EVALUATION OF MASSEY TWIST TESTER FOR TEXTURAL ASSESSMENT OF FRUITS AND VEGETABLES

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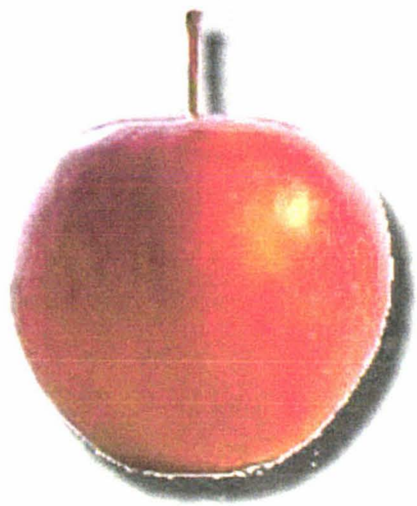
2000

To the Glory of God in Jesus Christ my Lord and Saviour, to Whom I owe Everything.



"One of the great joy known to man is to take a flight into ignorance in search of knowledge."

-Lynd

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ABSTRACT

The Massey Twist Tester is an instrument developed to assess the texture of fresh fruit and vegetables rapidly. Since its original development in 1990, the Twist Tester has been modified extensively and numerous prototypes have been developed. In principle a small rectangular flat blade is rotated inside the fruit, and the torque required is measured. The current version incorporates a motor driven unit rotating inside a set of needles which hold the fruit firmly. Although measurements of fruit properties have been reported in previous studies, these have all been based on earlier designs, and no data on the new version of the Twist Tester have yet been published.

The main aim of this study is to evaluate the performance of the new version of the Twist Tester by comparing it to the standard penetrometer, which has been widely used in many parts of the world for several years.

Samples of fruit and vegetables were stored in different conditions to vary the level of firmness in order to expose how well each instrument performed in detecting the changes of textural properties.

Generally, both Twist Tester and Penetrometer readings declined with storage time. In the testing of Braeburn apples, the Twist Tester has highly correlated with storage time as compared to penetrometer,

The Twist Tester and Texture Analyser produced results for the Royal Gala apples which were highly correlated with those obtained from the penetrometer, suggesting g that this test could be used, as it is more reliable for determining the maturity of apples. For plums, the correlation of the Twister with storage time at three storage

conditions were high (*r* =0.92, 0.95 and 0.92), compared to the correlated of penetrometer with storage time which was (*r* = 0.83, 0.44 and 0.77). The penetrometer has a slightly higher degree of correlation with storage time for pears, compared to the Twist Tester. Pears declined in crushing strength and penetrometer readings with storage time, but over the last 7 days the value of firmness increased. The literature review showed that when water loss from the fruit is extreme, it forms a rubbery texture, produces a higher degree of firmness. Further research work would need to be done to obtain a more reliable result.

The Twist Tester performed well in predicting the changes of textural properties of nashi, which showed a stronger correlation with storage time than the penetrometer relationship with storage time. During storage of kiwifruit, the penetrometer could not detect any changes after 14 days, while Twist Tester obtained a reliable result. This showed that penetrometer could not test the firmness of texture of any soft fruits. The relationship between the crushing strength and storage time produced a high coefficient in all three storage conditions (*r* = 0.91, 0.89, 0.80) while the penetrometer readings showed the following correlations with storage time (*r* =0.77, 0.76, 0.44). Thus the Twist Tester can determine the maturity of kiwifruit as well as any soft tissue products. Changes in the textural properties of potatoes also were well detected by the Twist Tester, which showed a stronger correlation with storage time than did the penetrometer.

Firmness and crispness as measured by both the Twist Tester and penetrometer readings were highly correlated, while other variables showed only a poor relationship with instrumental measurement. Further research is needed to improve these results by using a well-trained taste panel.

Changing the speed of Twist Test has no significant effects on the crushing strength of fruit and vegetables within the range of 5-10 rpm.

The Twist Tester is more accurate, easy to operate and may be used to determine the quality and maturity of a wider range of products than penetrometer.

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CHAPTER ONE – INTRODUCTION

Measuring firmness of fruit and vegetable is used to evaluate the state of the product. This method is widely used by researchers, producers and customers in order to evaluate the acceptability of the product for marketing and consumption. Many researchers indicated that fruit firmness was a very important in fruit quality. Lurie and Nussinovitch (1996) reported that tests conducted by marketing inspectors at harvest equated firmness and quality in apples, and this is now used as required method for determination of picking maturity of NZ apples. Wills, (1998) believed that the quality of fruit depend highly on their physical and chemical composition which contributed to the firmness of the product. For many products, the checking procedure prior to export involves assessment of fruit firmness either by gentle hand squeezing or by using a suitable device.

Hopkirk et al. (1996) suggested two general characteristics that determined the usefulness of the measuring instrument either for researchers or for commercial purpose: "(1) The ease of operation; and (2) the consistency of the values generated as fruit soften, and thus the ability of the device to discriminate between fruit of various firmnesses." Clearly the reliability of the readings also depend on the accuracy of the measuring instrument's performance. In practice the Penetrometer is used as the standard instrument for measuring the firmness of fruit (e.g. Bourne, 1982; Hopkirk et al. 1996; Bourne, 1994; Harker et al. 1996; Studman and Yuwana, 1992; McGlone & Kawano, 1998; Hung et al. 1998). Marques (1998) indicated that the Penetrometer was also use in

New Zealand industries as a standard instrument for measuring firmness for kiwifruit, when fitted with a 7.9mm diameter plunger.

In history, there have been a lot of devices developed with the purpose of measuring fruit firmness. Unfortunately these devices have limitations that affect the readings. These include operator differences, removal of skin before the test is performed and the fact that they are destructive (Harker et al. 1996, Yuwan; 1991; Studman and Yuwana,1992; Hopkirk et al. 1996). Due to the limitations displayed by the penetrometer, Studman (1992) developed a motor driven instrument called the Massey Twist Tester, which has operator aids and computerised data acquisition. Although this device remains a destructive instrument he suggested it may overcome some of the problems occurring with the penetrometer. In order for the Massey twist tester to be recognised and used commercially, there is a need to assess its performance for accuracy and reliability.

The general aim of this thesis was to study the performance of the Massey Twist Tester on a range of products, and the objectives are to:

1. assess the performance of the Massey Twist Tester on fruit and vegetables at different stored conditions and to examine whether it can detect variations in textural properties.
2. evaluate the performance of the Massey Twist Tester against a Texture Analyser and the standard Penetrometer.
3. examine the relationship of crushing strength and penetrometer readings to sensory assessment.
4. evaluate the effects of test speed on crushing strength of fruit and vegetables.

CHAPTER TWO – LITERATURE REVIEW

2.1 INTRODUCTION

The food quality measurements made by food industries use different kinds of textural assessment to produce quality commodities. Wills et al. (1998) believed that instruments and techniques for measuring the mechanical properties of fruits and vegetables are of fundamental importance in grading, quality control and in predicting the mechanical behaviour of the product under various environmental conditions. Surveys in earlier years in the food industry had clearly demonstrated an urgent need for a better food texture assessment instrument. In the United Kingdom and in Canada Muller, (1968) found that, although the Penetrometer was widely used within the food industry, the status of food texture measurements was unsatisfactory. Bourne (1982) commented that although there were adequate techniques to measure texture of some foods, there are many foods for which texture measurements were nonexistent. He suggested that better understanding of texture leads to better texture measurement. Therefore, the objectives of the literature review are:

1. To review the concepts of texture which are important in understanding the mechanical behaviour of fruit and vegetable material.
2. To review the history of texture measurement techniques.
3. To discuss texture measuring instruments and their ability to assess the texture of fruit and vegetables correctly.

2.2 UNDERSTANDING TEXTURE

The internal texture of fruit and vegetables is one of the major determinants of their quality (Wills et al, 1998). Poovaiah et al. (1986) argued that the cellular anatomy, cell wall composition and cell turgor of the fruit tissue determined the texture of the fruit. LaRue and Johnson (1989) stated that texture representing the properties of biomolecules involved in the cellular structure of cell walls. Thus degradation during natural physiological transitions or artificial processing operations may alter the textural properties of food. The parameters of texture are hardness, firmness and crispness. Rhodes (1980) and Knee & Bartley (1981) agreed that texture was highly dependent on chemical and physical properties of the cell wall. They further explained that texture was affected by its cellular anatomy, the water relations of the cell and the compositions of the cell - walls including the levels of different minerals such as Calcium, in the structure of the cell walls and cell membranes. These changes in the compositions of fruit cells, as explained by Harker (1997), are determined by preharvest and postharvest factors. The description of texture by Abbott et al. (1984) has contributed to the present study as it encompasses both sensory reaction and mechanical responses of the food material to applied forces. Muramatsu et al. (1999) concurred that texture is very important, as it displays and reflects the quality of fruit and vegetables.

2.2.1 Quality and Texture

Quality is a combination of several parameters, of which firmness of texture is often one of more important (De Belie et al. 1999). It can be defined *as the combination of fruit or vegetable characteristics that gives them their value as food* (Kader, 1992). Assessment of the quality of the texture of fruit and vegetables has been widely used in the world. For example, the New Zealand Fruit Industry has given a great amount of money, time and energy to studying and assessing the quality of apples and kiwifruit (Padfield, 1969; Studman, 1996; 1998). In assessing the texture of tomatoes, for example the fruit must be firm and not water- soaked, soft or shriveled (Kader, 1992). Quality assessment is highly subjective, as it is dependent on customer's satisfaction - which is very important, and not to be ignored. Therefore, the practice of assessing the features of fruit and vegetables for marketing has been widely used both in New Zealand, and in most other parts of the world. There are several methods of assessing the fruit and vegetables in terms of appearance, maturation, texture and other features. Quality is demonstrated by several characteristics such as cleanliness, maturity, ripeness, firmness, uniformity of size and shape, and the freedom from defects. Because of this, Saylor (1996) stated that the industry's quality system has its main focus on customer satisfaction. Quality is thus linked with profitability, and its successful implementation requires a complete understanding of texture and factors that affect produce (Wills et al. 1998). Therefore, instruments that measure texture should be able to determine 'quality' product in order to be able to meet market requirements.

2.2.2 Texture and Firmness

The firmness of the product depends on the skin and flesh toughness. It is one of the fruit texture parameters or characteristics used to evaluate quality, and is used by many agricultural producers in order to determine maturity (Ferguson, 1984 and Chen, 1996). For example, it is the key criterion in the maturity assessment of kiwifruit. (Banks et al. 1992; Bruh, 1995). LaRue and Johnson, (1989) considered firmness to be the most important quality factor as it is needed to enable fruit to withstand the effects of movement along the marketing chain during the postharvesting process.

The firmness of fruit and vegetables can be retained for several months when they are treated with calcium (Poovaiah et al, 1988). Several experiments have demonstrated that calcium delays softening by acting as a cementing agent in the cell walls, which helps to maintain cell function (Brower & Cutting, 1988; Fallahi et al. 1997). Calcium stabilizes cell membranes by bridging phosphate and carboxylate groups of phospholipids at the membranes' surface, and binding with the pectin chains in the cell wall to form linkages that will enhance the strength of the wall (Ferguson, 1984).

Temperature and storage times are also known to affect the measured firmness of a wide range of crops (Blapied et al. 1978; Werner et al. 1978; Bourne, 1982; Harker & Dunlop, 1994). Meheriuk et al. (1994) confirmed that the main purpose of storing fruit and vegetables in favourable conditions is to maintain acceptable quality. Controlled atmosphere storage and refrigeration are effective means of retarding the deterioration changes in many commodities, especially apples (Deman, 1976; Thompson, 1996). Fruit stored continuously at 0°C soften only slightly during storage and storage time has been proved to affect texture - especially the parameter *firmness*. Study has shown that the firmness of kiwifruit decreases with storage time (Marques, 1998). Similarly, Peleg (1993) stated that apple firmness is known to drop progressively with time, and that the firmness reduction is lower in cold storage than at room temperature.

2.2.3 Softening and Texture

Softening results in the middle lamella of fruit being dissolved, which changes the texture (Harker & Hallet, 1992). It is reasonable to expect that, when fruit becomes soft during the ripening process, its firmness will decrease (Ssczesnial & Bourne, 1969; Mohsenin, 1965; Peleg, 1980; El-Zoghbi, 1994; De Belie et al. 1999). Ethylene is a gas (C_2H_4) which is responsible for texture change through solubilization of pectins and cellulose that results in softening of the cell wall (Fluhr & Mattoo, 1996; Marques, 1998; Abeles et al. 1992). The synthesis of ethylene has been shown to play a vital role in fruit maturation and ripening by using ethylene inhibition and pulse ethylene treatments (Oetiker & Yang, 1995). The separation of cells is one mode of failure of plant tissue, which involves softening. Other wall enzymes (notably β-galactosidase) may contribute significantly to the softening process (Lazan & Ali, 1993). The cell separation involves softening which is initiated by the transport of polygalacturonases (PG) to the middle lamella (Waldron et al. 1997). Waldron et al. (1997) suggested that research should be aimed at developing procedures to prevent excessive cell separation, so that the decline in firmness of fruit tissue with time could be lessening.

3.1 TEXTURE MEASUREMENT

Growers, handlers and exporters of fruit and vegetables put considerable effort into providing and maintaining certain standards of quality for the customers. Therefore texture measuring instruments are an important tool (Chen, 1996). The demands and expectations of customers, as well as the markets, for a high quality product have forced marked changes in the methods of textural assessment (Studman, 1998; Chen, 1996; Mitcham et al. 1999). The quality of the product also decides the profitability of the industry. Therefore, its successful implementation requires a complete understanding of all factors that affect produce, and the measurement techniques that correctly determine 'quality' in order to meet customers' and market requirements (Wills et al. 1998). They stated that assessing fruit quality is not easy, as external characteristics such as skin colour and fruit size are not always good indicators of internal composition. Therefore, quality evaluation methods must assess internal properties, but unfortunately these may be destructive rather than non – destructive.

3.2 History of Texture Measurement

Traditionally, sensory assessment of texture, has been the method most commonly used to measure the textural properties of food – indeed this may led to the development of new instruments with the same intention (Bourne, 1982 and Mitcham et al. 1998). Sensory evaluation offers the opportunity to obtain a complete analysis of the textural properties of food as perceived by the human senses. A number of processes occur while food is being masticated, including deformation, flow, comminution, mixing and hydration with saliva - and sometimes changes in temperature, size, shape, and surface roughness of the food particles. All of these changes are recorded with great sensitivity by the human senses, but many of them are difficult to measure by objective methods.

3.2.1 Sensory Texture Assessment

Sensing texture, as Bourne (1982) explained, is based on the senses of seeing, smelling, touching, hearing and tasting. Kramer and Szczesniak (1973) divided the sensory qualities of food into a sensory circle with three zones according to the major senses, as in **Figure** 2.1. The eyes, the smell, sense the appearance of food by the olfactory epithelium of the nose, texture is sensed by the muscles, and flavour by the papillae on the tongue.

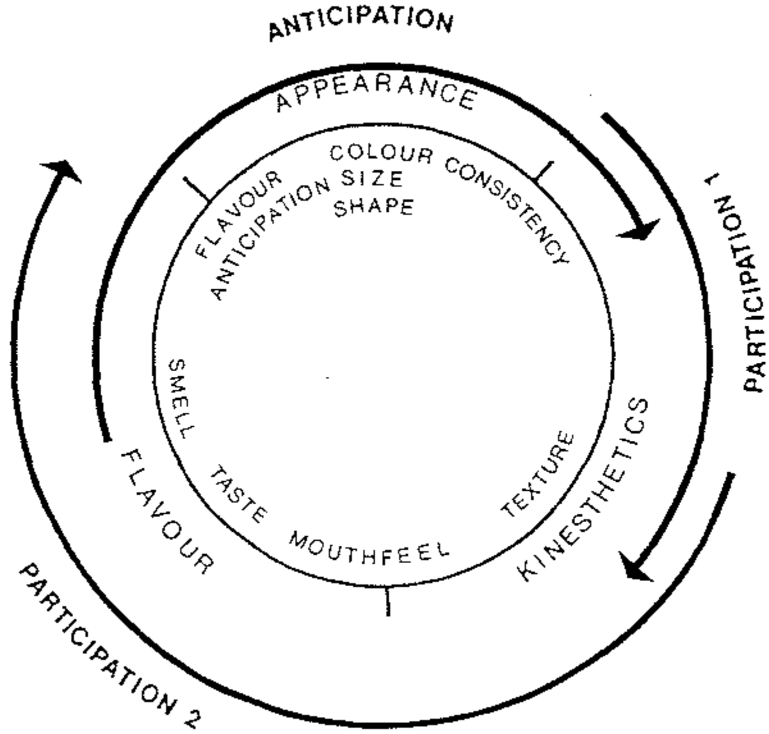


Figure 2-1. The sensory circle according to the major senses.

Kramer and Szczesniak, (1973)

3.2.2 Appearance of product

Appearance refers to the visual factors of the product, which include size, shape, colour, maturity and uniformity (LaRue & Johnson, 1989). The first impression of fruit is visual, since appearance is the only characteristics immediately available – and hence this is the criterion most commonly used by customers before selecting and buying a product, as they do not have access to texture - assessing instruments when inspecting the quality product in the market. However, making a texture assessment visually can be performed to only a certain level: for example premature ripening can give false colour. Human graders have been shown to fail in grading fruit correctly due to the influence of blush colour. Colour perception depends upon the individual's own ability to differentiate colour, the amount of light reflected off the fruit surface and the chemical and physical characteristics of fruit (Wills et al.1998). The specifications and standard system of grading tomatoes in New Zealand and USA require high quality tomatoes which have superior physical appearance (Gould, 1983). Although the visual method of assessing texture and maturity can be very inexpensive and useful to a small industry, it is time-consuming, often complex- and not highly reliable.

3.2.3 Sense of touch

It is also a common practice to assess fruit firmness by squeezing or compressing the fruit between fingers. This method was common due to insufficient standardized methods for the producers, packers and inspectors (Mitcham et al. 1998). However, there are still some disadvantages in applying this method, which include the fact that a study (Voisey & Crete, 1973) showed inconsistent results as male assessors generally squeezed harder, and applied force more quickly, than did female assessors.

3.2.4 Sense of hearing

Auditory sensations are important aids to the perception of the many fruits where sound quality is used. Dacremont (1995), stated that recent development of new techniques for objective evaluation of food texture are based upon analyses of sound, light transmission and vibration. The consumers usually test the maturity of fruit, especially watermelons, by tapping the fruit with the finger knuckles to judge the sound made in order to determine the degree of maturity of the fruit. This method known as acoustic response and can be used before and after harvest. Although this method is considered reliable and inexpensive, it is still under experimental stage of evaluation (Ronai & Shmulevich, 1995; Armstrong, 1997 and Stone et al. 1996)

3.2.5 Sense of tasting

The most common sensory texture assessment is made inside the human mouth during mastication, which is an enjoyable sensory experience that gives humans satisfaction (Bourne, 1982; Kohyama & Nishi, 1997). Bourne, 1982 wrote " To most people, eating is a very personal, sensual, highly enjoyable experience; enjoyment here and now, with little worry about long – term consequences". From previous research and studies, sensory evaluation of texture through tasting was proved to be correlated with the results obtained from other forms of assessment. Bourne (1982) suggested that designing instruments to measure texture should be guided by sensory assessment. Harker (1997) further supported this by stating that the validity of a textural assessment instrument is gauged by how well it reflects and defects the sensory texture attributes. Kader (1992) commented that a closed relationship was shown between the sensory assessment firmness of cherries and the durometer. Abbott et al. (1984) argued that there was a reasonable relationship between the measurement of apples by the puncture test, and by sensory evaluation. A similar relationship was shown in the study of the texture of parenchymatous plant tissue by sensory assessment and the hardness of the fruit tissue by tensile strength. Consistent evaluation of texture results requires carefully trained analytical sensory panels, because not all people are capable of making consistent judgements. Standard rating scales and a basic texture profile comparison analysis (TPA) score sheet for each commodity have been developed. (Civille & Szczesniak, 1973; Bourne,1982). However, difficulty and inconsistency of results were shown in assessment of the textural attributes of a range of foods, due to individual differences as each individual has his/her own perception of texture (Wendy et al. 1996). Solving these problems by using instruments, would therefore allow the fruit to be objectively assessed - whether non destructively or destructively- in order to present data which are independent of the individual observer. Such results should be fair, impartial, factual and free of personal bias (Langron, 1983; Thompson & MacFie, 1983; Naes, 1990).

