FACTORS AFFECTING THE REPLACEMENT OF WOODEN HARVESTING BINS WITH PLASTIC EQUIVALENTS FOR THE NEW ZEALAND KIWIFRUIT INDUSTRY

A thesis submitted in partial fulfilment

of the requirements for the degree of

Masters in Engineering

in Materials and Process Engineering

at

The University of Waikato

by

Harmandeep Jaura

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

Hamilton, New Zealand

July, 2010

Dedication

This thesis is dedicated to my family and friends for their continuous encouragement and support on this long journey.

Abstract

The New Zealand Kiwifruit Industry is one of the biggest in the world. New Zealand grown kiwifruit is exported to more than 60 countries with Europe, Japan, Asia and U.S being the major markets. Currently, wooden bins are used for picking, handling and storing kiwifruit. Horticulture industries in many countries including the U.S, Europe, and Australia started using plastic harvesting bins over 40 years ago due to additional benefits of using plastic. However, this technology is still not put into practice in New Zealand mainly due to wood availability, familiarity with wooden bins and lack of knowledge reflecting the benefits of plastic harvesting bins.

In this study, physical damage to kiwifruit in contact to different types of wooden and plastic harvesting bins was quantified and compared. The objective of the research was to indentify various physical damage mechanisms to kiwifruit and their relative significance during harvesting and storage. Mechanical damage was simulated as compression, abrasion and impact tests, conducted under laboratory conditions.

The main finding of this research was that contact with wooden surfaces caused a significant amount of visible damage to kiwifruit, more so than any plastic surface. In terms of venting, 10mm vents in plastic showed least amount of damage. Compression on 10 mm plastic vents resulted in only 10 % fruit rejection , which was the minimum among all tests under ambient and coolstorage conditions. Almost all tests with wood resulted in 100% fruit rejection; this means that the whole bottom layered fruit would be rejected from a wooden bin.

No significant differences were observed in percentage mass loss of fruit compressed on different wooden surfaces for both 10 and 25N firmness fruit under ambient and coolstorage conditions. This suggested that for wood, having flat or vented surface does not make a difference in percentage mass loss.

It was found that impacting fruit on wooden and flat plastic surfaces caused about 30% fruit bruising, however, no bruising was observed in fruit impacted on vented plastic surfaces.

It can be concluded that plastic bins are superior to wooden bins due to less fruit wastage and bruising. The research established that the initial investment of replacing a wooden harvesting with a plastic bin can be recovered within first 5 years. In addition, plastic bin would recover more than its cost by savings on less fruit rejection.

Acknowledgements

I would like to thank my supervisor, Dr.Johan Verbeek, for his endless guidance and support throughout the course of this project. He has been a real motivation all along the way.

Viscount Plastics for employing me to do this work and funding the research.

Natalie Hilterman from Viscount Plastics for sharing her experiences with me and also for guiding and inspiring me.

I would also like to thank Frank Bollen from Zespri International Limited who freely shared his experience and knowledge with me. Thank you, Frank for giving me valuable advice.

The University of Waikato staff for every help with equipment to any guidance with the project.

Thank you Gurpreet, my sister, for supporting me through regular phone calls and emails, thanks for everything.

I would also like to thank my brother, Jagmohan Singh Jaura, for giving my encouragement and support at difficult times.

And finally, I would like to thank my family and friends for their help and support at all times, without them I won’t be what I am today.

Contents

Dedication ii
Abstract iii
Acknowledgements v
Acknowledgements v
Contents vi
List of Figures ix
List of Tables xiii
Glossary xiv
Chapter 1: Introduction 1
Chapter 2: Kiwifruit Production, Rejection and Causes of Rejection 4
2.1 New Zealand Kiwifruit Industry 4
  2.1.1 Kiwifruit 4
  2.1.2 Role of Zespri 5
  2.1.3 Life Cycle of Kiwifruit Bins 6
2.2 Kiwifruit Production in NZ 7
  2.2.1 Orchard Operations 8
    2.2.1.1 Picking 8
    2.2.1.2 Drop Off/Pick up 9
  2.2.2 Packhouse Operations 10
    2.2.2.1 Canopy Storage 10
    2.2.2.2 Bin Tipping 11
    2.2.2.3 Grading 12
    2.2.2.4 Cool-Storage 13
    2.2.2.5 Controlled Atmosphere 14
2.3 Kiwifruit Waste and Rejection 14
  2.3.1 Criteria for Fruit Damage 15
  2.3.2 Reject Fruit Analysis 21
  2.3.4 Kiwifruit Production and Rejection Statistics 23
2.4 Role of Harvesting Bins in Fruit Quality 25

