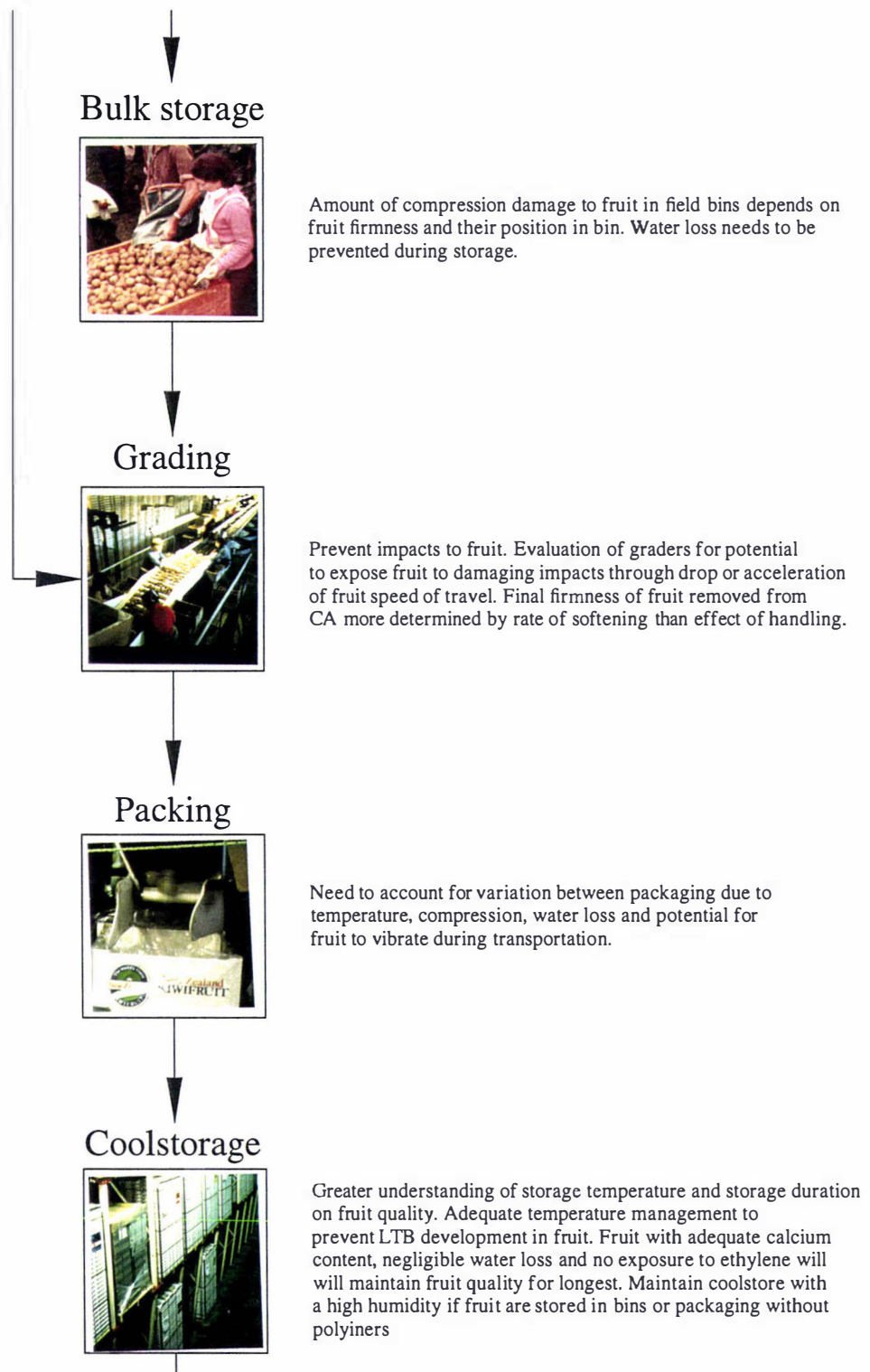


Fig. 9.1 A conceptual model of factor(s) which initiate and develop: physically induced soft patches (A); physiologically induced soft patches (B); premature softening of the whole fruit (C); and low temperature breakdown (LTB; D) in kiwifruit.

Fig. 9.2 Implications of the model for the initiation and development of premature fruit senescence due to soft patches, rapid softening of whole fruit, and low temperature breakdown (LTB) for the management of kiwifruit during the preharvest, harvest, and storage phases to minimise loss of fruit quality.





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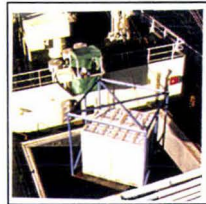
Condition checking



Need for accurate assessment of fruit. A line's firmness may not accurately predict the incidence of soft patches. Penetrometer limited in usefulness to detect soft patches and an alternative non-destructive instrument could be more helpful.

↓

Export



Fruit are now very vulnerable to impact, compression and vibration damage. Control of storage temperature very important for the maintenance of fruit quality.

↓

Market



Management of storage temperature vital to maximise fruit quality when fruit near final softening phase. Fruit very susceptible to rapid deterioration due to handling damage. Avoid deep layers of fruit when displaying. Need an effective strategy for the detection of deteriorated fruit and prevention of it from being purchased by a consumer.

↓

Consumer



Advise consumers on best practices for care of kiwifruit.