3.3 TEXTURE MEASURING INSTRUMENT

As reviewed by Bourne (1982), Lipowitz was possibly the first person to develop an instrument for testing foods in 1861 in Germany. This was a puncture tester for measuring the firmness of jellies. This worked by placing a flat disk attached to a funnel vertically on the surface of the gelatin jelly in a beaker. Lead shot was poured into the funnel, causing the disk to penetrate the jelly. The measurement of the consistency of the jelly was total weight of the shot, rod, funnel and the disk. Although this was stated to be the first puncture tester used, Professor Morrison is known to be the "Father of Texture". He is referred to by Bourne (1979) as the first to develop a puncture tester in 1917, since his work started a new era of quality measurement in the food industry. This instrument worked by measuring the force required to push an exposed portion of a marble embedded in paraffin wax into an apple as shown in **Figure** 2-2. Magness and Taylor (1925) altered this technique by attaching a spring force scale into the handle of the instrument and using a cylindrical plunger with a rounded end instead of the glass marble.

Morrison food puncture tester instrument

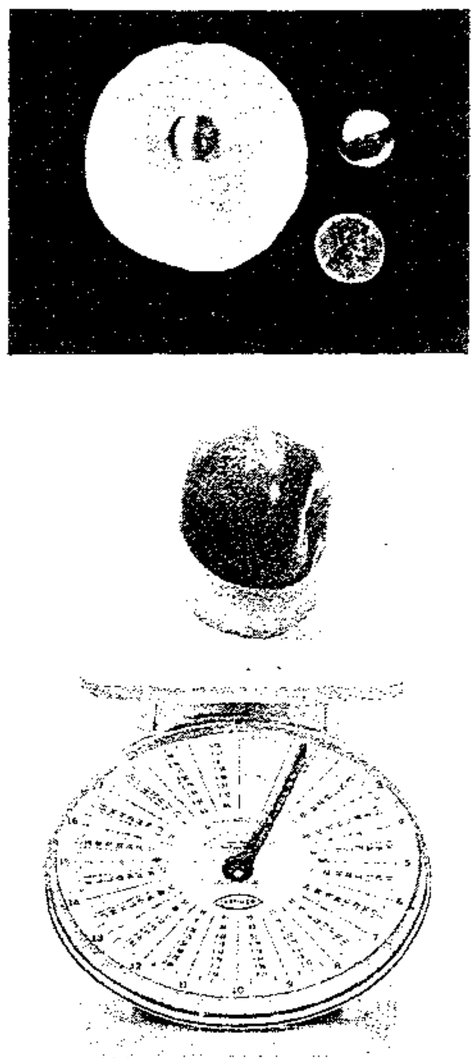


Figure 2-2. The reconstruction of Morrison fruit pressure tester (Bourne, 1979). The top shows a coin, which is compared, to the size of the unembedded marble, unembedded marble and a glass marble embedded in paraffin wax. The lower shows a kitchen scale to measure force and on top is an apple pressed against the wax disc containing the marble

In 1907 an instrument called the "Dexometer" developed in Germany to measure the toughness of meat as well as the softening of vegetables during cooking (Kramer & Szcresniak, 1973). Due to these early textural instrumentation developments, interest later spread to the development of instruments for measuring the texture of other foods including fruit and vegetables. However, Chen (1996) explained that this instrumentation development no longer remained just an interest, as agricultural production began to depend on these instruments for quality evaluation. He stated that a number of different devices were developed to measure the texture of fruit and vegetables, and that these devices could be destructive or non - destructive. They included objective scales based on instrumental reading, and subjective methods based on human judgement, using hedonic scales (Kader, 1992). Factors to be taken into consideration when determining the most suitable texture measuring instruments included whether the instruments are destructive or non – destructive, whether they produced reliable results, take less time to run tests, and are available to use in any location (Bourne, 1982; Bourne 1974; Yang & Mohsenin 1974; Abbott et al. 1976; Voisey 1977; Watters et al. 1963; Mehlsehan et al. 1981).

3.3.1 Non Destructive Methods

A non - destructive instrument measures the texture of fruit without destroying it (Studman, 1998; Hopkirk and White, 1992). Non-destructive methods can be administered at any time before harvest to determine fruit maturity, at harvest to remove soft fruit, and at the packing house to inspect fruits suitable for export (Hopkirk & White, 1992, Mitcham, 1998.). This method is very important, and is a useful technique for researchers as it can be used to retest the same fruit several times throughout its lifetime giving a reduction in variability as a result of random sampling of fruit during growth and storage. This leads to more reliable results and better correlations with fruit properties (Biggs, 1993; Studman, 1998). Other advantages of non-destructive devices as suggested by Studman (1998) are that on-line assessment of every fruit is a possibility, the same fruit can be re-tested without interrupting its normal life cycle, and re-tested sample fruits can be repacked or returned to the packing line without replacement. There are a number of non - destructive instruments, which include the Kiwifirm, Softsense and the Acoustic Response device, as outlined below.

3.3.1.1 Kiwifirm

The Kiwifirm device was developed by the New Zealand Crop & Food Research Institute and Industrial Reseach Ltd for the use in determining the maturity of buttercup Squash. Based on this device, a modified version was developed for use with other fruits. This is a small hand - held device that applies a small impact to the surface of the fruit using a non - penetrating tip. The characteristics of the resulting collision were measured using built in software, which displayed the value (Cabrera et al. 1995). The performance of Kiwifirm was compared to that of the Penetrometer on the softening of pears, and it was found that expressing rates of softening was simpler with Kiwifirm. They recommended that the Kiwifirm was a better device than the Penetrometer for measuring small changes in firmness. The advantages of this device were that it was non-destructive, capable of measuring without damaging the fruit, and had operator - independent operation. However, the device was reported as not robust enough to be used in an on-line grading process in its present form at that time.

3.3.1.2 Softsense

Softsense was an alternative non-destructive method for measuring the firmness of kiwifruit based on the impact response analysis, which was developed in New Zealand (Hopkirk & White, 1992). This method worked by dropping a fruit from a small distance (10 mm) on to a load cell. The characteristics of the resulting impact were used to calculate the firmness and fruit weight. Softsense did not damage the fruit, allowing for its use in industry to determine firmness and fruit weight. However the Softsense reading and relationship to fruit firmness needed fine-tuning in order to enable it to contribute to commercial fruit evaluation (Biggs, 1993).

3.3.1.3 Acoustic Response

The traditional technique of tapping fruit has been used for many years for determining maturity and is inexpensive. Based on this sonic vibration, an acoustic technique was derived for watermelons and other fruits in the early 1980's by Yamamoto et al. 1980; 1981. The resonant frequencies of the intact fruit were obtained by first recording the sound produced in hitting the fruit with a small wooden ball pendulum, and then performing a fourier transformation on the sound signal. The performance of the acoustic response was determined by Chen (1996) in a study on apples and watermelon. This showed that their resonant frequencies decreased with storage time.

Sugiyama et al. (1994) performed a study on the acoustic impulses of muskmelon and found a good relationship between the transmission velocity and the fruit firmness, with a correlation coefficient of 0.032. The results demonstrated that the method was a reliable estimate of fruit firmness. However, Muramatsu et al. (1996) commented that this device is time consuming, as it required 30 minutes to measure each fruit. Therefore, this method has inherent limitations for general adoption in quality evaluation, and is still in the experimental stage (Chen, 1993; Ronai & Shmulevich, 1995). The non-destructive instruments and methods which have been discussed are available in laboratories and industries and have been demonstrated in studies and experiments to be able to assess texture thus eliminating variations in geometry from piece to piece, and variations where various inhomogenities may exist between samples. However, limitations are still to be resolved in order to achieve better quality assessment (Armstrong et al. 1995; Armstrong et al. 1993; Kuono et al. 1993; Stone et al. 1996).

3.3.1.4 Calendar date

There are also some traditional technique for quality assessment and maturity. In particular the Calendar date and days from full bloom (DFFB), are often used as guides in predicting harvest date. They can be fine-tuned by using flesh firmness (eg. pears and apples - Bramlage & Watkins, 1994). It is easy to count days without the need for an instrumental test. Many factors can affect the number of days from full bloom to harvest including the crop variety, orchard location and temperature. These can alter the time required to reach maturity. Hopkirk, (1992) explained that kiwifruit from New Zealand is commercially appropriate to harvest earlier in the season to ensure the earlier arrival of the product in overseas market but this pose the problem of inappropriateness of long - term storage and eating quality. On the other hand he suggested that leaving of kiwifruit in the vine until late stage of maturity may result in damage from frost and winter storm, and packing of fruits which have begin to ripen and produce ethylene.

3.3.2 Destructive Instruments

Destructive instruments, as suggested by Bourne (1982), are currently the predominant type of instruments for food, since the majority of the textural parameters of foods are sensed destructively in the mouth through mastication. Destructive tests destroy the structure of the fruit, rendering it unsuitable for a firmness test to be repeated (Bourne, 1982; Linsken & Jacksons, 1995) and eventually Non-destructive instruments may replace them as these become more reliable as prediction of quality. The destructive texture measuring instruments generally consist of four main elements: a probe texture measuring instruments generally consist of four main elements: a probe contacting the fruit, a driving mechanism, a sensing element for detecting the resistance of the fruit to the applied force, and a system that reads or records the force. The probe can be a plunger, a pair of shearing jaws, a tooth shape attachment, a piercing core, a spindle, or a cutting blade (Kramer & Szczesniak 1973). Several studies have been undertaken to investigate the texture of fruit and vegetables using different destructive texture measurement instruments including the standard instrument, (the Penetrometer), and the recent motor driven Massey Twist Tester.

3.3.2.1 The Penetrometer

This is one of the oldest texture-measuring instruments. The Penetrometer takes many forms, including the Magness Taylor pressure tester and the Effe-gi tester. The Magness Taylor and Effe-gi measure the resistance of the flesh to the penetration of a standard probe. The name *Penetrometer* refers to its principle of measuring the force required to penetrate the product measured. The principle originated from Morrison in 1917, when he developed a device consisting of a marble embedded in paraffin wax as discussed in this review of the history of instruments at in section 3.2. The penetration was usually done with a tapered rod – like a cone shaped probe. The Penetrometer, which is a hand operated device, has been widely used for years as a standard instrument for testing firmness.

Abbott et al. (1976) and Kader (1985) stated that mounting the hand held Penetrometer in a drill stand can help to reduce measurement variability because the penetration force is applied at a more consistent rate. However, other studies (Voisey 1977; Bourne 1979; Bramlage 1983; Linskens & Jackson 1995) have found that this instrument gave unreliable results due to the inconsistency of force applied by the operators and the variation in the speed of the applied force. Peleg (1993) stated that a controlled application speed is vital, since the resistance to penetration is a function of the cell failure rate. The unreliable results obtained from this instrument, which was regarded as a standard measuring instrument for many years, have urged researchers and scientists to develop new instruments that could produce accurate results and which were fully controlled to avoid differences in force applied by operators. Yuwana (1991), using an early version of the Twist Tester, compared firmness measuring instruments in distinguishing the maturity of Royal Gala apples and found that the Twist Tester had a higher resolution than both the Penetrometer and the Brix test for characterizing the properties of fruit.

3.3.2.2 The Twist Tester

The former Twist Tester (**Figure** 2.3) developed by Studman (1990) was modified into the motor - driven Massey Twist Tester (Studman, 1996). It was developed for the purpose of measuring the crushing stress (σ_{cr}) of the flesh of fruit and vegetables. The theoretical analysis of this alternative test for the mechanical properties of fruit and the details of the principle has been documented elsewhere (Yuwana, 1991; Studman & Yuwana, 1992). The principle of the former twist tester and the Massey Twist Tester is shown in Figure 2.4.

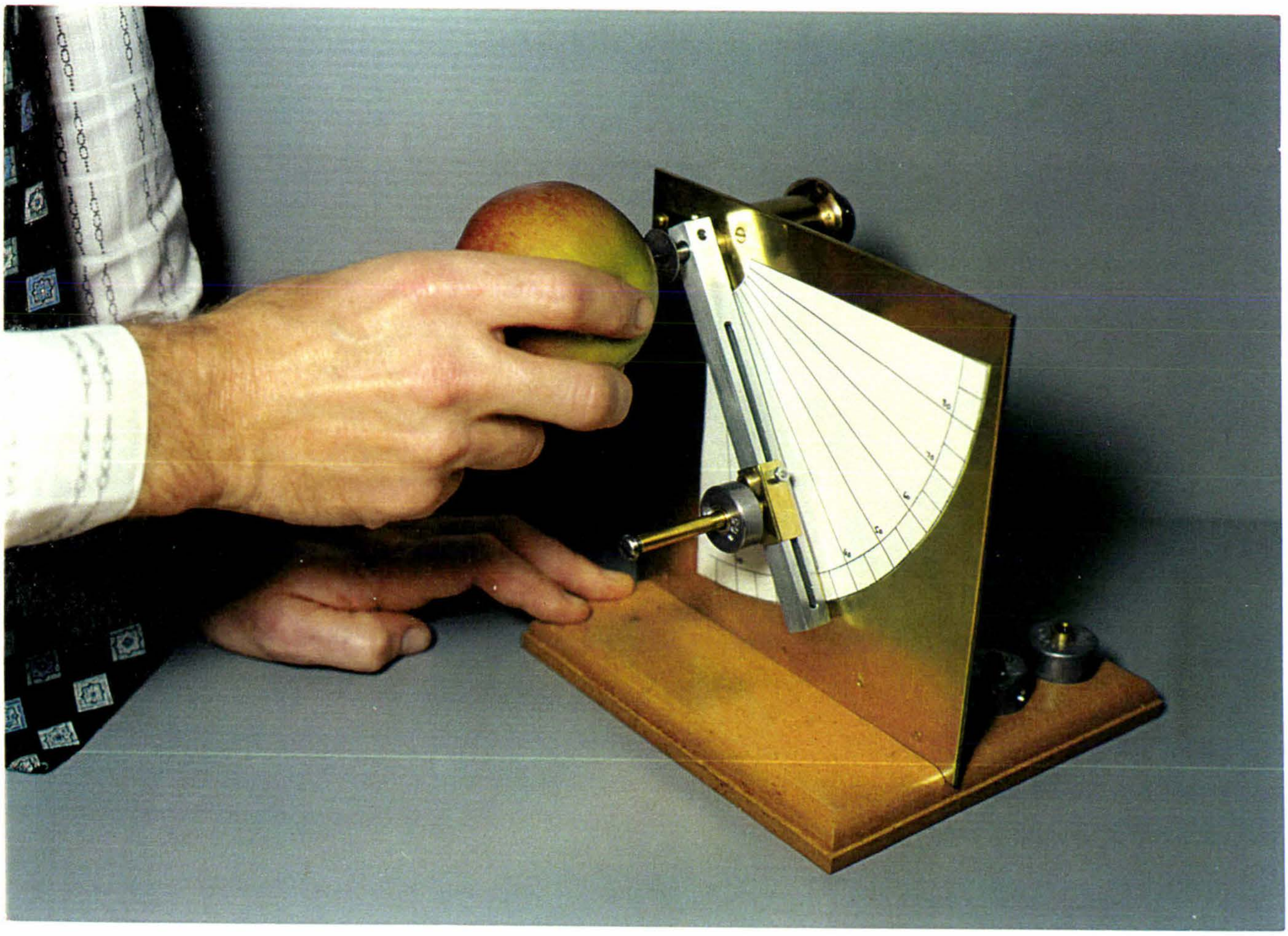
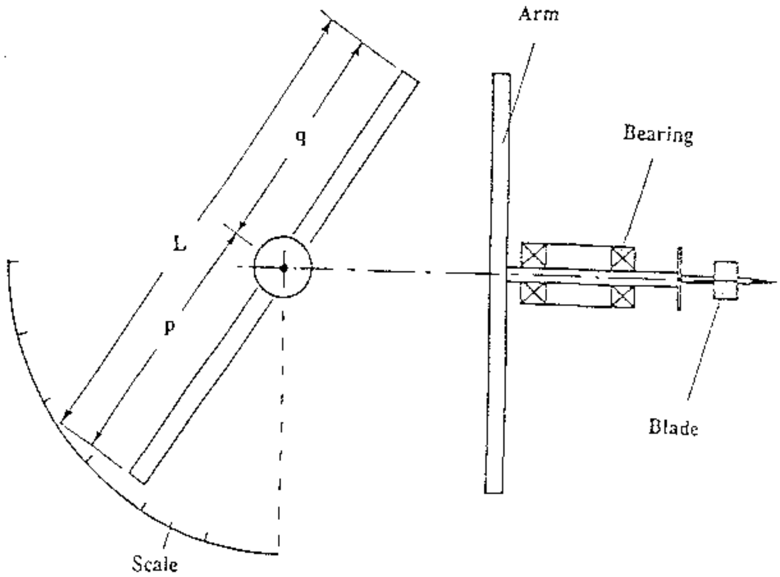


Figure 2-3. The former Twist Tester (Studman & Yuwana, 1992)

Principle of the Twist Tester

a. The general layout



b. Enlargement of the blade

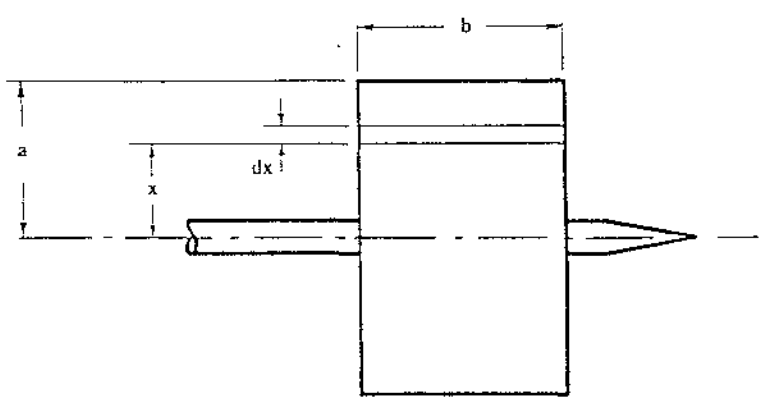


Figure 2-4. Principle of the Twist Tester (a) General layout. (b) Enlargement of blade. (Studman & Yuwana, 1992)

Studman (1992) demonstrated that this instrument was designed to rotate a blade in the fruit at a predetermined depth under the skin and to measure the torque produced as the product is crushed against the rotating blade. Therefore, the theory assumes that the fruit tissue is crushed at a uniform stress over the surface of the blade, which is equal to the crushing strength of the tissue, so that the maximum moment produced is the moment required crushing the fruit against the blade. The crushing strength is measured by the angle at which the cells completely fail (Studman & Yuwana, 1992).

For an element of fruit flesh with a radial width dx and length b, the crushing stress is obtained as:

$$df = b\, dx\, \sigma$$

Where:

σ = crushing strength of the fruit (Pa)

b = length of the blade (m)

The moment on the blade in Nm is given by integration:

$$M_b = 2 \int \sigma\, x\, b\, dx = \sigma b\, (a^2 - a_o^2)$$

Where:

a = the radius of the blade (m)

a_o = the radius of the spindle (m)

The moment produced by the rotating rod is given by:

$$M = m\, g\, Z \sin\theta$$

Where:

m = mass of the arm (kg)

Z = distance of the centre of mass of the rod from the axis of rotation (m)

θ = angle of rotation (degrees)

g = gravitational constant, 9.807 ms^{-2}

If M_b is the only moment produced by the fruit, then it is equal to M, and σ can be calculated from these equations directly

$$\text{Thus } \sigma = \frac{M\, g\, Z\ \text{Sin}\,\theta}{b\,(a^2 - a_o^2)}$$

In the motor - driven version, the product is attached to a disc with pins. The motor driven disc rotates at a slow speed, and as the angle of rotation increases, the load on the fruit increases. The fruit tissue fails when it cannot withstand any more stress. The angle of rotation of the blade is then recorded against time in a computer and the crushing strength of the produce is calculated from the system geometry as before (Studman & Yuwana, 1992; Opara, 1993) has many advantages. It is fast to operate where test runs last for only a few seconds, can assess texture at any required depth in the product without cutting, is free of operator differences, can run several tests in one sample as the damaged area of the fruit produced during testing is small, gives reliable results which are recorded automatically after each test in a computer connected to the instrument, and can test different ranges of fruit and vegetables.

Studman (1995); and Yuwana (1991) compared the Penetrometer and the Massey Twist Tester and concluded that the Twist Tester was more accurate, easier to operate, faster and more flexible compared to the Penetrometer. However, the version used by Yuwana was a hand-operated version, and was still subject to variability between operators.

The motor driven Massey Twist Tester has yet to produce the data required to establish a standard for future use, since it has been only recently developed. Therefore one aim of this thesis was to produce such data and, and on the basis of these, to provide an assessment of the motor – driven Massey Twist Tester.

3.4 Summary

Because of the demand for a better quality product, assessments of the features mainly the texture of fruit and vegetables have been widely used in New Zealand and in most other parts of the world (Kader, 1992).

In the past, texture assessment was commonly done through the sensory evaluation, as this was the only common and available technique. This technique makes use of the sensitivity of the human faculties of seeing, hearing, feeling, smelling and tasting to analyze the properties of the food. Although this technique is still practised today, the great demand for a better quality product has led researchers and scientists to attempt to develop instruments to serve the same purpose (Mitcham et al. 1998).