2.4.1 Plastic bins 27
2.4.2 Advantages of Plastic Bins 28
Chapter 3: Characterization of Physical Damage 30
3.1 Introduction 30
3.2 Classification of Mechanical Injury 31
3.3 Identification of Mechanical Injury 32
3.3.1 Compression Damage 34
3.3.2 Vibration Damage 36
3.3.3 Impact Damage 37
3.3.4 Abrasion Damage 39
Chapter 4: Experimental Work 40
4.1 Materials Used 40
4.1.1 Fruit 40
4.1.2 Bin Material 40
4.2 Analysis of Physical Damage 41
4.2.1 Visible Symptoms of Damage 41
4.2.2 Assessment Criteria 42
4.2.2.1 Measurement of Flesh Firmness 42
4.2.2.2 Measurement of Percentage Mass Loss 42
4.2.2.3 Measurements of Percentage Deformation 43
4.2.2.4 Measurement of Percentage Bruised Area and Compressed Area 43
4.2.2.5 Criteria for Visible Damage Rejection 44
4.3 Experimental Design 44
4.3.1 Compression Damage 44
4.3.2 Impact Damage 46
4.3.3 Abrasion Damage 48
4.3.4 Moisture Uptake 49
4.3.5 Accelerated Transport Damage 50
Chapter 5: Results and Discussion 51
5.1 Preliminary Experiments 51
5.1.1 Moisture Content of Wood 51
5.1.2 Accelerated Transportation Damage 54

5.1.3 Abrasion Damage..55
5.2 Damage Caused by Wood or Plastic Surfaces...56
5.2.1 Compression Damage..57
5.2.1.1 Green Kiwifruit..57
5.2.1.2 Gold Kiwifruit..70
5.2.2 Impact Damage...83
5.2.2.1 Green Kiwifruit..83
5.2.2.2 Gold Kiwifruit..83
5.3 Economic Analysis..87
Chapter 6: Conclusions and Recommendations...91
References...93

List of Figures

Figure 2.1: The two types of kiwifruit (left) A. deliciosa 'Hayward', (right) *A. chinensis 'HORT 16'* 5

Figure 2.2: Lifecycle of kiwifruit bins 6

Figure 2.3: Block flow diagram of the kiwifruit production process in New Zealand 7

Figure 2.4: Kiwifruit being emptied by pickers from picking bags into wooden harvesting bins 8

Figure 2.5: Bin tractor and trailer 9

Figure 2.6: Pick up or drop off point in a kiwifruit orchard....9

Figure 2.7: Kiwifruit wooden bins being loaded onto a truck to be transported to a packhouse 10

Figure 2.8: Schematic organization of a typical kiwifruit packhouse....11

Figure 2.9: Bin tipping (tipper and bin being tipped onto a conveyor belt) 11

Figure 2.10: Black flow diagram of the kiwifruit bin tipping process....12

Figure 2.11: Grading table 13

Figure 2.12: Flat kiwifruit....16

Figure 2.13: Dropped shoulder defect....16

Figure 2.14: Blemishes on fruit skin....17

Figure 2.15: Hayward mark on the gold variety 17

Figure 2.16: Flesh damage on gold variety....18

Figure 2.17: Superficial damage on gold fruit 18

Figure 2.18: Bin and pressure marks in gold and green varieties 19

Figure.2.19: Dehydration damage in green kiwifruit....19

Figure 2.20: Botrytis rot in green kiwifruit....20

Figure 2.21: Pitting damage on kiwifruit 20

Figure 2.22: Nally Megabin manufactured by Viscount Australia is used widely in the Australian horticulture market and a wooden harvesting bin used in New Zealand. 27

Figure 2.23: An isometric view of the proposed plastic bins to match the needs of the New Zealand Industry [43]....28

Figure 3.1: Breakdown of physical damage to kiwifruit....31

Figure 3.2: Water soaking of the flesh indicating vibration injury on kiwifruit....37