Non- destructive methods and destructive instruments (which include the standard texture – measuring instrument, the Penetrometer) and the recently developed motor- driven Massey Twist Tester) measure the texture by destroying the structure of the product. Although use of the Massey Twist Tester results in the loss of some of the product, this remains the most effective way of obtaining an accurate assessment of its quality.

In general only destructive test have been available for assessing texture. However, more and more non-destructive tests have been developed, and these may eventually replace destructive tests in many situations. However, such tests must mimic human taste panels, and since texture is essentially a property related to the failure of tissue, destructive tests are likely to remain as essential methods for textural evaluation in the future.

CHAPTER THREE – METHODS AND MATERIALS

3.1 INTRODUCTION

The experiments were conducted during the years 1999 - 2000 at the Massey University Postharvesting Laboratory in Palmerston North, New Zealand. The first part of the experiment was conducted in October 1999 while the second and third parts took place in the year 2000.

3.2 EXPERIMENTAL DESIGN AND TREATMENTS

This experiment was divided into three parts. The aim of the first and second parts was to measure the firmness of various kinds of fruit with destructive instruments and the third part of the experiment consisted of a speed test conducted with one instrument.

This first part of the experiment was designed to (a) measure the firmness of fruit and vegetables when stored in different temperatures by using two destructive instruments (Penetrometer and the Massey Twist Tester) and (b) perform a sensory assessment on the same samples.

The second part of the experiment was designed to measure the firmness of Royal Gala apples with the two instruments used in the first part of the experiment and the Textural Analyzer.

The third part of the experiment was designed to compare the results obtained from the five different speeds of the Massey Twist Tester on the same samples.

3.3 SAMPLES

Based on availability, 6 varieties of fruit and vegetables, Braeburn apples, plums, pears, nashi, kiwifruit and potatoes were chosen for the first part of the experiment. Royal Gala apples were used in the second part of the experiment, and Braeburn apples and carrots in the third.

The samples for the first part of experiment were obtained on 15th October 1999. One hundred (100) samples from each variety were randomly selected. Nashi and Braeburn apples were delivered from the Massey University Fruit Crops Unit, while the pears, kiwifruit, plums, and potatoes were obtained from a local supermarket.

For the second part of the experiment, 320 samples of Royal Gala apples in total were obtained from Grocorp Pacific, Waipawa, during the second and third weeks of March 2000. The first lots of 160 samples were stored under 10°C for 7 days before the experiment was performed and the second lot of 160 Royal Gala apples three days after harvesting.

Samples of 40 carrots and 40 Braeburn apples were obtained from the supermarket for the third part of the experiment the speed tests. The carrots were bought on the 16th of March 1999 and Royal Gala apples on the 25th of March 2000.

The samples were from the same source and were checked to confirm that they were free from physical disorders such as bruises, infections, rots or any physical damage before they were transported to the Massey University postharvest laboratory for the experiments.

3.3.1 Treatments .

For every variety: -

1. Each type of fruit was labelled with an indelible marker.
2. Samples of 10 were taken from each fruit type for fresh tests on the day of delivery.
3. The rest of the samples were divided into 3 equal groups of 30 samples and stored at 3 different storage temperatures (0°C, 20°C and 30°C) in order to vary their textural properties.
4. Samples of 10 were taken from each storage temperature every 7 days - except for apples (Braeburn and Royal Gala) at 0°C, which were tested every 14 days due to slower changes of physical properties.

3.4 FIRMNESS MEASUREMENT OF FRUIT AND VEGETABLES

The instruments used to measure for firmness of the fruits and vegetables were Penetrometer, Massey Twist Tester and the Texture Analyzer. The treatments for experiments 1 and 2 were similar - except that in Experiment 1, the instruments used were the Penetrometer and the Massey Twist Tester only.

3.4.1 Firmness Measurement Procedures

The first part of the experiment firmness test was conducted with the Massey Twist Tester and then the Penetrometer before sensory assessment. In the second part of the experiment, where the Texture Analyzer instrument was included, the Textural Analyzer was used first for compression tests, then the Massey Twist Tester, the Penetrometer and finally the Texture Analyzer again to perform the three bending tests. Sensory assessment was conducted after the firmness measurement. During the sensory assessment, in order to avoid experimenter bias, the labels were covered before the researcher and helper used a sensory testing scale to assess the fruits.

The speed tests were performed on 40 sample carrots and 40 Braeburn apples by altering the speed of the Massey Twist Tester. A single blade (size 4x7mm) was used with five different speeds to test each sample product. The speeds used were 1.82, 6, 10, 15, and 20 rpm.

3.4.2 Firmness measuring instrument – the Massey Twist Tester

The motor - driven Masssey Twist Tester was used in this experiment to measure the crushing strength. The fruit was pushed onto a blade mounted on a spindle as shown in **Figure** 3.1 so that the blade turned at a fixed depth. A rising weight on the end of an arm was used to apply an increasing moment (torque) to the blade, to resist the rotation. Output was determined by recording the angle as a function of time electronically (Studman, 1998).

From this the crushing strength was calculated using the formula (Studman, 1998):

$$\theta = \frac{W_g \, \mathrm{Sin}\, \theta}{(a^2 - a_o^2)\, b}$$

where W is the maximum moment produced when the arm is horizontal (i.e θ = 90)

θ is an angle of rotation of twist arm at full crushing

a is the blade radius(m) and

b is the blade width (m)

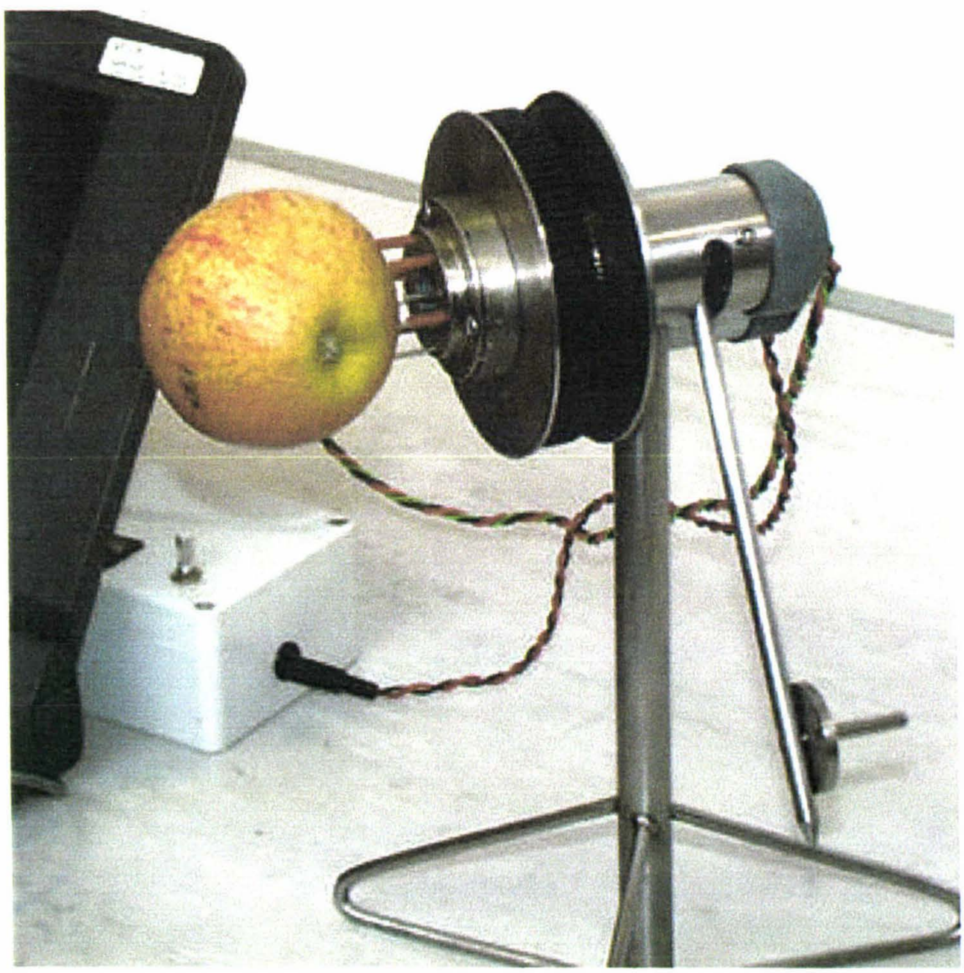


Figure 3-1. Motor driven Massey Twist Tester with an apple pushed onto the blade.

The speed used for the tests was 10 rpm, and the sizes of blade and depths of blade penetration for each variety sample are shown in **Table** 3.1.

Name- fruits and vegetables	Size of blade	Depth of penetration
Apples(R.Gala & Braeburn)	4 x 14 mm	15 cm
Pears	4 x14 mm	10 cm
Nashi	4 x 14 mm	10 cm
Plums	4 x 14 mm	10 cm
Kiwifruit	4 x 14 mm	6 cm
Potatoes	3 x 7 mm	10 cm

Table 3.1 The blade size and depth of penetration used by the Massey Twist Tester

3.4.3 Firmness measuring instrument - the Penetrometer

An *Effegi Penetrometer* was mounted on a drill press and hand operated as shown in **Figure** 3-2. This was used to assess the firmness of the fruit and vegetables in parts 1 and 2 of the experiment. A layer of skin on the fruit cheek was removed with a potato peeler to expose the flesh for testing. A cylindrical probe of 11mm was used to test fruit, and a 7mm probe was used for potatoes. The probe was pushed to a depth of 8 mm, and the result was recorded manually. The flesh firmness was recorded in kg and converted to Newton (N) by multiplying by the gravitational constant g (9.807 m s^{-2}).

Figure 3-2. Effegi Penetrometer mounted in a drill press

3.4.4 Firmness measuring instrument - the Texture Analyzer

In the second experiment the Texture Analyzer compression test was performed before the other test on the sample. The sample was covered with a thin layer of flour placed on the platform. It was then uniaxially compressed in one direction with a flat top platten as shown in **Figure** 3-3 and unrestrained in the other directions. It was compressed to a 10% strain at a constant deformation rate of 1mm per second. The load was held for 1 second and then unloaded at 1 mm per second. The top platten was moistened with water to remove a thin layer of flour at the point of contact, so that the contact area could be measured with digital calipers to find the modulus of elasticity (Figure 3-4).

The modulus of elasticity was calculated from these tests using the formula (Mohsenin, 1986, Studman, 1999):-

$$E = \frac{0.338\, k^{3/2} F (1 - \mu)}{D^{3/2}} \left(1/R_1 + (1/R_1')\right)^{1/2}$$

Where E is the Modulus of Elasticity

F is the force (N)

D is the deformation at single contact (m)

k is the constant for analysis of convex bodies

μ is the Poisson's ratio

R_1 and R_1' are the radii of convex body (m)

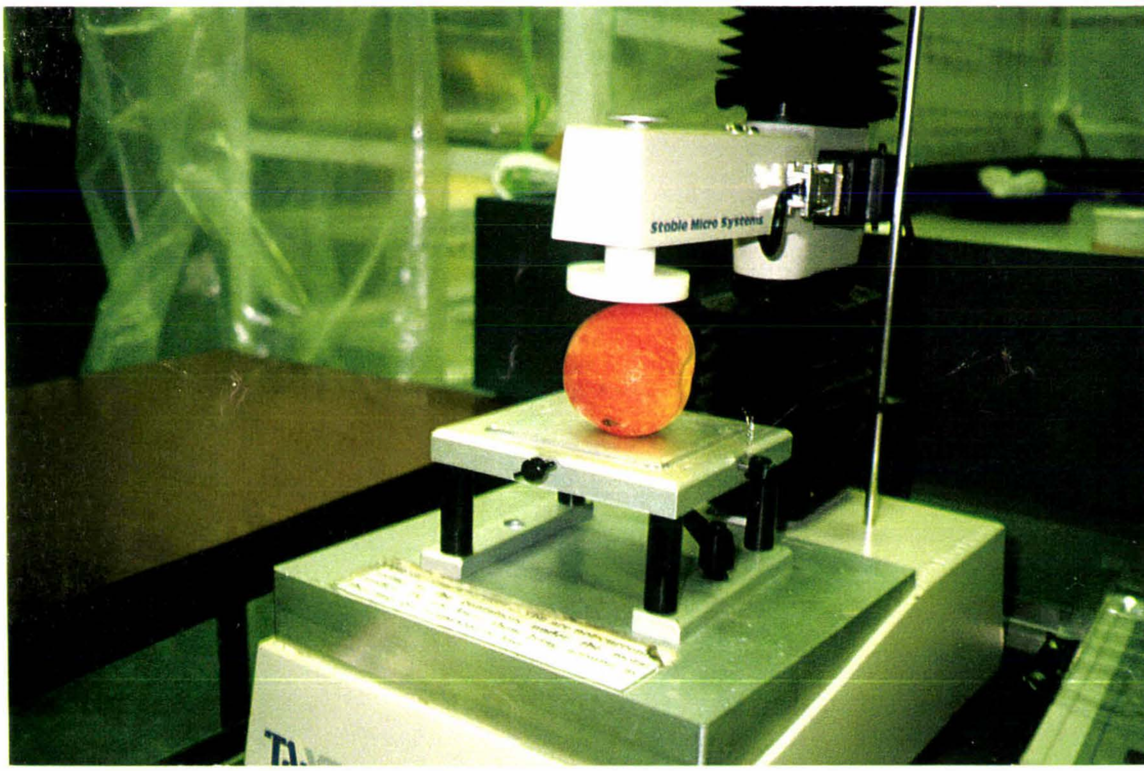


Figure 3-3. Texture Analyser with the compression plattens.

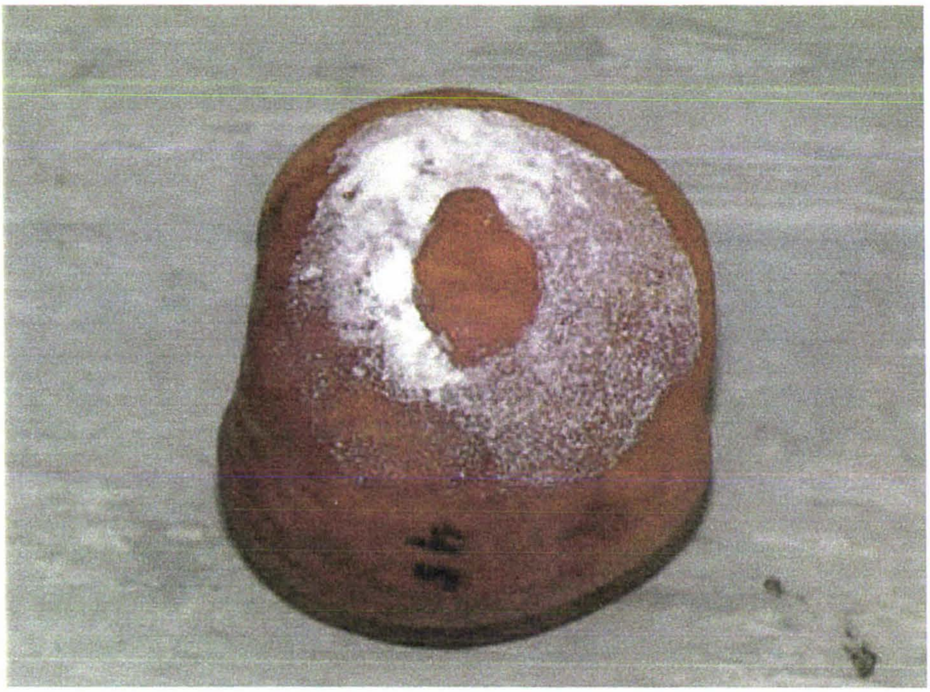


Figure 3.4. An apple dipped in dry flour showing the point of contact.

3.4.5 The fracture test

A 40 mm long plug 12 mm in diameter was removed from each fruit with a cork borer. The fracture test was performed using the Texture Analyser to measure the force required to cause the sample to break in a three-point bend test. There were two supports mounted on the platform where the sample was placed, and the other load was applied in the centre between the 2 supports using the Textural Analyzer as shown in **Figure** 3-5. It pressed the sample at 1 mm per second deformation rate until failure occurred. The results of the tests were collected and recorded by a computer connected to the instrument, then the results were transferred to Microsoft Excel for analysis.

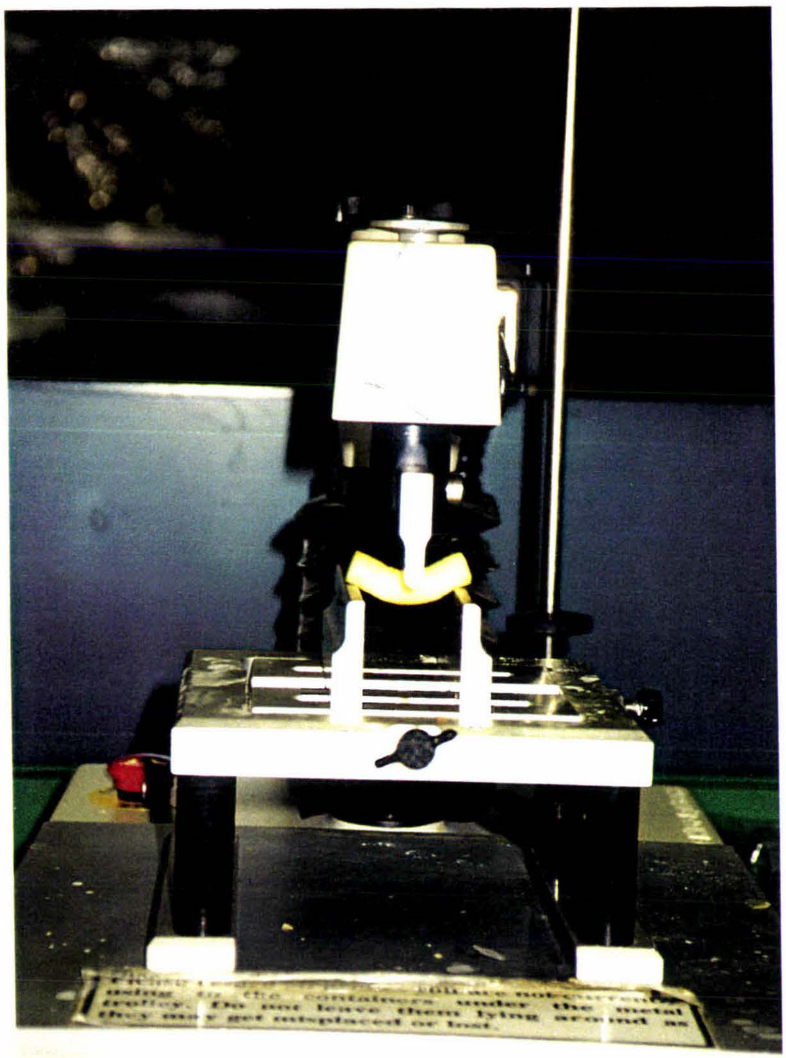


Figure 3-5 The three point- bend rig.

3.4.6 Sensory evaluation

The researcher conducted the tests with a helper giving an independent assessment. The test scale as shown below in **Table** 3.2 was established to assist in obtaining true textural properties for the assessments. The panel of two persons assessed the textural properties separately for every fruit and vegetable and the final texture assessment value was taken from the average value of the two results. The fruit label was covered with a sticker to avoid experimenter bias in the results. The assessment scale of fruit texture properties was used to test for crispness, firmness, juiciness and mealiness of the products.

Dryness	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**Very juicy**
Softness	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**Very firm**
Not Crisp	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**Very crisp**
Mealy	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**Very mealy**

Table 3.2: Sensory Assessment Scale

3.5 ANALYSIS OF EXPERIMENTAL DATA

Relationships between the instrumental measures, and between the instruments and sensory measures were inspected graphically, and were then compared using correlations. Initially correlations were calculated separately for each fruit and each storage temperature, later, correlations were calculated for each fruit, by combining all the data for all storage temperature.

Comparison of the speeds was done using the software Minitab version 12, for analysis of variance. The individual fruit were treated as blocks, and the speed as a factor. The blocks, and the speed as a factor. The blocks (individual fruit) differed significantly, but the speed factor was not significant.

CHAPTER FOUR – RESULTS.

4.1 INTRODUCTION

This chapter presents the results of changes in mechanical properties as measured with the Penetrometer, Massey Twist Tester, Texture Analyzer and sensory evaluation. The results for each type of sample will be presented first, followed by the results of speed tests performed with the Massey Twist Tester.

In general, the experiments demonstrated that storage conditions had affected the physical and mechanical properties of the sample products. Not suprisingly, fruit stored at high temperatures were often found to be shrivelled and rotten after a period of storage – while fruit stored at low temperatures were not. Great changes in mechanical properties were found as presented below.

4.2 TWIST TESTER STRENGTH AND PENETROMETER CHANGES FOR EACH TYPE OF SAMPLE PRODUCT.

4.2.1 Apples (Braeburn)

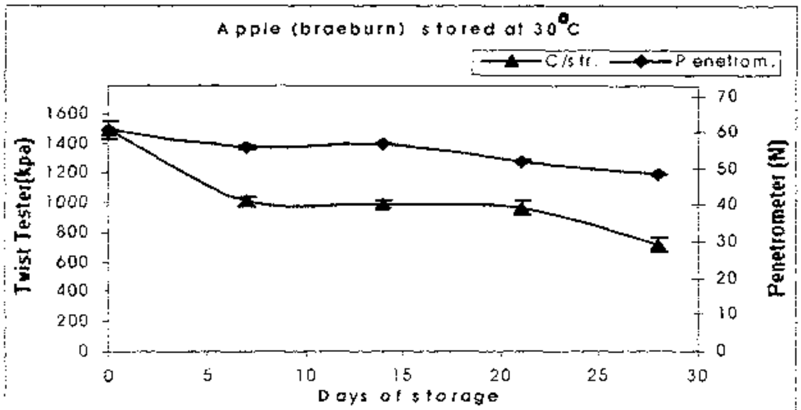
As discussed in chapter 3, Braeburn apples purchased from the Crop Unit at Massey University had been stored at 4°C. In the tests, they were then stored at 30°C and 20°C for 28 days, and tested every 7 days - while apples stored at 0°C were stored for 58 days and tested every 14 days.

Both the Penetrometer measurement and crushing strength results for apples (Braeburn) stored at 30°C (Figure 1a) showed similar features of decreasing in firmness over the whole storage time. The Penetrometer measurement declined by 53.8N (28.2%) and crushing strength by 775 kPa (52%) from initial values. At 20°C storage (Figure 2b) the crushing strength and the Penetrometer values gradually declined during the first 21 days of storage. However, a divergence in results during the last 7 days storage was obtained whereby the Penetrometer measurement slightly increased by 1.4N, while crushing strength continued to decrease.

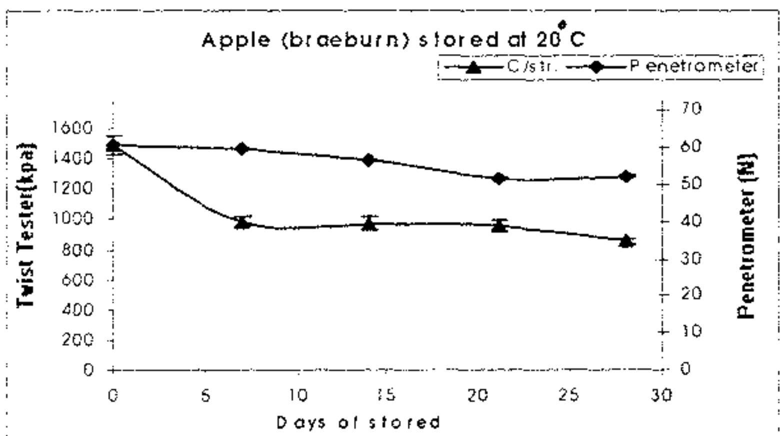
At 0°C storage (Figure 3c) both the crushing strength and the Penetrometer results showed a gradual decline with increased storage time.

Values obtained from the sensory evaluation for the different storage conditions of Braeburn apples (30°C, 20°C and 0°C as in figures 1d, 1e and 1f) showed a decrease in firmness, crispness and juiciness with increasing storage time, while mealiness for all storage conditions increased with storage time. Fruit stored at 0^0 C showed the smallest changes.

a.



b.



c.

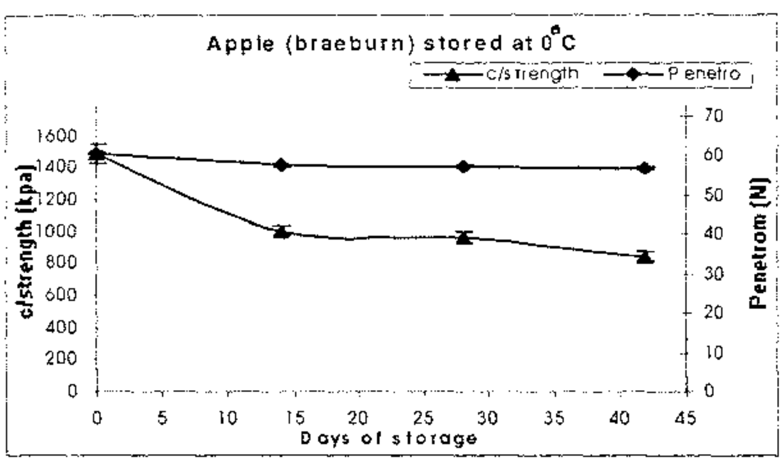
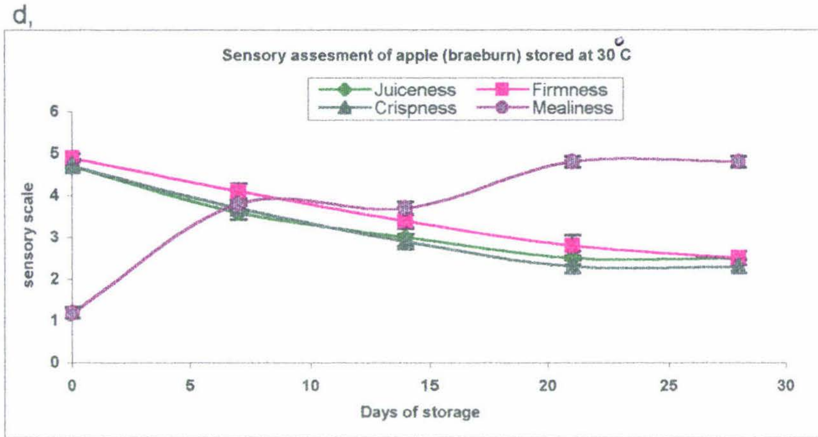
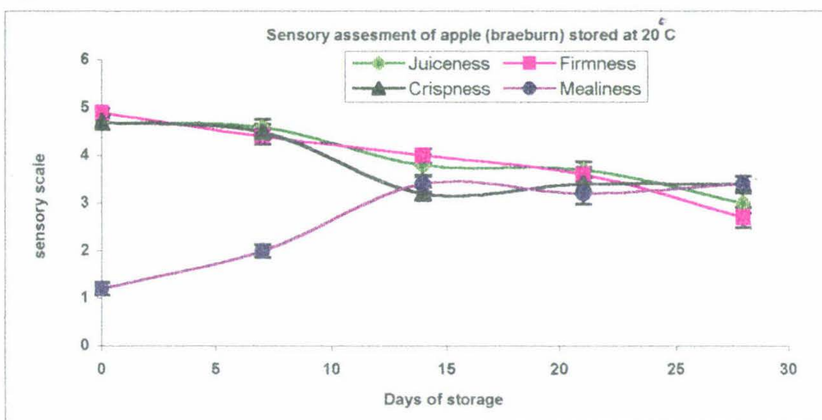


Figure 4-1a, b and c. Twist strength and Penetrometer values for Braeburn after storage at 30°C, 20°C and 0°C. Vertical bars represent the standard errors of the means.

d,



e.



f.

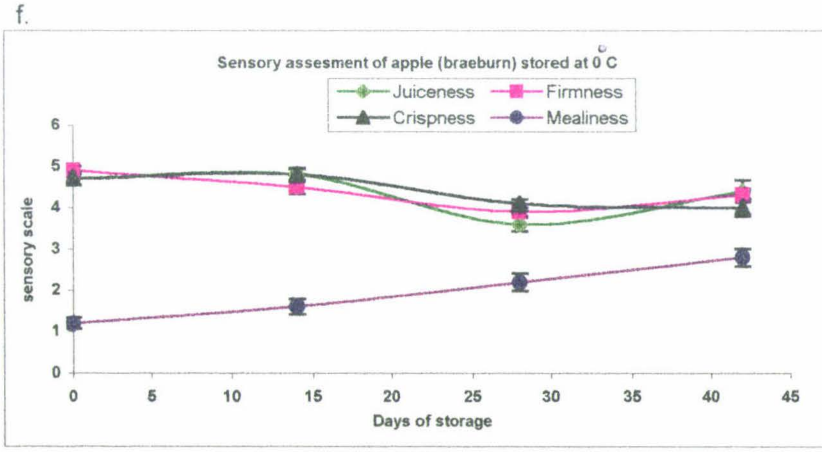


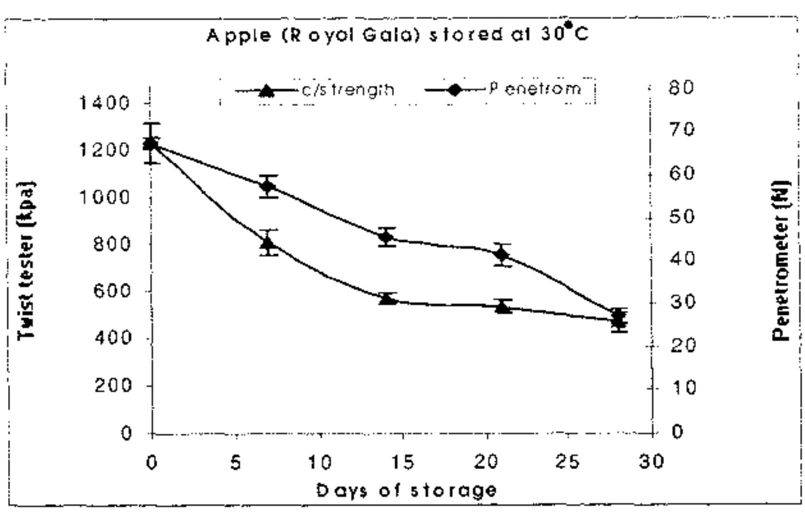
Figure 4-1d,1e,1f. - Sensory assesment for Braeburn stored at 30, 20 and 0 °C
Vertical bars represent the standard errors of the means.

4.2.2 Royal Gala apples (Trial 1)

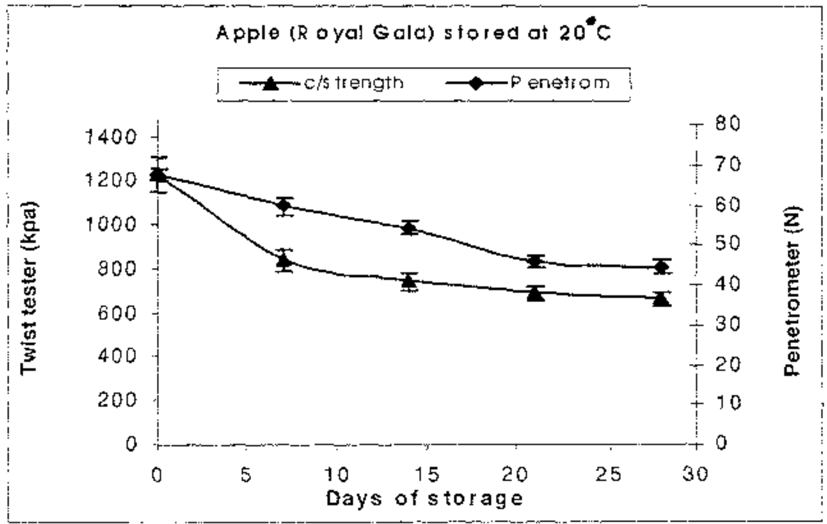
As discussed in Chapter 3 fresh Royal Gala apples were tested using 3 instruments: the Massey Twist Tester, Penetrometer and the Texture Analyser. A first trial test was made on apples harvested and stored at 10°C for 7 days before the tests were performed. A second trial test was conducted on apples that had been freshly harvested, and at the storage duration for apples which, at 30°C and 20°C were 36 days, and at 0°C was 56 days.

The Penetrometer and crushing strength values of Royal Gala apples at different storage conditions declined with increased storage time. However, during the third stage of storage at 0°C (Figure 4.2c) the Penetrometer values increased, then apparently decreased during the last stage of storage. Apples (Royal Gala) stored at 30°C (Figure 4.2a) had the highest percentage of firmness loss of more than 50% when measured with both the Penetrometer and the Massey Twist Tester.

a.



b.



c.

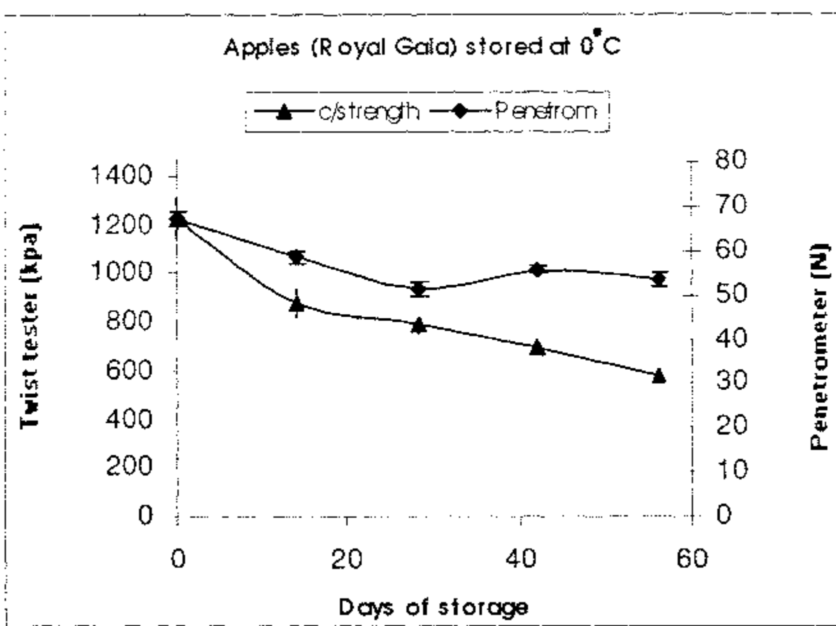


Figure 4-2a, 2b and 2c. Twist strength and Penetrometer measurement changes in Royal Gala at 30°C, 20°C and 0°C storage. Vertical bars represent the standard errors of the means.

The fracture strength of apples stored at 30, 20 and 0°C declined continuously during the whole storage time. The Royal Gala apples stored at 30°C (Figure 2) decreased in fracture strength by about 79%, the 20°C stored apples by 63% during the 35 days' storage. The Royal Gala apples stored 0°C declined about 58% with storage time of 56 days, but at a slower rate.

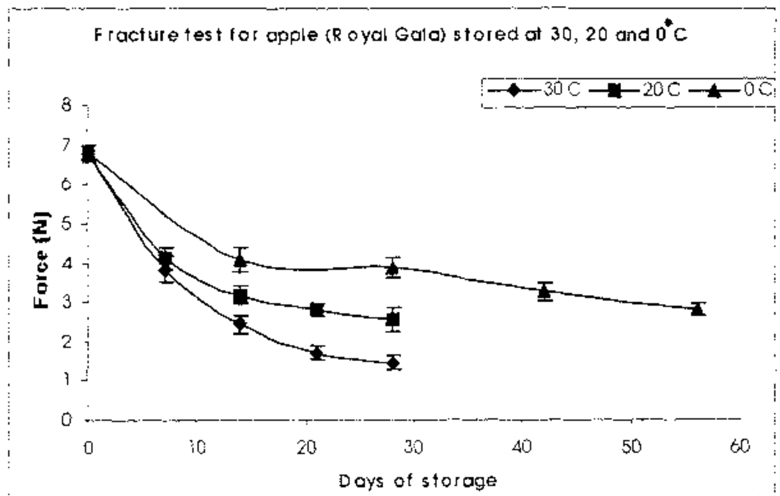


Figure 4-3 The fracture strength changes of Royal Gala apples at 30°C, 20°C and 0°C storage. Vertical bars represent the standard errors of the means.

The elastic modulus result for apples (Royal Gala) stored at 30°C (figure 4.4) showed a significant decrease of more than 70% during the first 14 days' storage. The elastic modulus result for the apples stored at 20°C fell at a slower rate with storage time, while the elastic modulus of apples stored at 0°C (Figure 4.4) declined slightly during the first 28 days, then appeared to rise during the last 14 days of storage.

a.

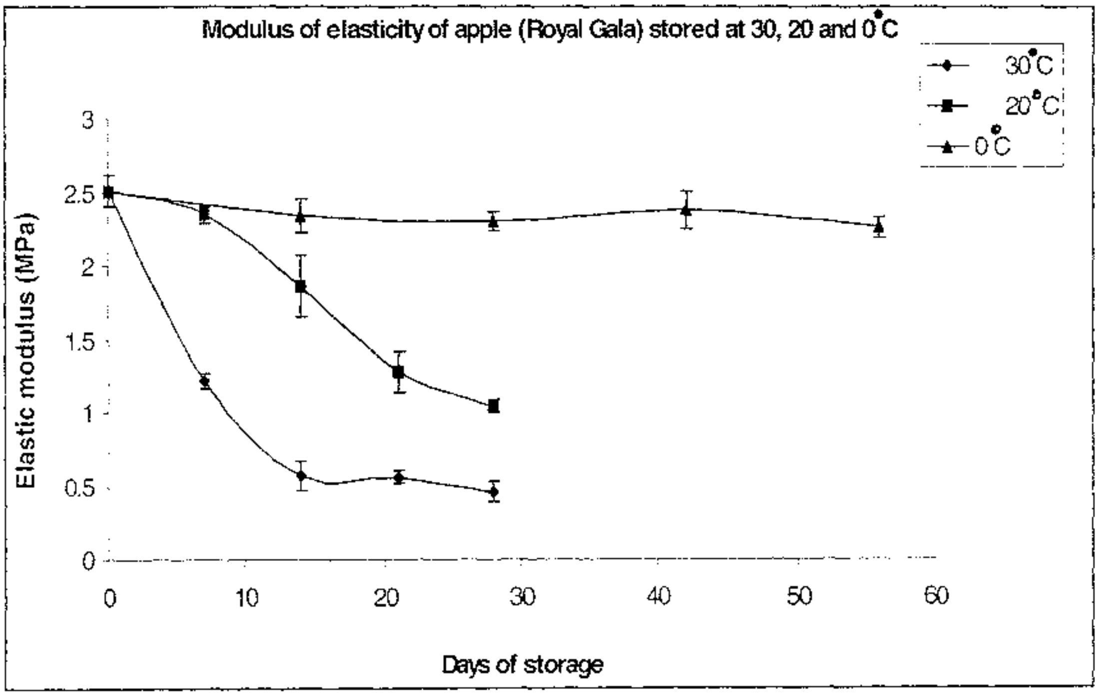


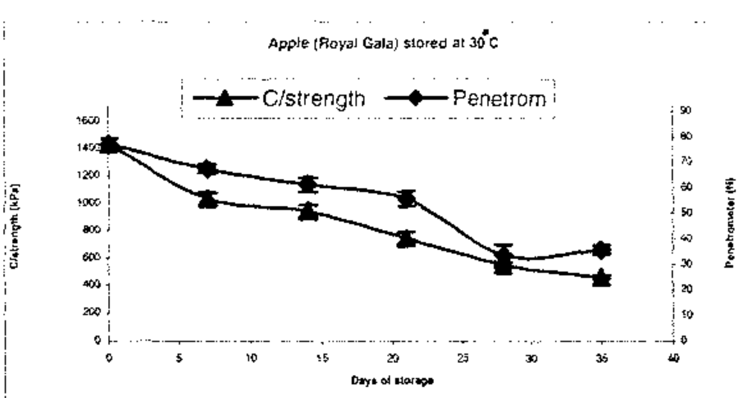
Figure 4-4. The elastic modulus changes in Royal Gala apples at 30°C, 20°C and 0°C storage. Vertical bars represent the standard errors of the means.

4.2.3 Royal Gala apples (Trial 2)

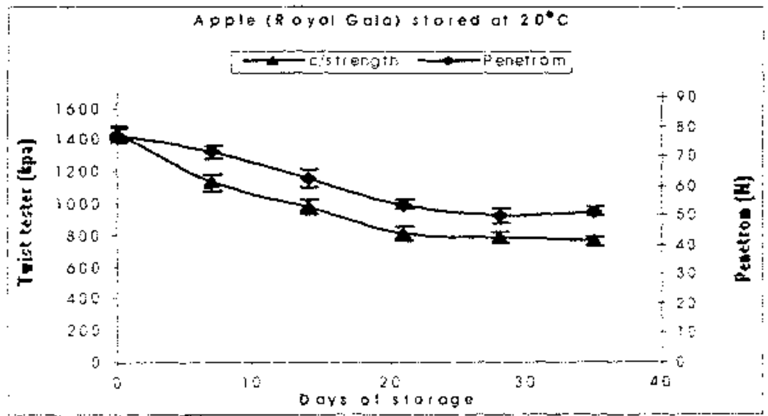
The Royal Gala apples used for this test were brought straight from, the Waipawa pack house. They were fresh tested 3 days after harvest, before storage.