Figure 3.3: Impact damage in kiwifruit. 39

Figure 3.4: Rough surfaces of wooden bins....39

Figure 4.1: Materials used in testing....41

Figure 4.2: Projected bruised area 43

Figure 4.3: Projected compressed area on kiwifruit 44

Figure 4.4: Summary of compression tests....45

Figure 4.5: Compression test set up....45

Figure 4.6: Summary of impact tests 46

Figure 4.7: Schematic of the pendulum apparatus used for impacting kiwifruit in early experiments....47

Figure 4.8: Nally Megabin manufactured by Viscount Australia is used widely in the Australian horticulture market and a wooden harvesting bin used in New Zealand. 47

Figure 4:9: Schematic of fruit drooping in bins....48

Figure 4.10: Abrasion tool used for scuffing fruit 48

Figure 4.11: Surface Profilometer....49

Figure 4.12: Summary of Moisture uptake experiments 50

Figure 4.13: Orbital shaker 50

Figure 5.1: Percentage mass loss of green and gold kiwifruit on wooden boards with different moisture content....52

Figure 5.2: Average firmness of green and gold kiwifruit on wooden boards with different moisture content....52

Figure 5.3: Percentage deformation of green and gold kiwifruit on wooden boards with different moisture content 53

Figure 5.4: Visible damage **o**f green and gold kiwifruit on wooden boards with different moisture content. 53

Figure 5.5: Fruit following accelerated transport damage in small laboratory scale wooden and plastic bin...54

Figure 5.6: Visible damage in gold and green kiwifruit after abrasion tests 55

Figure 5.7: Damage to green kiwifruit measured directly after two days of compression under ambient conditions. A: % mass loss; B % deformation; C: % rejected fruit; D: % compressed area. 60

Figure 5.8: Visible damage to 10 N firmness green kiwifruit observed directly after two days of compression under ambient conditions for wood and plastic surfaces. 61

Figure 5.9: Visible damage to 25 N firmness green kiwifruit observed directly after two days of compression under ambient conditions for wood and plastic surfaces. 62

Figure 5.10: Damage to green kiwifruit measured after a 30 day holding period preceded by two days of compression under ambient storage. A: average firmness; B % bruised fruit; C: % bruised area 63

Figure 5.11: Bruise damage in green kiwifruit after a 30 day holding period preceded by two day compression under ambient conditions. 63

Figure 5.12: Damage to green kiwifruit measured directly after a 30 day compression under coolstorage conditions. A: % mass loss; B % deformation; C: % rejected fruit; D: % compressed area.. 66

Figure 5.13: Visible damage to 10 N firmness green kiwifruit observed directly after 30 days compression under coolstorage conditions for wood and plastic surfaces. 67

Figure 5.14: Visible damage to 25 N firmness green kiwifruit observed directly after 30 days compression under coolstorage conditions for wood and plastic surfaces. 68

Figure 5.15: Damage to green kiwifruit measured after a 30 day holding period preceded by 30 days of compression under cool storage. A: average firmness; B % bruised fruit; C: % bruised area 69

Figure 5.16: Damage to gold kiwifruit measured directly after two days of compression under ambient conditions. A: % mass loss; B % deformation; C: % rejected fruit; D: % compressed area.. 72

Figure 5.17: Visible damage to 10 N firmness gold kiwifruit observed directly after two days of compression under ambient conditions for wood and plastic surfaces 73

Figure 5.18: Visible damage to 25 N firmness gold kiwifruit observed directly after two days of compression under ambient conditions for wood and plastic surfaces. 74

Figure 5.19: Damage to gold kiwifruit measured after a 30 day holding period preceded by two days of compression under ambient conditions. A: average firmness; B % bruised fruit; C: % bruised area.. 75

Figure 5.20: Bruise damage in gold kiwifruit after a 30 day holding period preceded by two day ambient compression 75

Figure 5.21: Damage to gold kiwifruit measured directly after a 30 day compression under coolstorage. A: % mass loss; B % deformation; C: % rejected fruit; D: % compressed area. 78

Figure 5.22: Visible damage to 10 N firmness gold kiwifruit observed directly after 30 days of compression under coolstorage conditions for wood and plastic surfaces. 79

Figure 5.23: Visible damage to 25 N firmness gold kiwifruit observed directly after 30 days of compression under coolstorage conditions for wood and plastic surfaces. 80

Figure 5.24: Damage to gold kiwifruit measured after a 30 day holding period preceded by 30 days of compression under cool storage. A: average firmness; B % bruised fruit; C: % bruised area.. 81

Figure 5.25: Average firmness, percentage bruised fruit of 10 and 25N Green kiwifruit following impacts tests...85

Figure 5.26: Impact bruises in green kiwifruit..85

Figure 5.27: Average firmness, percentage bruised fruit of 10 and 25N Gold kiwifruit following impacts tests..86

Figure 5.28: Impact bruises in gold kiwifruit 86

List of Tables

Table 2.1: Sample reject analysis sheet 22

Table 2.2: New Zealand kiwifruit production from 1971 to 1986 23

Table 2.3: Kiwifruit production over a three year period for two kiwifruit packhouses, percentages are presented individually for green and gold variety. .24

Table 2.4: Kiwifruit waste over a period of 3 years for packhouse 1 and 2 25

Table 2.5: Comparison of wooden and plastic bin properties 26

Table 5.1: Summary of parameters for assessing economic benefit 87

Table 5.2: Summary of payback periods for different bin options........................89

Glossary

CA: controlled atmosphere

Chapter 1: Introduction

"The greatest service which can be rendered any country is to add a useful plant to its culture...One such service of this kind rendered to a nation is worth more to them than all the victories of the most splendid pages of their history, and becomes a source of exalted pleasure to those who have been instrumental in it" [1].

Thomas Jefferson, c.1800

Harvesting bins are used by packers and growers in the horticulture industries worldwide for picking, transporting and storing fruit. Wood has been the primary choice for making harvesting bins in many countries including New Zealand, primarily from a historical point of view. Apart from familiarity with using wooden bins, other major benefits of using wood include low cost and easy availability.

Kiwifruit was first grown in Wanganui, New Zealand in the early 1930s as a world first [2]. Today, kiwifruit are harvested in many parts of the world such as Australia, Europe, New Zealand and U.S. However, with commercialization came new challenges of improving the traditional harvesting techniques to minimize fruit rejections in order to keep up with increasing fruit demand and to maintain good industry standards. Reject/waste kiwifruit is fruit that is not sold in local or export markets because they do not meet required standards [3]. Standards are high for export fruit; however, damage on fruit skin which does not affect fruit appearance is acceptable for local markets. Standards and various kinds of damage will be discussed in Chapter 2. A study carried out by Scion in 2008 estimated fruit rejection to be between 16 to18 % of total kiwifruit harvested in the Bay of Plenty region, where 86% of the total NZ kiwifruit is harvested [3]. Another source suggested that general rejection rates are between 15% to 35% for gold and 10% to 20% for green kiwifruit [4]. 95% of the rejected fruit is given away to farmers as supplement for animal fodder at a negligible cost of 0 - $10 per tonne [3].

It has been suggested that wooden harvesting bins are playing a major role in fruit rejection. Major drawbacks of wooden bins are:

- **Hygiene Risk (Absorption of chemicals and moisture):** the porous nature of wood makes sanitization difficult. Wood can absorb moisture from fruit and chemicals used in harvesting processes. Moisture absorption from fruit by wood could result in fruit rejection due to dehydration. A clean looking wooden bin used over many packing seasons could harbor harmful bacteria and germs which could prove detrimental to fruit quality. However, no such research has been conducted to date, which studies the effect of the porous nature of wood on products contained within.

- **Abrasive surface:** Surfaces of wooden bins are splintery, uneven and rough. Abrasion (wear) damage from wooden bins includes damage from nails, rough wooden surfaces with splinters scuffing fruit. This can result in significant loss by lowering fruit quality, fruit rejection and monetary loss.

- **Bin deflection/flexure:** Due to the porosity of wooden bins they can absorb moisture and swell. When the bin is full of fruit shape of the bin can suffer uncontrolled distortion due to the swelling of wood.

International harvesting industries identified these issues with wooden bins much earlier on and began searching for a better material for fresh fruit and vegetable harvesting and storage. For example, research regarding plastic harvesting bins used by the Apple Industry started in 1992 [5]. Alan F. Hauff concluded that despite wooden bins being an industry standard since 1957, plastic bins have advantages over wooden bins [6]. This work also explored the fact that collapsible plastic harvesting bins are suitable for both long-term fruit storage and transport to the local fruit markets.

Literature suggested that countries such as Europe, Australia, and U.S switched to using injection molded plastic bins because of their ability to preserve fruit quality better [5]. In Europe, plastic harvesting bins have been used for more than 40 years [5].