The apples (Royal Gala) stored at 30°C (Figure 4.5a) showed that crushing strength decreased continuously to about (70%) over the whole storage time, while the Penetrometer measurement declined up to 43.5N (56.5%) during the first 28 days and apparently increased during the last 7 days' storage. A similar result was obtained for the Royal Gala apples stored at 20°C (Figure 4.5b) where a continuous decline in crushing strength occurred with storage time, while the Penetrometer values declined in the first 28 days then slightly rise during the last 7 days' storage. Royal Gala apples stored at 0°C (Figure 4.5c) showed a similar pattern of conversion for the Penetrometer measurement and the crushing strength, where they declined at a very slow rate with storage time, retaining a value close to the initial one.

a.



b.



c.

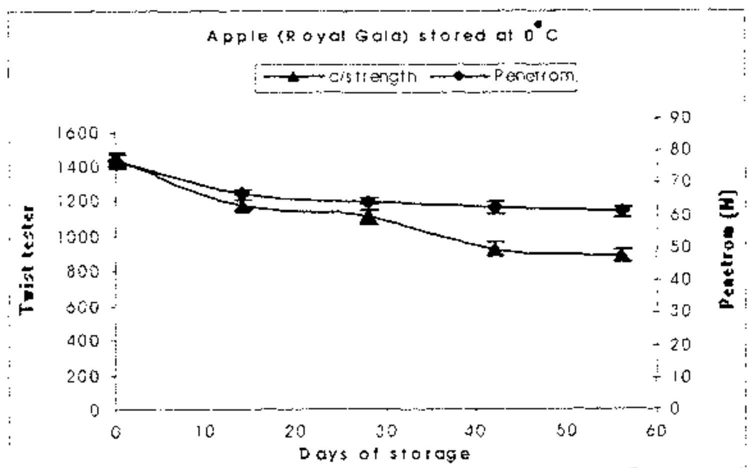


Figure 4-5a, 5b and 5c. Twist strength and Penetrometer value changes in Royal Gala apples (2nd trial). Vertical bars represent the standard errors of the means.

The fracture strength for Royal Gala apples stored in the 3 different storage conditions showed similar features, as their fracture strength declined with storage time. The Royal Gala apples stored at 30°C showed the highest percentage of decrease – 83.% - while the apples stored at 20 °C showed a decrease of only 68.5% from initial value. Although the

Royal Gala apples stored at 0°C decreased in fracture strength, as shown in Figure 4.6, this fell at a slower rate compared to the apples stored at both 30 and 20°C.

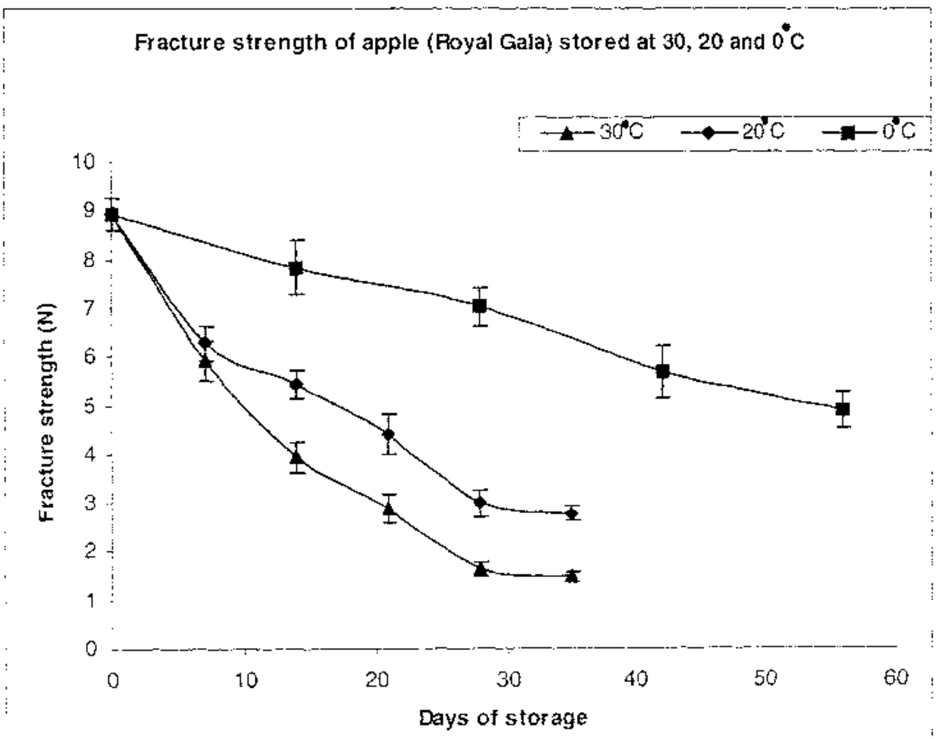


Figure 4-6 Fracture strength changes of Royal Gala apples at 30°C, 20°C and 0°C (2nd trial). Vertical bars represent the standard errors of the means.

The elastic modulus of apples (Trial 2) showed that apples stored at 30°C (Figure 4.7) declined much faster than those stored at 20°C and 0°C. The elastic modulus of apples stored at 30°C declined more than 70% over the first 14 days of storage, as compared with a decline of only 28.8% for the apples stored at 20°C (Figure 4.7) and 8.3% for the apples stored at 0°C. The elastic modulus for the apples stored at 30 and 20°C continued to decline with storage time, but the 0°C stored apples showed a rise and fall pattern during the last 28 days of storage (Figure 4.7).

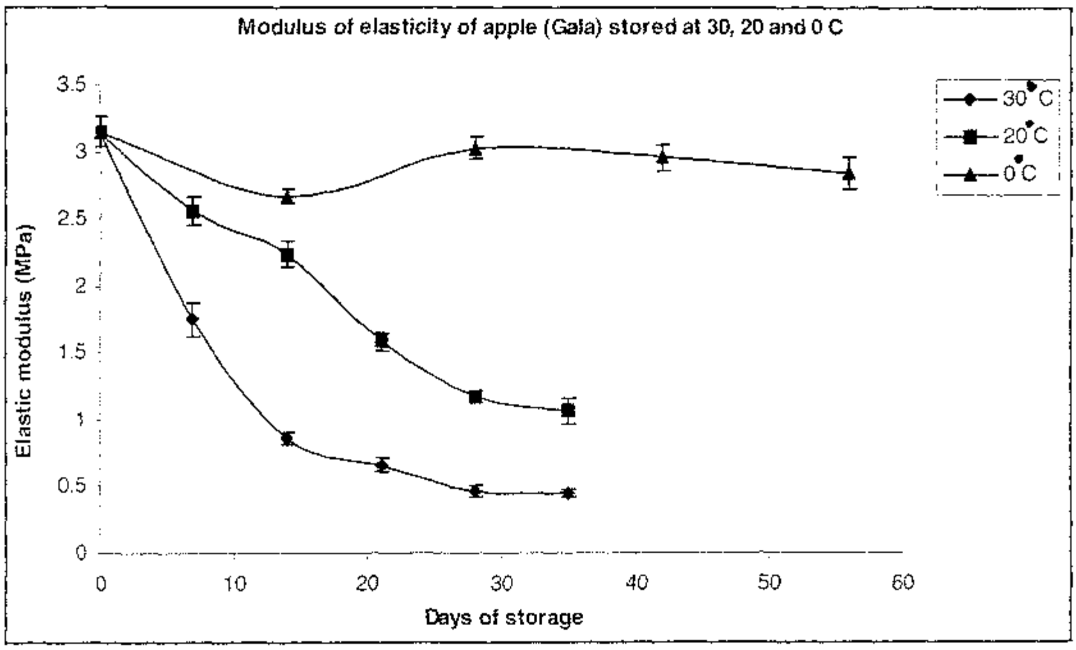


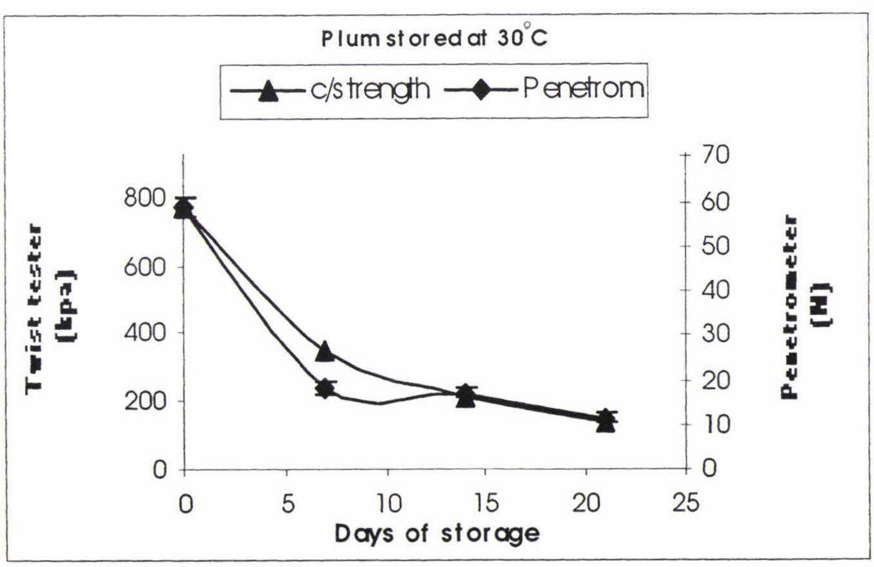
Figure 4-7 The elastic modulus changes in Royal Gala apples at 30°C, 20°C and 0°C storage. Vertical bars represent the standard errors of the means.

4.3 Plums

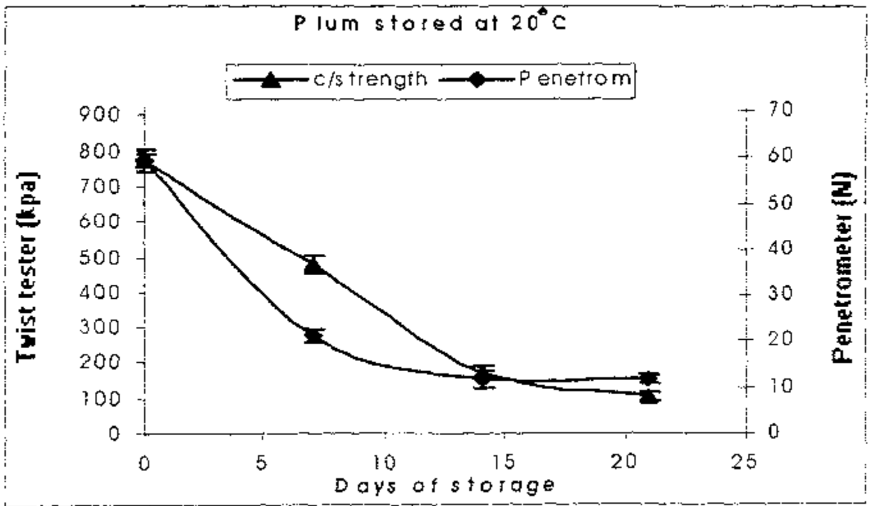
The plums were stored for 21 days and tested every 7 days. The Penetrometer and crushing strength of plums stored at 30°C decreased over the entire storage time by 80.9 and 82.% respectively (Figure 4-8a). There was a significant decrease in both measurements during the first 7 days' storage. Similar results were obtained at 20°C (Figure 4-8b) except that the Penetrometer values increased slightly during the last 7 days of storage time. Values for plums stored at 0°C (Figure 8-c) fell at a very slow rate with storage time, with little change for the first 7 days. Crushing strength values then gradually decreased up to 469.8 kPa (60.8%) after 21 days. Similarly, the Penetrometer measurement declined only slightly for the first 14 days, then quickly decreased to 29.7 N (50%).

The textural sensory assessment for plums stored at 30°C, 20°C and 0°C (Figures 4-8d, 8e and 8f) showed a decline in crispness, juiciness and firmness with storage time – except that a rise in juiciness value was obtained during the first 7 days and the last 7 days storage at 0°C. Furthermore, the firmness and crispness values of plums stored at 0°C remained close to the initial values.

a



b.



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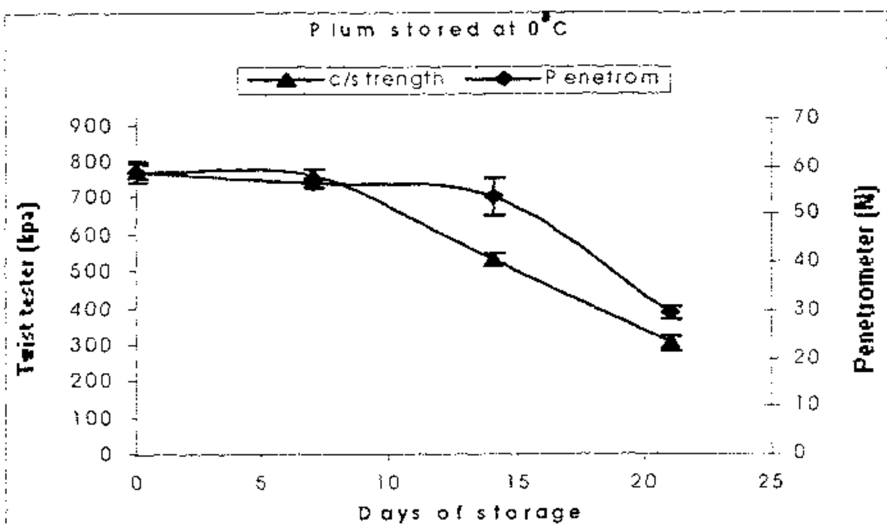
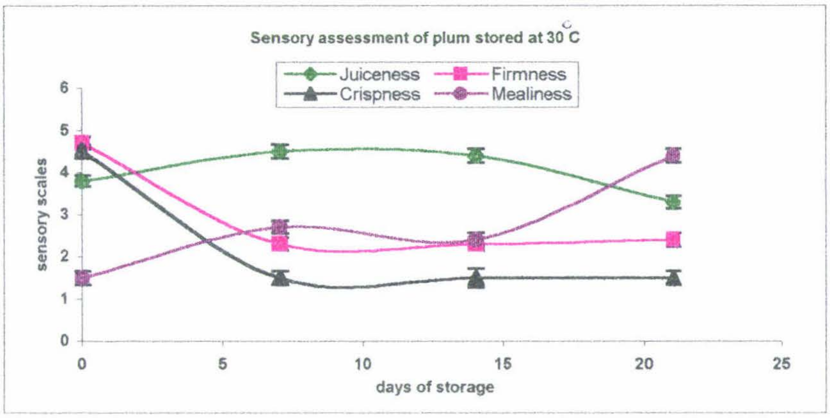
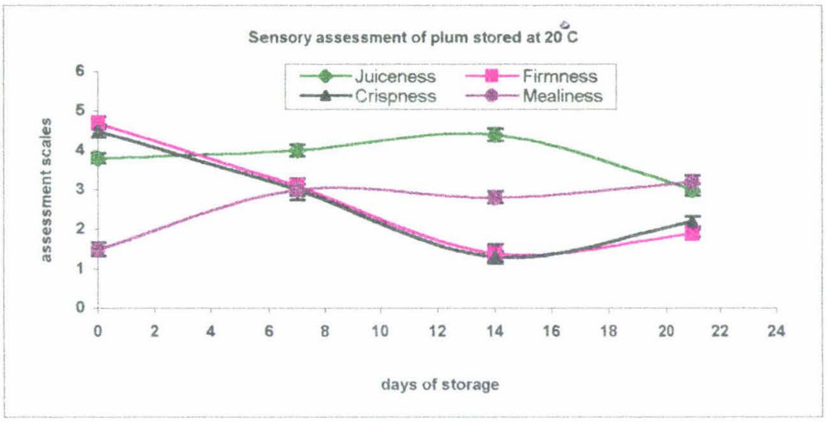


Figure 4-8a, 8b, 8c. The twist strength and Penetrometer changes in plums during 30°C, 20°C and 0°C storage. Vertical bars represent the standard errors of the means.

d.



e.



f.

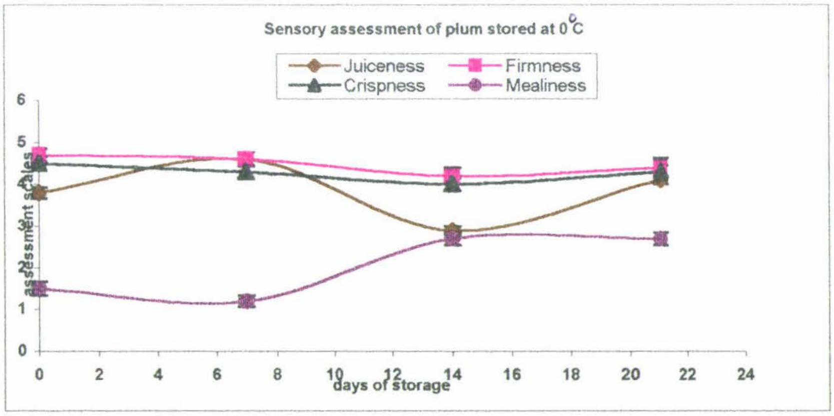


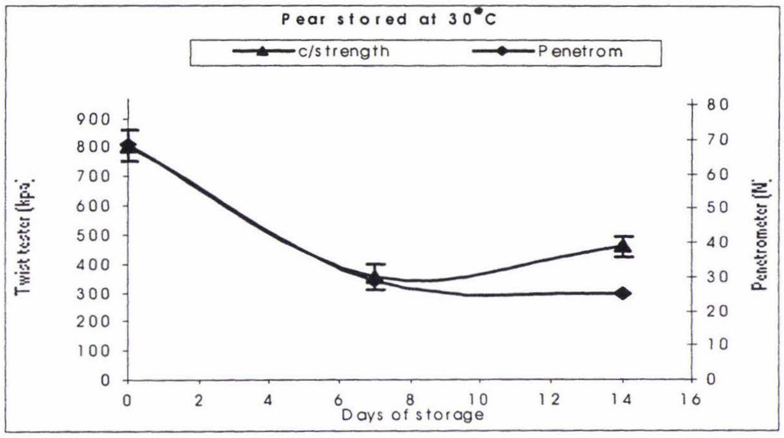
Figure 4-8d,8e,8f. - Sensory assessment of plum stored at 30, 20 and 0°C

4.4 Pears

The pears fruits were stored for 14 days and tested every 7 days as discussed in Chapter 3. The 30°C stored pears (Figure 4-9a) showed a uniform steep initial decrease of 56.% for crushing strength and 57 % for the Penetrometer measurement after the first 7 days storage. However, in the last 7 days' storage the crushing strength increased by 105.8 kPa (13%), while the Penetrometer values continued to decline by 3.9 N (5.7%). Pears stored at 20°C (Figure 4-9b) showed a rise and fall pattern for crushing strength with decreases in values during the first 7 days, then slight increases during the last 7 days' storage. The Penetrometer showed a continuous decrease with storage time. The values obtained at 0°C (Figure 4-9c) for both Penetrometer and crushing strength showed a similar pattern of decline during the first 7 days storage (by about 36%), then increasing in the last 7 days by less than 25%. The pears at 30°C showed the highest firmness loss (83%) during the first 7 days for both the Penetrometer and crushing strength.

The textural taste for pear at all storage conditions of 30°C, 20°C and 0°C showed a decrease in firmness, juiciness and crispness with storage time. The firmness at 30°C (Figure 4-9e) was an exception in that it rose slightly during the last 7 days' storage. The values obtained for firmness, crispness and juiciness for pears stored at 0°C (Figure 4-9d) showed to maintain close values to the fresh test (or the initial value. The mealiness of pears under all storage conditions, on the other hand, increased with storage time.

a.



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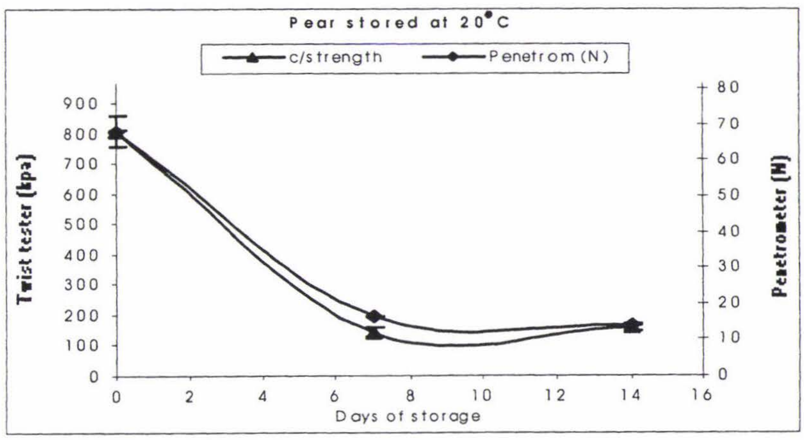


c.