Issues with wooden bins have probably been overlooked for all these years in New Zealand Industry due to fact that wood has been seen as an easy option due to its availability. In order to cope with the increasing kiwifruit demand and higher fruit rejection rates, the New Zealand Kiwifruit Industry has began to realize the need for a better bin material that can preserve the fruit quality, minimize fruit rejection rate, offer higher resistance against environmental factors and provide better sanitation.

Internationally, research has shown plastic bins to be significantly better at maintaining fruit quality compared to wooden bins [5; 7-12]. However no research has been conducted in New Zealand to examine kiwifruit behavior in wooden and plastic bins. This project will examine the use of plastic harvesting bins for the New Zealand Kiwifruit Industry with an aim of replacing traditional wooden bins. In order to replace wooden bins with plastic equivalents, fruit damage has to be characterized and quantified to facilitate the design and manufacture of plastic bins. More specifically the objectives of this study were:

- To investigate the available literature exploring the advantages and disadvantages of wooden and plastic bins in other industries.
- To identify and characterize mechanical damage mechanisms.
- To quantify the relative damage in wooden and plastic bins.
- To assess the economic feasibility of changing to plastic harvesting bins.

This work has been based entirely on tests conducted on New Zealand grown kiwifruit. Kiwifruit representative of mid and late season firmness were tested.

Chapter 2: Kiwifruit Production, Rejection and Causes of Rejection

2.1 New Zealand Kiwifruit Industry

New Zealand is the third biggest kiwifruit producer in the world after China and Italy, producing 21% of the world's kiwifruit [13]. New Zealand kiwifruit is exported to over 60 countries and is the largest export crop, earning around $720 million (FOBs) in March 2005 [13; 14]. Approximately 93.2 million trays of kiwifruit are exported to the world market annually [13]. In 2009, New Zealand kiwifruit exports amounted to 64.4% of the total fruit and nut export [13]. As kiwifruit are now grown in many parts of the world, competition within the world markets for kiwifruit sales is increasing [14]. In order for the New Zealand Kiwifruit Industry to maintain a solid position in the world kiwifruit market, it must take measures to meet the growing demands of the export market and reduce fruit wastes. A better understanding of kiwifruit harvesting processes in New Zealand is required.

2.1.1 Kiwifruit

The kiwifruit is one of about 60 species of the genus *Actinidia* [2]. It is a berry fruit with thousands of small dark seeds embedded in soft juicy flesh [2] . Kiwifruit are grown in many countries such as Europe, U.S, New Zealand, Chile, South Africa, Italy, Greece, France, Australia and Japan. Kiwifruit was first commercialized in New Zealand and now has developed into the most important export horticultural crop [15]. The two main kiwifruit varieties of commerce in New Zealand are green 'Hayward' (Actinidia deliciosa) and gold 'HORT 16' (Actinidia chinesis) as shown in Fig.2.1 [2]. Gold kiwifruit are hairless and have yellow flesh while green kiwifruit have fuzzy brown hair and green flesh. Green variety has a tangy taste whereas gold is sweet.

Figure 2.1: The two types of kiwifruit (left) A. deliciosa ‘Hayward’, (right) *A. chinensis ‘HORT 16’*

2.1.2 Role of Zespri

Zespri Group Ltd (formerly known as the New Zealand Kiwifruit Marketing Board) is the sole marketer and exporter of kiwifruit in New Zealand. The Zespri business and the Zespri brand are owned by the kiwifruit growers. Zespri is responsible for marketing almost all the export kiwifruit from New Zealand [15]. According to the latest records, Zespri has 3077 listed orchards and 2754 growers [13]. Standards on kiwifruit production in New Zealand are set by Zespri who audits all pack houses twice a year and are required to be adhered to by the growers [4]. They also provide growers with the information and tools for improving fruit quantity and producing high quality fruit. All the operations in various areas of kiwifruit production such as growing, packaging, storing and exporting are governed by Zespri regulations.

In order to create a consistent supply of kiwifruit internationally, Zespri has formed partnerships with growers around the world. Zespri kiwifruit is exported to more than 60 countries in the world with Europe, Japan, Asia and U.S being the major markets [13].

2.1.3 Life Cycle of Kiwifruit Bins

In NZ, bulk wooden bins, made from untreated timber, are used for picking, transporting and storing kiwifruit. When not in use, they are stored either outside, exposed to the harsh and variable New Zealand weather conditions or under cover [2; 16]. There are no particular industry standards about the shape of wooden bins. Therefore, packhouses basically construct wooden bins based on their understanding and requirements. Some packhouses use wooden bins with solid sides (no vents or gaps), believing that the absence of gaps avoid pressure points on the fruit. Most packhouses use wooden bins with air gaps/vents, however, significant variations can be found in vent dimensions ranging from 3 to10 mm.

Kiwifruit bins are used many times in a season. Figure 2.2 illustrates the journey of kiwifruit bins, starting from stage 1 when empty wooden bins are transported to kiwifruit orchards from pack houses.

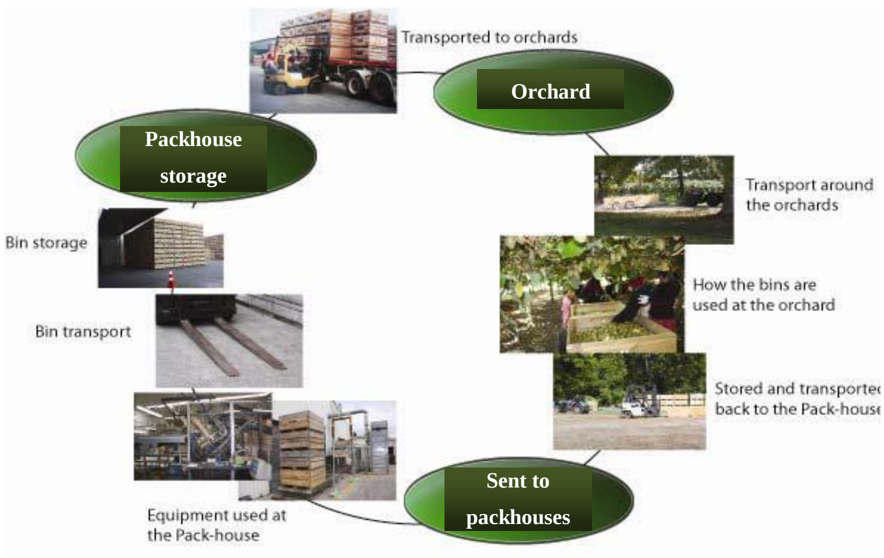


Figure 2.2: Lifecycle of kiwifruit bins [16]

After picking, full bins are sent back to the pack houses where fruit are graded and stored in coolstores or CA (controlled atmosphere) stores. Kiwifruit are in contact with harvesting bins for a significant time before reaching the consumer and this could influence fruit quality to a large extent. Stages in the harvesting process will be discussed in detail in Section 2.5.

2.2 Kiwifruit Production in NZ

The harvesting process used in the New Zealand Kiwifruit Industry is summarized in a simple block flow diagram, shown in Fig.2.3. Pickers work under supervision during picking and are given proper training ensuring that they do not put rotten or damaged fruit into bins which could affect neighboring fruit. Based on this, the majority of fruit leaving orchards are assumed free of mechanical injury. Initiation of physical damage can be expected to occur when kiwifruit come in contact with the bin surface i.e. from picking to bin tipping (between stages 1 & 2 in Fig. 2.3).

Damage during these stages would mostly comprise cuts, punctures, scuffs, bruising, and pressure marks. During these stages, changing to plastic bins could make a significant impact on reducing fruit rejections. Rejections from physical damage are considered in more detail in Section 2.3.4.