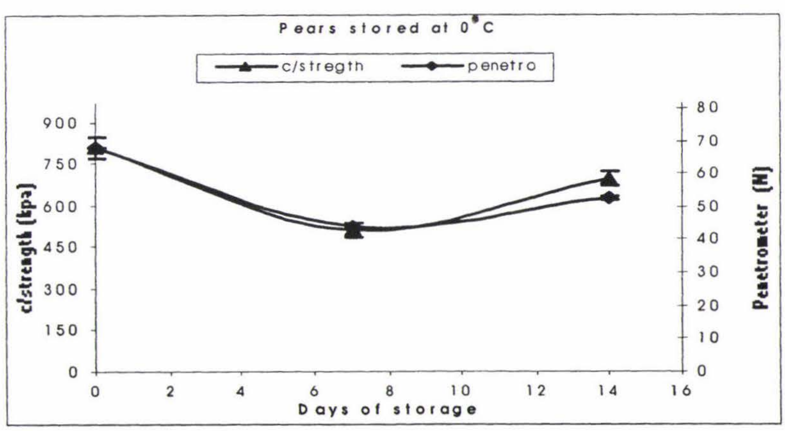
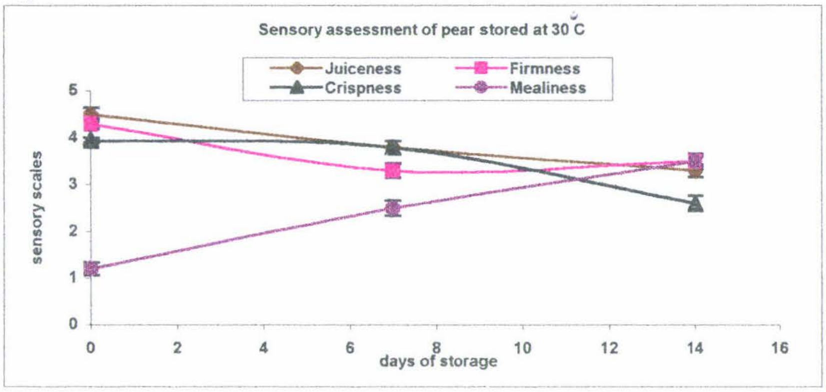
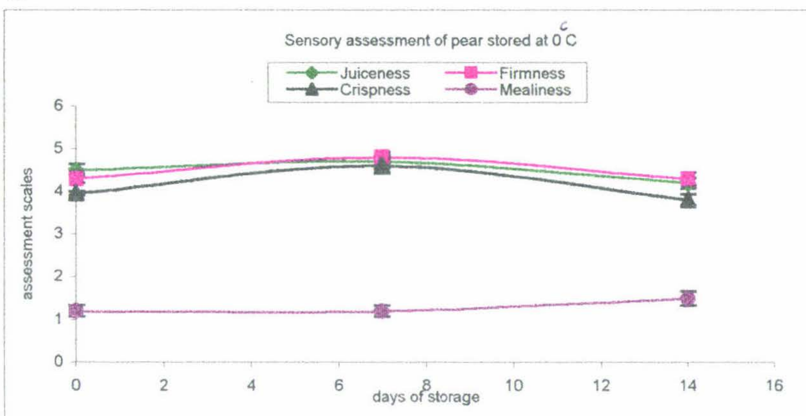


Figure 4-9a, 9b and 9c. Twist strength and the Penetrometer changes of pears during 30°C, 20°C and 0°C storage. Vertical bars represent the standard errors of the means.

d



e.



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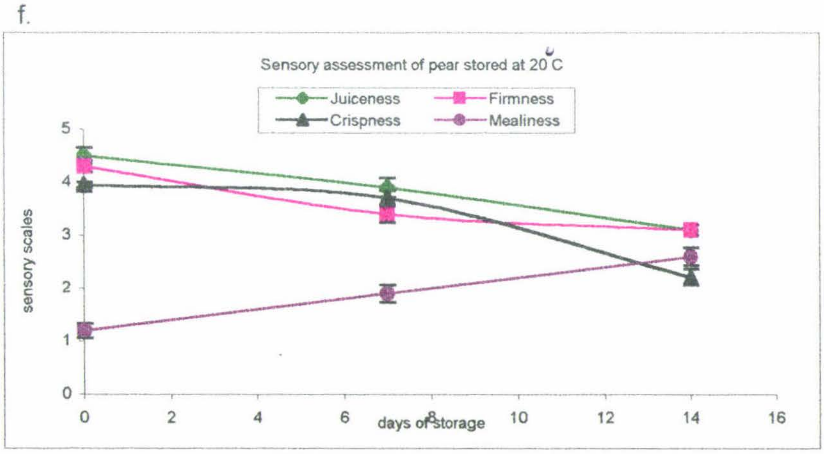


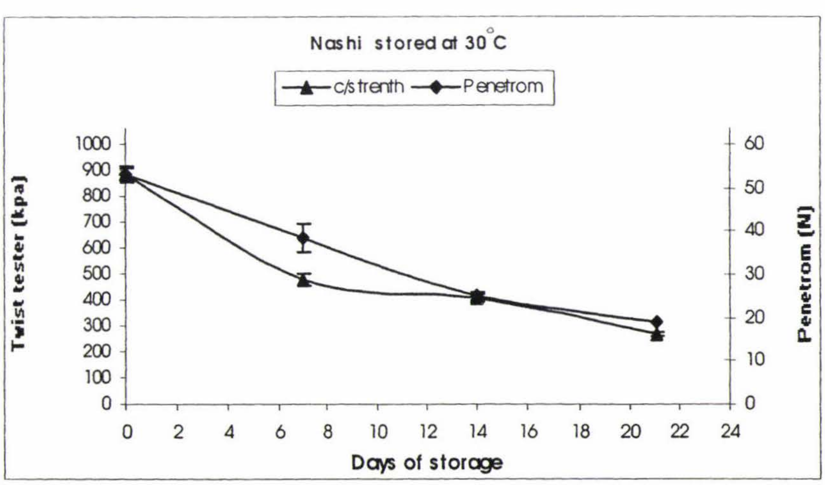
Figure 4-9d, 9e, 9f. Sensory evaluation of pears stored at 0, 20 and 30°C

4.5 Nashi

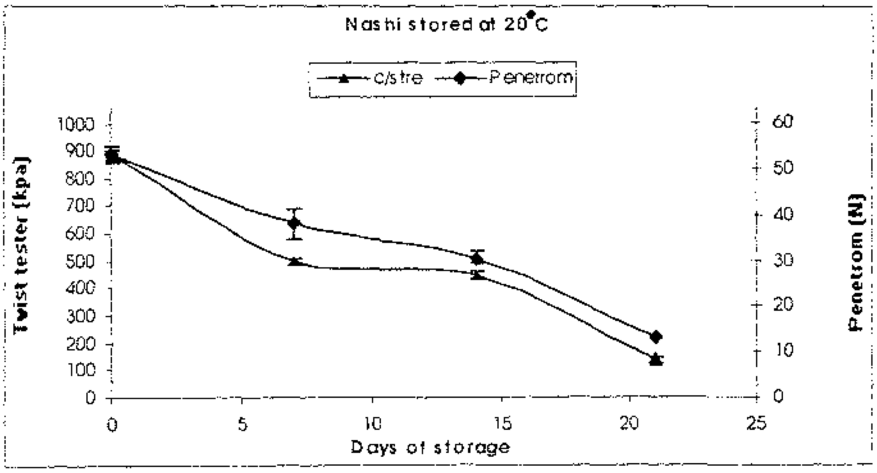
The nashi were stored for 21 days and tested every 7 days. The firmness measurement values for the Penetrometer and crushing strength of nashi at 30°C (Figure 4-10a) decreased over the entire storage time by 69.8% and 64% respectively from initial values. Similar morphological features were shown for the 20°C-stored nashi (Figure 4-10b) where the crushing strength declined by 747.8 kPa (84%) and Penetrometer values by 9N (75%) from initial values. These showed a higher percentage of firmness loss than did the 30°C-stored nashi. The values obtained for the nashi stored at 0°C (Figure 4-10c) fell at a very slow rate with less than 40% firmness loss during the whole storage duration for both measurements.

The textural taste assessment of nashi at all 3 storage conditions (Figures 4-10d, 10e and 10f) showed a decrease in firmness, crispness and juiciness with storage time and again the mealiness for all storage conditions increased with storage time. The values obtained for the firmness, crispness and juiciness for nashi stored at 0°C showed to remain close to initial values.

a.



b.



c.

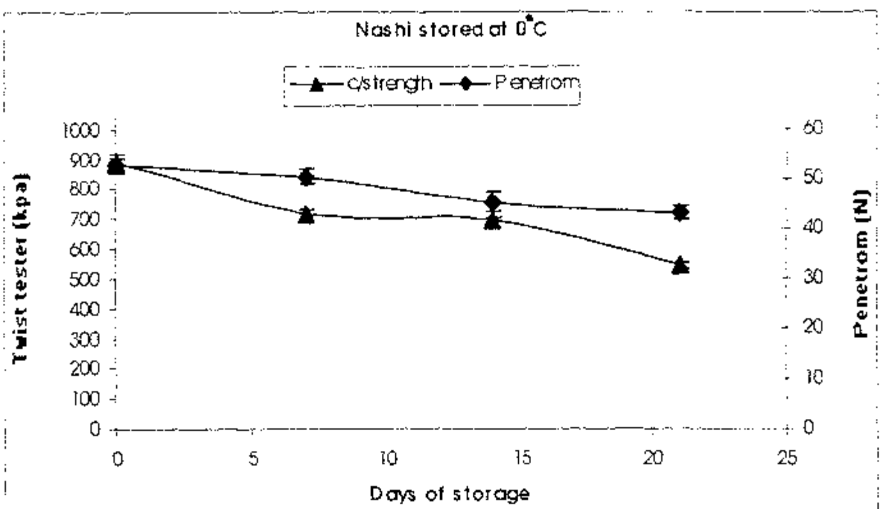
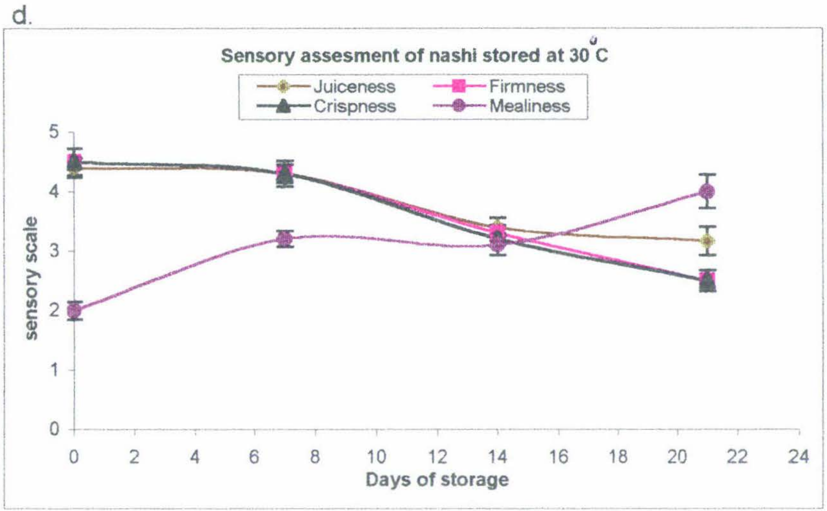
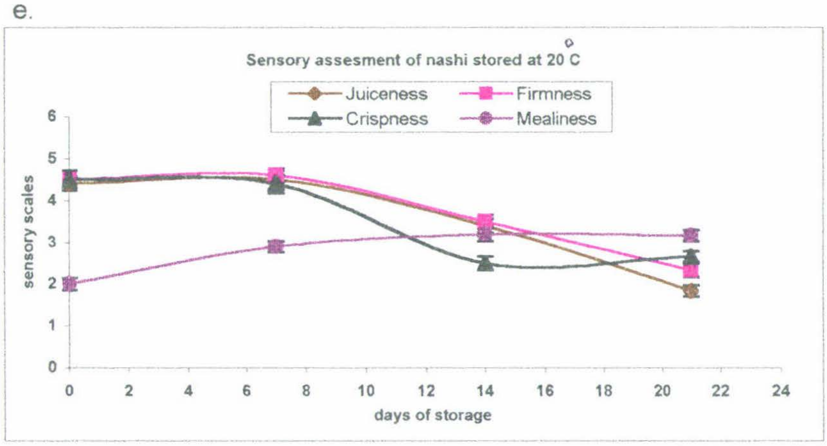


Figure 4-10a, 10b and 10c. Twist strength and Penetrometer changes in nashi during 30°C, 20°C and 0°C storage. Vertical bars represent the standard errors of the means.

d.



e.



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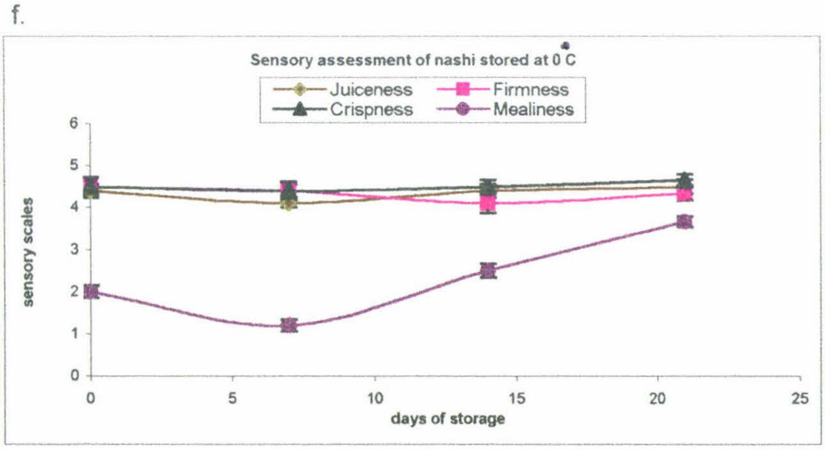


Figure 4.10d, 10e, 10 f - Sensory assessment of nashi after storage at 0, 20 and 30°C.

4.6 Kiwifruit

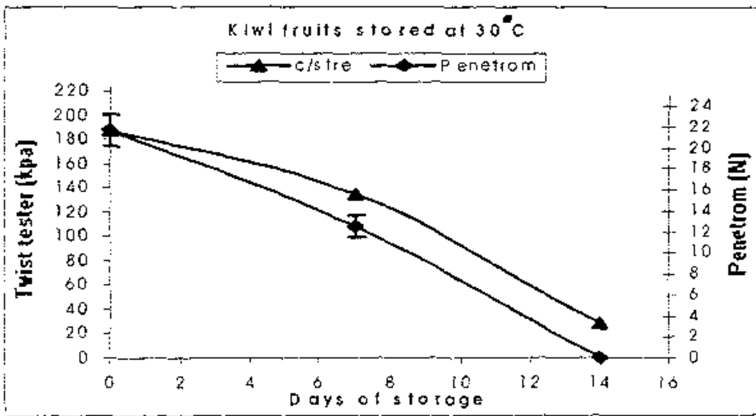
Samples of Howard variety kiwifruit were bought from supermarket shelves, which were put in cool stored for 3 months. They were tested while arrived at the laboratory, and stored for 14 days (testing every 7 days).

The results for Kiwifruit stored at 30°C (Figure 4-11a) showed similar morphological features for crushing strength and the Penetrometer measurement results, in that they decreased with storage time. The Penetrometer measurement declined significantly up to 100%, and crushing strength to 159kPa (85%). The Penetrometer was not able to detect the flesh firmness of kiwifruit after 14 days of storage with a 0 N value. Similar results were obtained for the kiwifruit stored at 20°C, a decrease of 135.7kPa (72.6%) for crushing strength while penetrometer was not able to detect any changed at all.

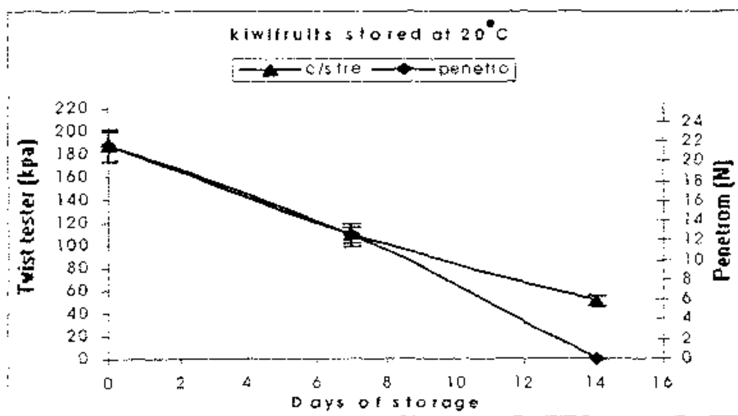
At 0°C (Figure 4-11c) storage results for both showed a decrease with storage time by 5.8 N (27%) from initial value for the Penetrometer test, and 122 kPa(65%) for the crushing strength.

The sensory taste assessment obtained for the kiwifruit showed a decline in juiciness, firmness and crispness with storage time for the 30°C and 20°C storage, (Figure 4-11d and 11e) and increase in mealiness with storage time. Kiwifruits stored at 0°C (Figure 4- 11f) showed to decrease in crispness and slightly for firmness while juiciness and mealiness values showed to increase with storage time.

a.



b.



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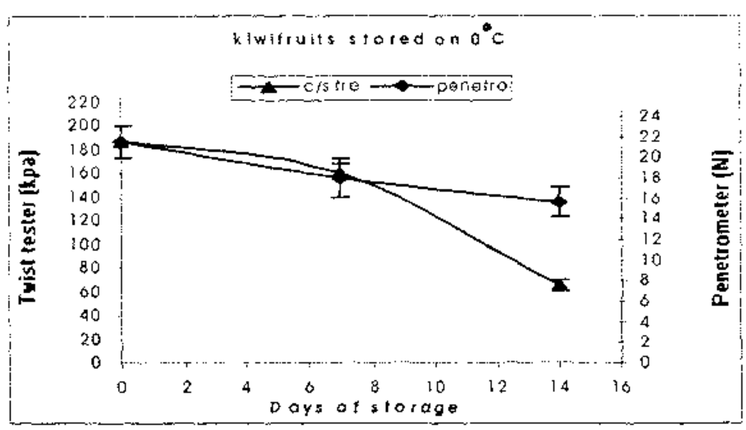


Figure 4-11a, 11b and 11c. Twist strength and Penetrometer measurement of kiwifruit during storage at 30°C, 20°C and 0°C. Vertical bars represent the standard errors of the means.

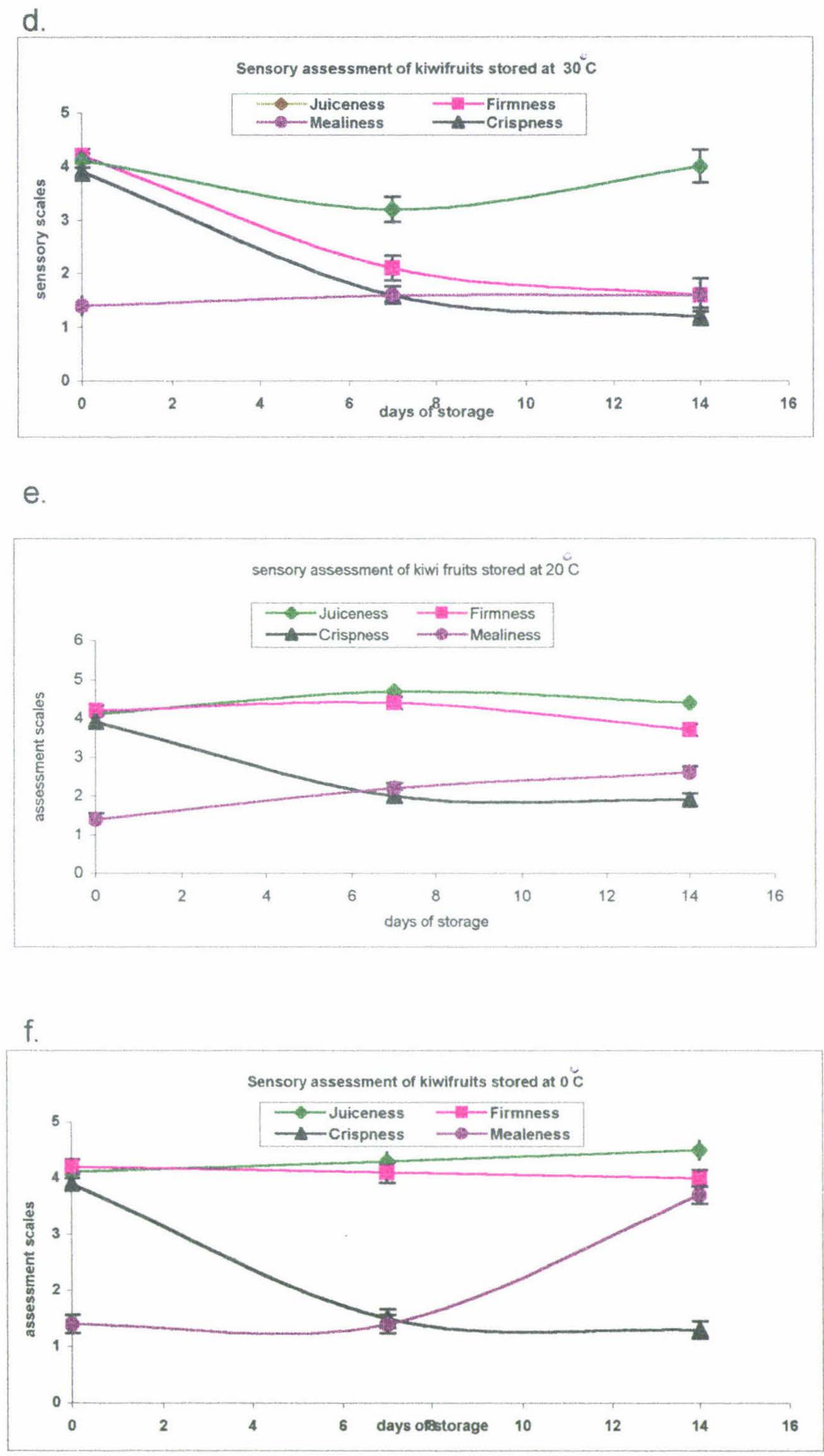


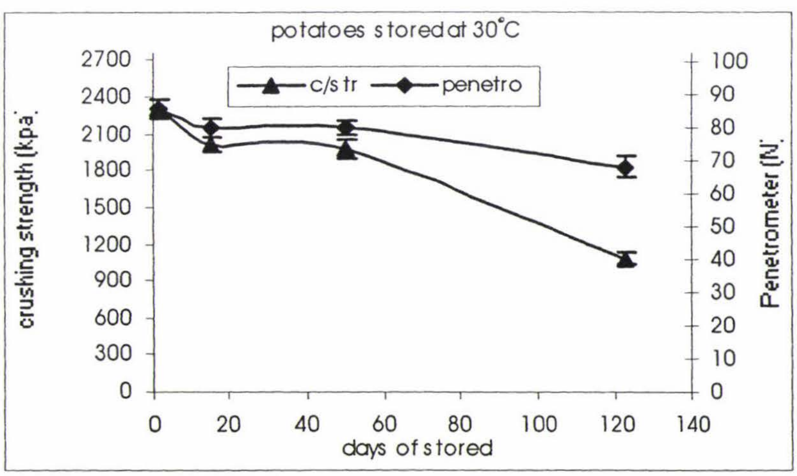
Figure 4-11d, 11e, 11f Textural assessment for kiwifruit after at 30, 20 and 0C
Vertical bars represent the standard errors of the means.

4.7 Potatoes

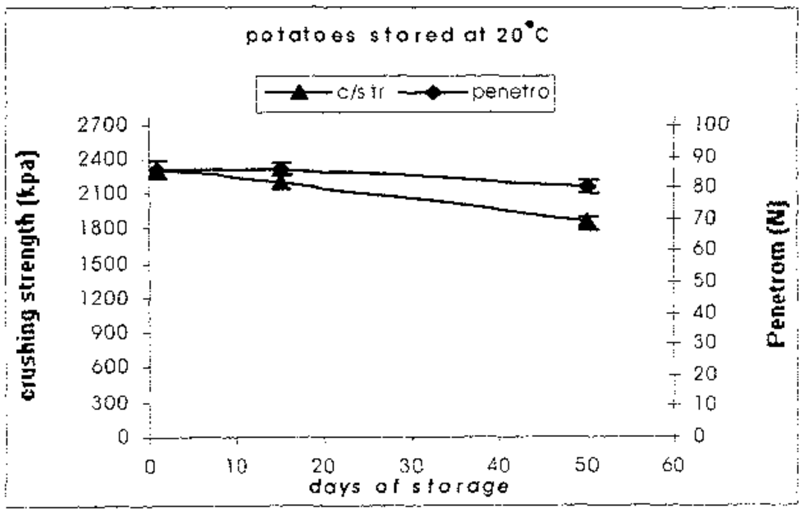
The potatoes were stored at 30°C and 0°C for 123 days, while potatoes were stored at 20°C for only 50 days.

The results obtained for the crushing strength and Penetrometer measurement of potatoes stored at 30°C showed a decline with storage time, with a delay in declining for at least 28 days after the first 14 days of storage (Figure 4-12a). The Penetrometer measurement declined by 17.5N (20%) and the crushing strength by 1224.6 kPa (53%) from initial values during the 123 days of storage. The result for the potatoes stored at 20°C showed a divergent pattern for the Penetrometer measurement and crushing strength (Figure 4-12b) in the first 7 days' storage, whereby the Penetrometer values initially increased by 0.3 N before declining - while the crushing strength continued to decrease gradually with storage time. A similar divergent pattern of results was obtained for the potatoes stored at 0°C (Figure 4-12c) during the first 14 days' storage. The Penetrometer measurement initially increased by 1.2 N, then gradually declined during the last 112 days - while the crushing strength gradually declined over the whole storage time.

a.



b.



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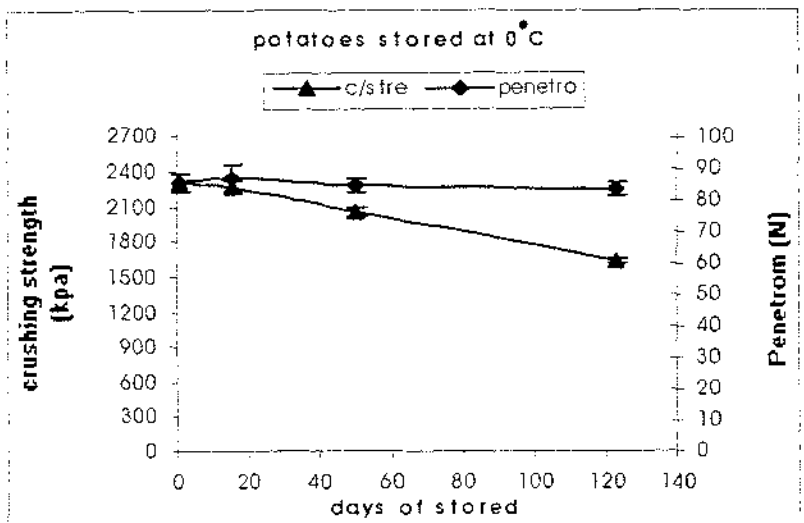

Figure 4-12a, 12b and 12c. Twist strength and Penetrometer measurement changes in potatoes during storage at 30°C, 20°C and 0°C storage. Vertical bars represent the standard errors of the means.

4.8 THE EFFECTS OF SPEED ON CRUSHING STRENGTH

4.8.1 Speed of crushing carrots and Braeburn apples

A 4x7 mm blade with 5 different speeds was used to test fresh apples and carrots. The five speeds, namely, the first speed of 1.82 revolution per minute, the second speed (6 rpm), the third speed of 10 rpm, fourth speed (15 rpm) and the fifth speed of 20 rpm showed increased of crushing strength when speeds were increased (Figure 4-13). Similar result was obtained for the speed tests of both products, where the crushing strength showed to increase with increased of speeds (Figure 4-13).

a.

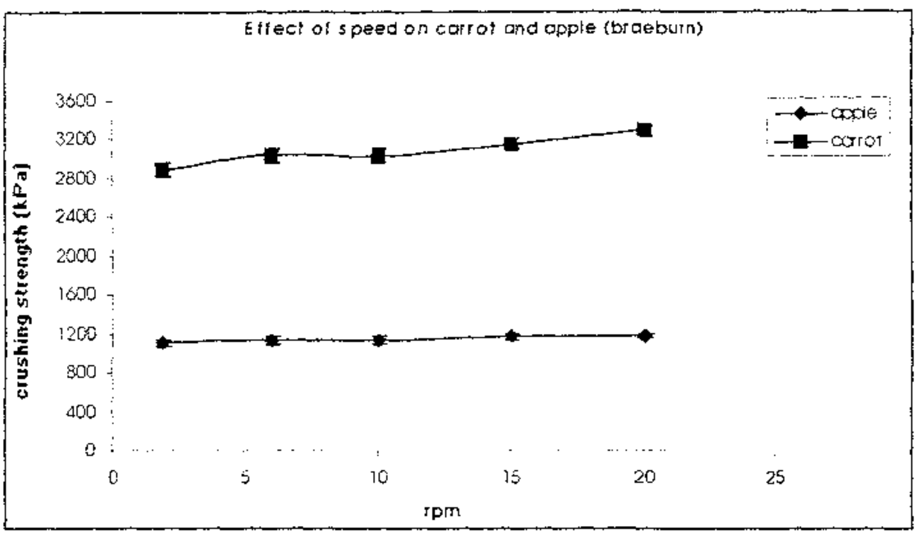

Figure 4-13: Crushing strength changes with increasing speed for carrots and braeburn apple.

5.1 SUMMARY OF RESULTS

The types of texture measuring instruments used in this experiment affected the results obtained as well as the storage conditions and time of storage. The results showed that almost all samples in the different storage conditions declined in values with storage time when measured with the Penetrometer, Massey Twist Tester and the Texture Analyser. However, there were a few exceptions. First, the values obtained from the Penetrometer at some stages of storage increased (Figures 4-5a, 4-5b, 4-9a, 4-9c, 4-12b and 4-12c). Second, the crushing strength and penetrometer readings for pears at all storage conditions slightly increased during the last 7 days (Figure 4-9a,9b and 9c).

Almost all types of sample products stored at 30° had the greatest firmness loss compared to samples stored at both 20 and 0°C. The nashi at 20°C (Figure 4-10b) was an exception where it showed a higher percentage of firmness loss than the nashi stored at 30°C when measured with both the Penetrometer and the Massey Twist Tester. The results obtained at 0°C storage for all sample products showed a very slow rate of decline in firmness as well as producing the lowest percentage of firmness loss.

The sensory textural taste evaluation for almost all types of sample products showed a decline in firmness, crispness and juiciness values with storage time for the different storage conditions while mealiness values increased with storage temperatures and time.

The speed test showed similar results for both carrot and apple. The crushing strength showed to slightly increase with the speed increased. In particular the least variation in speed appeared to be at rates between 5 and 10 rpm, where there was virtually no increase in crushing strength value for both products.

CHAPTER FIVE - ANALYSIS AND DISSUSION

5.1 INTRODUCTION

In order to assess the performance of the Massey Twist Tester in detecting the firmness of fruit and vegetables, all results obtained from the devices (Twist Tester, Penetrometer and Texture Analyser) at the three storage treatments (30°C, 20°C and 0°C) were compared using SAS software. The results showed that storage conditions, time of storage and the type of measuring instrument could affect the results obtained. Generally, the results obtained from the experiment showed similar patterns for almost all types of fruit in different storage conditions as values of fruit firmness declined with storage time. However, some irregularities during the research, which will be discussed.

5.2 THE EFFECTS OF STORAGE TIME AND CONDITIONS

As shown in Chapter 4, storage conditions have significant effects on the postharvest storage life and quality of fruit and vegetables. Results obtained in this study showed that although the firmness attributes of fruits and vegetables decrease with storage time, the readings obtained were affected also by storage conditions. **Table 5.1** shows the average values of crushing strength and penetrometer rating over time. In general, fruit stored at higher temperatures deteriorated more quickly than fruit stored at lower temperatures which indicates that " the longer the time of storage the higher the firmness loss." According to the findings of Jeffery and Banks (1994), the effects of temperature on firmness in some instances are proportionally very large as for example, at 30°C - while others are negligible as shown at 0^0C storage.

Fruit	Days of storage	Temperature			Temperature		
		30 °C	20 °C	0 °C	30° C	20 °C	0 °C
		Penetrometer (N)			Crushing strength (kPa)		
Braeburn Apples	1*	60.6	60.6	60.6	1490	1490	1490
	7	55.8	59.6		1010	986	
	14*	56.8	56.6	57.5	991	974	999
	21	52.1	51.6		967	956	
	28*	48.4	52.2	57.2	715	851	956
	42*			56.8			845
R/Gala 1 Apples	1*	67.6	67.6	67.6	1230	1230	1230
	7	57.5	59.7		808	841	
	14*	45.5	54.2	58.7	568	743	876
	21	41.4	45.8		531	691	
	28*	27.2	44.5	51.6	465	665	789
	42*			55.7			697
	56*			53.5			580
R/Gala 2 Apples	1*	77	77	77	1434	1434	1434
	7	67	71		1036	1133	
	14*	61	62	66	945	976	1172
	21	56	53		749	810	
	28*	34	49	64	554	784	1110
	35	36	50		464	761	
	42*			62			922
	56*			61			882
Plums	1	59	59	59	773	773	773
	7	19	21	57	352	481	762
	14	17	12	54	210	172	532
	21	11	12	29	137	103	303
Pears	1	68	68	68	806	806	806
	7	29	16	44	354	142	560
	14	25	14	52	460	157	694
Nashi	1	53	53	53	886	886	886
	7	38	38	50	478	496	715
	14	25	30	45	407	448	694
	21	19	13	43	267	137	542
Kiwifruits	1	22	22	22	187	187	187
	7	12	13	18	134	109	161
	14	0	0	16	28	51	65
Potatoes	1	86	86	86	2306	2306	2306
	15	80	86	87	2014	2191	2263
	50	80	80	85	1974	1868	2053
	123	68		83	1081		1627

(* test date for fruit at 0 °C)

Table 5.1 – All values are mean of crushing strength and penetrometer readings.

Generally, as shown in **Table** 5.1, fruit and vegetables at higher temperatures (30 and 20°C) have a greater percentage of firmness loss compared to product stored at 0°C. This result confirmed that temperature is known to affect the firmness of a wide range of fruit and vegetables (Werner et al., 1978, Bourne 1982; Harker & Dunlop, 1994).

5.3 COMPARISION OF TWIST TESTER AND PENETROMETER FOR SPECIFIC DATA SETS.

These sets of experiments showed different results of firmness obtained from different fruits and vegetables as measured with the penetrometer and Twist Tester.

Table 5.2, summarises the figures, showing the length of storage time for each type of fruit and vegetable, the decrease in values as measured by the penetrometer and the Massey Twist Tester as a percentage, and the correlation (r) between the readings and the storage time for each storage temperature.

Fruit	Temp	Length of Trial	Penetrometer		C/strength	
			% drop	R	% drop	r
Braeburn	30	35 days	20%	0.55	52%	0.73
	20	35 days	14%	0.54	43%	0.73
	0	42 days	6%	0.23	43%	0.80
Royal Gala 1	30	28 days	60%	0.86	62%	0.80
	20	28 days	34%	0.85	46%	0.72
	0	56 days	21%	0.67	53%	0.83
Royal Gala 2	30	35 days	54%	0.91	68%	0.93
	20	35 days	34%	0.82	47%	0.82
	0	56 days	21%	0.62	39%	0.70
Plum	30	21 days	81%	0.83	82%	0.92
	20	21 days	80%	0.44	87%	0.95
	0	21 days	50%	0.77	61%	0.92
Pear	30	14 days	63%	0.85	43%	0.61
	20	14 days	79%	0.86	81%	0.82
	0	14 days	23%	0.44	14%	0.23
Nashi	30	21 days	64%	0.88	70%	0.91
	20	21 days	75%	0.89	84%	0.94
	0	21 days	19%	0.60	39%	0.89
Kiwifruit	30	14 days	100%	0.77	85%	0.91
	20	14 days	100%	0.76	73%	0.89
	0	14 days	27%	0.44	65%	0.80
Potato	30	123 days	20%	0.59	53%	0.93
	20	50 days	6%	0.45	19%	0.72
	0	123 days	36 %	0.15	29%	0.85

Table 5.2 – Correlation between the penetrometer readings and crushing strength and storage time, and their percentage decrease.

In almost all cases the correlation coefficient for Twist Tester was higher than the corresponding value for the penetrometer, indicating that the Twist Tester gave more consistent results (assuming that storage time is in fact a major factor in quality).

5.3.1 Braeburn

The firmness of apple tissue, as measured by the Twist Tester and the penetrometer, and represented by crushing strength and penetrometer readings was found to decrease in all storage conditions at different rates. At 30^0 C the average crushing strength decrease by 52% and the penetrometer readings by 20% over storage time. The coefficient of correlation value for both crushing strength and penetrometer readings and their storage time is $r = 0.73$ and $r = 0.55$ respectively as shown in **Table 5-2**. A similar trend to that of the 30°C storage condition is obtained at 20 °C. The average crushing strength decreased by 42.8%, and the penetrometer reading by 13.8 % with storage period except for the final 7 days of storage, when a divergent result is obtained whereby the crushing strength continued to decrease while the penetrometer reading slightly increased. The coefficient and correlation produced is $\boldsymbol{r} = 0.73$ for crushing strength and $\boldsymbol{r} = 0.54$ for the penetrometer readings. Braeburn stored at 0^0 C for 42 days showed that the average crushing strength decreased by 43% and the average penetrometer readings by 6%. The coefficient and correlation value of crushing strength shows a significant difference from the penetrometer reading of $\boldsymbol{r} = 0.80$ and 0.22 respectively.

The divergent result showed at 20°C during the last 7 days of storage (**Figure** 4.1b) could be due to a limitation of the penetrometer instrument caused by operator differences, as reported by researchers (Linskens & Jackson, 1995; Harker et al., 1994).

In all three storage conditions, the Twist Tester had a higher correlation than the penetrometer. This showed that the Twist Tester is relatively more reliable when used to detect the changing of mechanical properties of Braeburn during storage.

5.3.2 Royal Gala 1

As described in **Chapter 3**, the Texture Analyser was included for testing the mechanical properties of Royal Gala by finding the fracture strength of a 12 mm diameter sample cut from the apple in an equatorial direction, and the modulus of elasticity of the whole fruit when compressed. A summary of the results is given in **Table** 5.3, together with the Penetrometer and Twist Tester data presented ealier.

Fruit	C^0	Length of trial	Penetrometer		Twist Tester		Modulus of elasticity		Fracture strength	
			% drop	*r*	% drop	*r*	% drop	*r*	% drop	*r*
Royal Gala 1	30	28 days	60%	0.86	62%	0.80	82%	0.74	79%	0.87
	20	28 days	34%	0.85	46%	0.72	58%	0.81	62%	0.81
	0	56 days	21%	0.67	53%	0.83	10%	0.22	58%	0.84
Royal Gala 2	30	35 days	54%	0.91	68%	0.93	86%	0.70	83%	0.91
	20	35 days	34%	0.82	47%	0.82	66%	0.55	69%	0.85
	0	56 days	21%	0.62	39%	0.70	9%	0.63	45%	0.76

Table 5.3 - Correlation of mechanical testing and storage time of Royal Gala stored at 30, 20 and $0\,^0$C.

Trial 1 test was carried out on apples harvested and stored at 10^0 C for 7 days before they were distributed to their storage conditions for tests to be conducted. The average crushing strength at 30°C decreased from 1230.4 kPa to 465.6 kPa after 28 days of storage, while the average penetometer readings decreased from 67.6 N to 27.2 N. The relationship between the crushing strength and storage time and the penetrometer reading and storage time produced comparable values which were $r = 0.80$ and $r = 0.86$ respectively.

At 20 ^{0}C the average crushing strength decreased from 1230.4 kPa to 665.4 kPa and the average penetrometer readings decreased from 67.6 N to 44.5 N. The correlation coefficients were $r = 0.72$ and 0.85 respectively.

From 0 ^{0} C, both the crushing strength and penetrometer readings decreased at a slower rate than at 30^0 C and 20 ^{0}C. The average crushing strength decreased from 1230.4 kPa to 580.2 kPa and the average penetrometer reading decreased from 67.6 N to 53.5 N. The relationship of average crushing strength and storage time obtained was $r = 0.83$ and the average penetrometer readings was $r = 0.67$.

For the first series tests of Royal Gala, the Twist Tester readings were comparable with those obtained from the penetrometer, which can trace the changes in fruit firmness during storage time.

5.3.3 Royal Gala (Trial 2)

The trial 2 apples were brought directly from the Waipawa pack house in fresh condition. Similarly to the results of trial 1, the crushing strength and penetrometer reading decreased over time. At 30 ^{0}C the average crushing strength decreased from 1434.2 kPa to 464 kPa (67.6%), while the average penetrometer reading decreased from 77 N to 35.7 N. The correlation of crushing strength and storage time was $r = 0.93$, and the correlation of the penetrometer readings with storage time was $r = 0.91$.

The total changed in average crushing strength at 20 ^{0} C was 46.9%, and the percentage change in readings obtained from the penetrometer is 33.8 %, which are both lower than 30^0 C percentage changes. Within the storage period of 35 days the average crushing strength decreased from 1434 kPa to 761 kPa, while the average penetrometer readings decreased from 77 N to 50.9 N. The correlation of average crushing strength and storage time is $r = 0.82$ while the correlation of average penetrometer reading and storage time is $r = 0.82$.