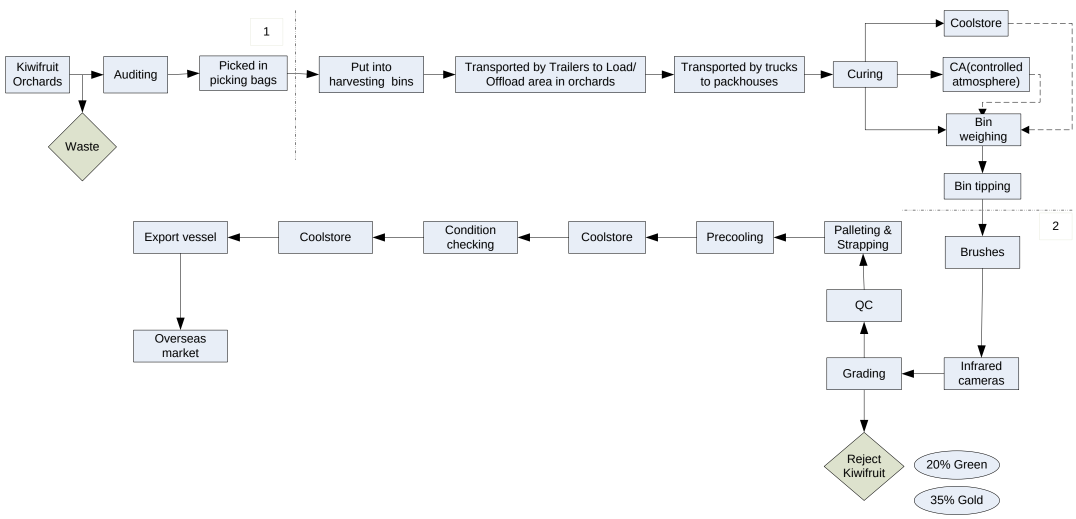


Figure 2.3: Block flow diagram of the kiwifruit production process in New Zealand [4].

2.2.1 Orchard Operations

Kiwifruit are harvested when they are unripe and firm but physiologically mature, and stored under refrigeration (0°C, 90-95% RH) before packaging and shipping [17]. Good quality kiwifruit can be maintained for 4-6 months [17]. Many factors such as flesh and core firmness, soluble solids concentration and flesh color are used to determine maturity. A soluble solids content of 6.2% is required in mature fruit and is widely used by the New Zealand Kiwifruit Industry [2].

2.2.1.1 Picking

As seen in Fig 2.4 kiwifruit are attached by a stalk to the vine. At harvest, fruit are snapped off with stalks left on the vine [2]. Kiwifruit are picked by pickers into apron style picking bags that normally hold about 20 kg of fruit and collected into wooden bins that usually hold about 250 kg of fruit [2]. Kiwifruit picking in NZ is done manually although mechanized harvesting methods are also being considered. High quality wooden bins are used for export fruit, slightly damaged bins are used for local/Australia fruit while damaged bins are used for stock fruit [4].

Pickers are expected to carefully handle fruit and are required to gently empty fruit from picking bags to bulk bins [2]. They are required to wear cotton gloves to avoid damage to fruit from fingernails. Any physical damage to fruit can result in a wound that could develop into a rot or fruit softening during post-harvest storage of fruit resulting in ethylene production and premature softening of the fruit [18; 19].

Figure 2.4: Kiwifruit being emptied by pickers from picking bags into wooden harvesting bins [16]

Following picking, bins full of fruit are loaded onto tractor trailers with the help of fork hoists and moved to the pick up/drop off sites.

Orchard roads are recommended to have smooth ground (Figure.2.5 and 2.6) in order to avoid mechanical damage from rough orchard roads. A study by Bollen et al showed that significantly higher levels of bruising was observed in apples on the base of a bin after transport over rough surfaces in orchards [20].

Figure 2.5: Bin tractor and trailer [16].

2.2.1.2 Drop Off/Pick up

A typical pick up/drop off point in a kiwifruit orchard is shown in Figure.2.6. The pickup/drop off points could either be open or under cover and bins could sit there for a few hours before they get picked up to be transported to the packhouses [16]. At the drop off/pick up points; labels are stapled onto full bins stating details such as, picking date, orchard number, consignment number and grower details.

Figure 2.6: Pick up or drop off point in a kiwifruit orchard [16].

2.2.2 Packhouse Operations

Kiwifruit bins are transported to the packhouses by truck or trailer, depending on the distance [2]. Figure 2.7 shows the loading of wooden harvesting bins onto trucks for transit to the kiwifruit packhouses. Bins are normally stacked 4 to 5 high on trucks [16].

Figure 2.7: Kiwifruit wooden bins being loaded onto a truck to be transported to a packhouse [16].

2.2.2.1 Canopy Storage

When full bins arrive at the packhouses they are kept in a canopy (a covered shed) for 24 to 48 hours. This process is known as curing and is done in order to cool fruit down as soon as possible after harvest to maintain a good storage life and quality [2]. The ideal ambient temperature for curing is less than 16°C [21]. If curing is not done there is a possibility of fruit weeping and leading to possible rot during storage. Ethylene production of wounded kiwifruit declines during curing as wounds are healed [21]. After curing, fruit bins are either taken straight to bin tipping or stored in controlled atmosphere (CA) rooms. Early season fruit are directly exported by conventional refrigerated shipping.