At 0^0 C, the average crushing strength decreased from 1434 kPa to 882 kPa, while the average penetrometer readings decreased from 77 N to 60.8 N at 56 days. The correlation of crushing strength and storage time was $r = 0.70$ and penetrometer reading is $r = 0.62$. The crushing strength had a higher coefficient correlation than the penetrometer readings, which suggests that the Twist Tester is more reliable than the penetrometer for testing the standard of apples at any storage condition.

5.3.3.1 Elastic Modulus

As discussed in Chapter 3, the whole fruit was compressed between two parallel flat plates. Whole fruit compression test by horticulturalists is second only to puncture tests, as mechanical test method. It is a non-destructive (at least intially), and could therefore be considered to be useful test method. However, there are some concerns.

The measurement involved application of constant force with measurement of the incurred fruit deformation (Polderdijk et al. 1993). Apples are viscoelastic (i.e. their mechanical behaviour is neither purely elastic nor purely viscous but shares the propeties of both), so that deformation still occur when a certain force is applied. The rate of compression must be specified because it significantly affects the measurement of strength, however, it is possible to calculate the modulus of elasticity, deformability and stress index of fruit (ASAE Standard S368.1 1984, Harker et al. 1993).

Unfortunately there are further problems with this method. The question has been raised as to whether or not these two tests respond to changes in properties of fruit in a similar fashion? The answer is, "Not always!" Jackson and Humber (1990) said that whole fruit compression is a relatively insensitive method compared to a puncture test or tissue compression, and this is due to a variety of confounding influences such as variation in fruit morphology, size, shape, turgor, viscosity and content of locular fluid (Jackman et al., 1992).

Results obtained in this study showed that over two trials, the elastic modulus of Royal Gala apples declined with storage time. The decrease in elastic modulus was affected by both storage temperature and time. As shown in **Figures** 4.4 and 4.7, the modulus of both trials was very similar and changed in the same way. The elastic modulus of Royal Gala 2 is higher than that of Royal Gala 1 - which is 3 Mpa to 2.5 MPa, which showed that the whole fruit compression test can identify the different levels of firmness and freshness of the samples. Apples for trial 2 were brought directly from the packing house and tested within 24 hours of arrival, while the apples for trial 1 were stored at 10 ^{0}C for 7 days before testing.

A liner regression model using the modulus of elasticity and storage time showed a good relationship for both trials, with the exception of fruit stored at 0^0 C at trial 1 as shown in **Table** 5.3. This suggests that the whole fruit compression test is able to detect the changed of apple firmness. This method is also relevant for finding the maturity of the apple.

5.3.3.2 Fracture strength

Fracture strength is the force needed to break the tissue sample. This kind of test is known as *three-point bending*. Generally, a cylindrical tissue sample is supported at both ends by pivots with a blunt blade located between the pivots, then drive down at constant speed so that sample bends, then breaks (Harker, et. al. 1997). However, there are problems with this method when used to test fruit and vegetables.

When three bending test is used to measure the stiffness of biological materials, the surface of the sample should be hard and not deform. The main reason why three bending test is not commonly used is because some fruit do not fulfil this requirement (Vincent, 1990). Bolin et al. (1964) and Lapsley (1989) said that apple has mainly been used in this test because it has a relatively hard tissue.

The results obtained in this study showed that the fracture strength of both Royal Gala trial 1 and 2 showed a similar trend decline with storage time. The fracture strength of apples stored at higher temperatures decreased faster than apples stored at lower temperatures, as shown in **Figure 4.3 and 4.6**. The Three-Bending test is able to identify the different level of stiffness of fruit samples. The fracture strength of apples brought straight from the packing house is higher than that of apples stored at 10^0 C for 7 days before testing.

The differences in fracture characteristics were due to the physical and chemical changes occurring in the cells and cell wall of the apples. Waldron et al., (1997) said that the softening of the fruit is the consequences of the dissolution of wall polymers of which many are involved in cell adhesion. When the tissue is soft, the cell become completely separated.

Further analysis showed that there is a high degree of correlation between fracture strength and storage time, as shown in **Table** 5.3. When using the four devices for testing the firmness attribute of Royal Gala, the two trials showed that they all have a similar correlations, which are reasonably high except for the elastic modulus at 0^0 C trial 1.

As shown in **Table** 5.4 the correlation between the Twist Tester and the Texture Analyser data was generally slightly higher than the correlation of Penetrometer and Texture Analyser. This suggests that the Twist Tester is more reliable than the penetrometer for testing the firmness attribute of apples.

Fruit	Temp (^{0}C)	T/Analyser	Penetrometer	T/Tester
Royal Gala Trial 1	30	3 bending test	0.85	0.89
	20		0.76	0.52
	0		0.42	0.52
	30	Elastic Modulus	0.76	0.86
	20		0.79	0.79
	0		0.05	0.04
Royal Gala Trial 2	30	3 bending test	0.78	0.87
	20		0.76	0.76
	0		0.42	0.52
	30	Elastic Modulus	0.72	0.85
	20		0.79	0.79
	0		0.05	0.04

Table 5. 4– Correlation and coefficient of Penetrometer, Twist Tester and Texture Analyser of Royal Gala stored at 30, 20 and 0 ^{0} C.

5.3.4 Plum

The results obtained from plums generally indicate that firmness decreases with storage time and temperature. The crushing strength at 20°C storage decreased with storage time with the highest percentage (82%) of firmness loss being higher than the firmness loss of plums stored at 30°C. Plich, (1998), states that, acceleration of plum softening should occur at room temperature, which associated with the rise in ethylene production. The crushing strength at 0°C storage gradually decreased with storage time, which also stresses the fact that plum softening generally could be considerably delayed when the temperature in the storeroom is maintained as low as possible, but above the freezing point of tissue (Smith, 1967). Penetrometer readings, on the other hand similarly decreased with storage time at different temperatures - but a slight rise in values was indicated in the graph **Figure 4-8 a,** at 20°C storage during the last 7 days of storage- while the crushing strength continued to decrease with storage time. This implies that the penetrometer readings alone could be inaccurate due to the inconsistency of the force applied by the operator during the puncture test. This could mean also that the removing of skin from the cheek of the fruit must have affected the readings (Abbott et al.1976; Yuwana, 1991; Studman & Yuwana, 1992; Harker et al. 1996; Salada, 1996;). The coefficient correlation of the penetrometer reading with storage time is low compared to the coefficient correlation of the crushing strength with storage time at all storage temperatures, which were very high (30°C- r = 0.92, 20°C – r = 0.95 and 0°C – r = 0.92). This was so especially at 20°C where a large difference is observed between the crushing strength and the coefficient correlation of the penetrometer reading with storage time. This further demonstates the inaccuracy in the penetrometer readings.

5.3.5 Pear

The results present a different pattern of firmness loss with increase in temperature as in Chapter 4. At 20°C storage the percentage of firmness drop is greater for both the penetrometer reading (79%) and the crushing strength (81%) of pears than for pears stored at 30°C. At 30°C storage both crushing strength and penetrometer readings decreased with storage time except during the last 7 days of storage where the penetrometer readings continued to decrease while the crushing strength slightly increased in values. This rise in crushing strength at the last stage of storage agrees with Harker et al., (1996) "when water loss is extreme," many fruits tend to develop a "rubbery" texture and a higher maximum force is required during the puncture testing which indicates that the texture is firmer. The Massey twist tester at this point indicated that it can detect slight changes in firmness due to water loss as stressed in this matter. These researchers reported that since the water loss is high the texture becomes mealy and dry, which is associated with "lack of free juice on the cell wall surface that makes the texture firmer" (Harker & Sutherland 1992).

The result for pears stored at 0°C presents a fall and rise pattern for both measurements- which fell from their initial value and rose in firmness during the last 7 days of storage for both the penetrometer readings and crushing strength. This result reflects the findings of rehardening of fruit in cool storage. Werner et al. (1978) stated that low temperatures induce rehardening in small fruit, including pears, to some extend. Further analysis showed that the coefficient correlation value of the Penetrometer at all storage temperatures (30°C $r = 0.85$, 20°C - $r = 0.86$ and 0°C – $r = 0.44$) were slightly higher than the coefficient correlations of the crushing strength (30°C – $r = 0.61$, 20°C – $r = 0.82$ and 0°C – $r = 0.23$) as in **Table 5.2.**

5.3.6 Nashi

The firmness results for nashi at all storage temperatures declined with storage time for both the penetrometer readings and crushing strength. The reading for the crushing strength at 30 °C storage showed a large drop in firmness during the first 14 days of storage, and declined slightly during the last 7 days of storage. The sudden firmness loss during the first 14 days reflects the large amount of water loss at high storage temperature and the delay in firmness loss during the last 7 days of storage indicated that the texture becomes dry and mealy due to low cell- to- cell adhesion (Harker & Hallet, 1992). Nashi stored at 20°C have a greater percentage of firmness loss -more than 70% - for both measuring instruments, while at 0°C storage the crushing strength and penetrometer readings showed a gradual decrease with storage time. Peleg, (1993) stated that it is well known that fruit firmness drops progressively with time, and that in cold temperatures the firmness reduction is slower, but faster at room temperature. Although the crushing strength and penetrometer readings show an almost similar pattern of firmness loss for all storage temperatures, the Massey Twist Tester has the highest correlation coefficient at all storage tempeartures as shown in **Table** - 5.2. It showed that Twist Tester is performed well in assessing the state of the fruits in any condition, it is more sensitive to any changes in textural properties of the fruit and vegetable. Twist Tester is more reliable for determining the freshness and maturity of nashi and other fruit.

5.3.7 Kiwifruit

The result of crushing strength and penetrometer readings of kiwifruit at the different temperatures shows the greatest firmness loss as compared to the other products. The crushing strength showed a decrease of over 60% for all storage temperatures (30°C, 20°C and 0°C) and the penetrometer reading decreased up to 100% during storage temperatures of 30°C and 20°C. From **Table 5**, the correlation coefficient value of crushing strength and storage time for all storage temperatures was shown to be greater than the correlation coefficient and storage time of the penetrometer readings.

The result obtained for the firmness measurement of kiwifruit clearly indicated that the penetrometer was not able to detect the firmness of kiwifruit after 14 days of storage at 20 and 30°C as shown in **Figure** 4-11a and 11b. Therefore, the firmness changes could be described more accurately with the Massey Twist Tester than with the penetrometer -particularly for soft- tissue fruit such as ripe kiwifruit, there is no change of penetrometer firmness with time, while in fact softening still proceeds. In a study performed on the comparison of the firmness tester, mainly the puncture tests, the Twist Tester was found to be among the most accurate instruments for measuring kiwifruit firmness (Yuwana, 1991; Harker et al. 1996; Hopkirk et al. 1996). The rapid loss of kiwifruit firmness at 20 ^{0} C and 30 ^{0} C related to the process of tissue softening during early and later ripening stages of the fruit which is associated with reduction in cell to cell adhesion (Harker & Hallet, 1994). Further analysis showed that there are significantly differences of correlation and coefficient ($p \leq 0.05$) between the crushing strength and storage time than the penetrometer readings indicated, which is shown on **Table** 5.2. This result proved the previous findings that Twist Tester could be a more reliable method for determining kiwifruit maturity than the penetrometer (Voisey, 1977; Yuwana, 1991; Studman, 1995).

5.3.8 Potatoes

Storage losses of potatoes are often specified as weight and quality losses and are caused mainly by respiration, sprouting, dehydration, changes in chemical composition of the tuber or damage by extreme temperatures (Brook, et al., 1995; Es and Hartmans, 1987; Rastovski, 1987). The loss of water from potatoes during storage depends on three factors: permability of periderm (Villa & Bakker-Arkema, 1974), the freedom for water inside the tuber to transport outside, and the difference in vapor pressure inside the tuber and the storage atmosphere.

In tests on potatoes, average values of crushing strength and penetrometer readings were plotted against time for each storage temperature, as shown in **Figure** 4.12. At 30 ^{0} C, the crushing strength and penetrometer readings decreased more quickly in the first 15 days, and then more slower thereafter. This was probably due to the high level of water in fresh tubers, which can easily be lost to the atmosphere with a low vapour concentration.

At 2O and 0^0 C the average crushing strength and penetrometer readings both decreased at a slower rate. In all the three storage conditions, crushing strength decreased more than penetrometer readings with storage time.

Further analysis showed that the correlation coefficient of crushing strength is significantly higher ($p \leq 0.05$) than the penetrometer reading. Linear regression between crushing strength and storage time at 3 storage conditions gave r value = 0.93, O.72 and 0.85, whereas that between the penetrometer readings and storage time gave an r values of 0.59, 0.45 and 0.15. This suggests that Twist Tester could be more reliable than penetrometer for determining the standard of firmness of potatoes in any situation.

Generally, at 30C and 20C, both the penetrometer and the Twist Tester readings are highly correlated with the storage time. For Royal Gala 1, the two instruments have similar correlations. For the Pears, the penetrometer shows a higher degree of correlation with storage time than does the Twist Tester. For the rest (Braeburn, Royal Gala 2, Plums, Kiwi Fruit, Nashi and Potatoes), the Twist Tester shows a higher correlation than does the penetrometer. At OC, the Twist Tester almost always shows a higher degree of correlation with storage time than does the penetrometer (the one exception being Pears). The correlation of crushing strength and penetrometer readings with storage time was weaker, and this was due to the small changes in the textural properties of fruit at low temperature. It might be said that the instrument with the high percentage of change over time was the one with the strongest correlation, which was showed by the Twist Tester.

On a statistical basis, this study supported the findings by Yawana (1991); Studman, (1992, 1993,1995); and Hopkirk et al., (1996) that the twist test proved to be more reliable when used to assess the maturity of kiwifruit. As shown in these results, the Twist Tester performed better than the penetrometer not only in kiwifruit but also in apples, plums, nashi, pears and potatoes. The Twist Tester is able to detect the small changes in soft tissue of fruits which the penetrometer could not detect.

In reality, the Twist Tester can be used as a means of identifying the state of fruit and vegetables to meet the needs of both producers and consumers.

5.4 SENSORY ASSESSMENT

Firmness has been used for assessing fruit maturity, storage behaviour and quality for many years. In this study the Massey Twist Tester and Penetrometer have been found to be capable of detecting the changes in the physical properties of fruit and vegetables.

Mechanical methods used to assess the texture of fruit and vegetables may not accurately reflect the responses of the human sensor. However, the suitability of a textural measurement is gauged by how well it correlates with the human senses (Szczesniak, 1966), and its ability to detect and quantify texture parameters.

The correlation between sensory tests and mechanical tests were often poor. A possible cause may have been variability in sensory evaluations from week to week. In order to test this hypothesis, the data for selected samples were normalised between weeks for selected samples as in **Table** 5.5. Normalising process was as follows:-

The data set was examined for a sample set displaying little change in mechanical test results 0^0 C, the lowest temperature of storage. The sensory values were then adjusted by scaling so that the same average values were obtained for all weeks for the sensory values at 0^0 C. Data for other temperatures were then scaled accordingly. As a result of this normalisation, the Regression coefficients for all the tests changed. However, the correlations were similar to those obtained before normalising (and in some cases they were lower), indicating that normalising did not prove the reliability of the sensory data in any recognisable fashion.

		Before normalising				After normalisng			
Fruit	Devices	Juicenes	Firmness	Crispnes	Mealines	Juicenes	Firmness	Crispnes	Mealines
Plum	Penetro	-0.04	0.81	0.80	-0.29	0.001	0.79	0.80	0.19
	T/Tester	0.11	0.74	0.73	0.52	0.03	0.69	0.71	0.36
Kiwifruit	Penetro	0.11	0.22	0.37	-0.38	0.18	0.40	-0.17	-0.38
	T/Tester	-0.17	0.34	0.54	-0.35	0.14	0.27	-0.10	-0.20
Nashi	Penetro	0.59	0.66	0.65	-0.42	0.60	0.63	0.59	-0.47
	T/Tester	0.60	0.62	0.64	-0.36	0.59	0.60	0.59	-0.47
Pear	Penetro	0.59	0.59	0.49	-0.52	0.63	0.64	0.69	-0.51
	T/Tester	0.52	0.55	0.37	-0.38	0.63	0.64	0.60	-0.40
Braeburn	Penetro	0.37	0.41	0.33	-0.32				
	T/Tester	0.28	0.42	0.40	-0.50				

Table 5.5 Coefficient and Correlation of mechanical test and sensory assessment.

As shown on **Table** 5.5 , the correlations between the mechanical tests and sensory measures come up with some composite indices which describe the main variations in the sensory quality of various fruit over time.

For plums, both the Twist Tester and the penetrometer show high correlation for firmness and crispness, while juiciness and mealiness have show poor correlation.

Instrumental measures of juiciness, firmness and mealiness, were weakly correlated while the Twist Tester showed slightly better correlation with crispness at r = 0.5. Nashi showed better correlation between instrumental measures and sensory attributes of juiciness, firmness and crispness while mealiness showed a poor relationship.

The sensory attributes of pears showed a good correlation between the Twist Tester and the penetrometer after normalising, as shown in **Table** 5.5, while the sensory evaluations of apples showed a weaker relationship with instrumental measures.

5.5. EFFECT OF SPEED ON CRUSHING STRENGTH

The 5 speed used to test carrots and Braeburn apples showed a small increase in crushing strength when the speed was higher. Further analysis showed that there is no significant effect of the speeds on the two products. It was clear that speed had a minor or no effect over the range considered. In particular the least variation in speed appeared to be at rates between 5 and 10 rpm, as shown on **Figure** 4-13, where there was virtually no increase in crushing strength value for either products.

5.6 LIMITATIONS TO VALIDITY OF SENSORY TESTS

Due to financial limitations, there was no qualified taste panel for sensory assessment. The sensory assessments were conducted by only two persons, which may have affected the accuracy and reliability of the assessment when comparing them to mechanical testing.

CHAPTER SIX – CONCLUSION

The main aim of this study was to evaluate the performance of the Massey twist tester for the textural assessment of fruit and vegetables. Research carried out was focused mainly on the firmness testing of fruit and vegetables at different storage conditions, by using the twist tester, penetrometer and texture analyser, then comparing the results. The conclusions from this study are:

Temperature is known to affect the firmness of a wide range of fruit and vegetables. The products stored at higher temperature conditions show a higher percentage drop in firmness than products stored under low temperature conditions.

The results obtained from the twist tester correlated more highly with storage of Braeburn and Royal Gala apples, compared with the penetrometer readings. They showed also stronger correlation with the results obtained form the texture analyser for Royal Gala, than the penetrometer. This suggests that Massey Twist Tester was more reliable for determining the state of apple maturity.

The modulus of elasticity and fracture strength values were both decreased by temperature and storage time, and dropped more rapidly in higher temperatures than in low temperature.

Comparing the Massey twist tester with the penetrometer for testing plums, showed that the twist tester has better correlation with storage time than do penetrometer readings, suggesting that this test is more reliable as a means of assessing the maturity of plums.

Pear measurement produced readings, which were different from those of other fruit in that, over the last few days of storage the firmness value increased. Although the Penetrometer showed a slightly higher degree of correlation with storage time than the twist tester, it is argued that an excess loss of water from the pear makes the texture become firmer. Further research work needs to be done to prove this result.

Nashi declined its crushing strength and penetrometer readings with storage time. They showed a similar pattern of firmness loss for all storage temperatures, and the twist tester readings were more highly correlated with storage time at all temperatures compared to those of the penetrometer, suggesting that twist tester is suitable for use in predicting the state and maturity of nashi.

Kiwifruit that were softening rapidly and 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. The twist tester result were significantly more highly correlated with storage time for kiwifruit than where those from the penetrometer. It can detect the changes in soft tissue while the penetrometer could not detect any changes when the fruit soft. So the Massey twist tester could be used as a means predicting the maturity not only of kiwifuit but of other soft fruit also.

The twist test results are more highly correlated with storage time for potatoes, compared with penetrometer readings. This suggests that the twist test is more reliable than penetrometer for determining the state of potato.

The twist test is a reliable method which can be used to test almost all fruit and vegetables. It may be used to test any sort of texture, even a very soft tissue which other instrumental devices could not test. Massey twist tester is easy to operate, fast and much more accurate compared with the penetrometer.

Sensory assessment relationship with instrumental measures was poor. Only two attributes, firmness and crispness of plums and Nashis correlated highly with results obtained from both the twist tester and the penetrometer, and the pear was slightly better, while the other sensory attributes were very weak. This suggests that the twist tester and penetrometer can be used to predict the firmness and crispness of fruit and vegetables, but further research work needs to be done to improve this result.

For testing the effect of speed on the crushing strength of the products, further analysis showed that there is no significant effect of speed on the crushing strength of fruit and vegetables in the range 5 – 10 rpm.

FURTHER RESEARCH SUGGESTIONS

Further research needs to be done to extend this research. This study showed that the characteristics of pears were different from those of other fruits when stored. It would be worthwhile to repeat the same test to improve the results. Secondly, the results from sensory assessment and mechanical testing could be more accurate and improved by using well –trained taste panels.

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