2.2.2.2 Bin Tipping

A schematic diagram of the general organization of a kiwifruit packhouse is shown in Fig.2.8. Bin tipping, as shown in Fig.2.9, is the process of empty harvesting bins on a roller conveyor system which takes fruit to grading tables. Each bin is weighed individually on an automatic weigh cell before tipping. A lid is automatically placed on the top of the bin. The bin is then lifted up and tipped on its side. The lid carefully opens to slowly release fruit out of the bin onto the roller conveyor. Empty bins are picked up by a fork-hoist or sent along to another conveyor to be re-stacked and stored to be washed later [16]. A block diagram of the bin tipping process is shown in Fig.2.10.

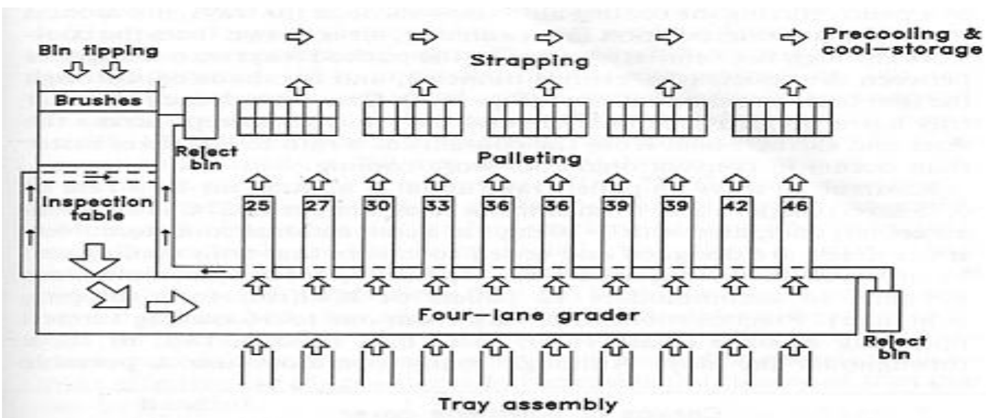


Figure 2.8: Schematic organization of a typical kiwifruit packhouse [2].

Figure 2.9: Bin tipping (tipper and bin being tipped onto a conveyor belt) [16].

As fruit enters the packing facility, they first go under a set of soft brushes for hair removal from the fruit skin. After brushing, fruits on the conveyor are scanned using infrared cameras to identify cosmetic defects. Infrared spectroscopy is a fast and non-destructive method used for detecting external as well internal properties of kiwifruit [22]. It is of commercial importance as applications of this technique can be used during in-line grading of kiwifruit [22]. Fruit with cosmetic defects i.e. blemishes or skin rub are automatically removed.

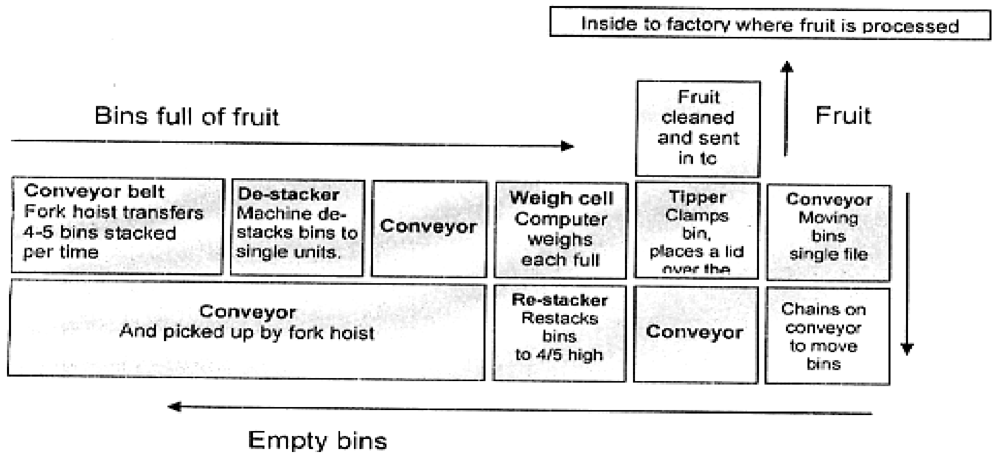


Figure 2.10: Block flow diagram of the kiwifruit bin tipping process [16]

2.2.2.3 Grading

Grading is critical in order to monitor the quality of fruit received by the packhouse and to ensure export of high quality fruit [2]. As seen in Fig 2.11, well trained graders stand on the sides of well lit conveyor belts and check the passing fruit. They remove fruit that are damaged in any way such as softs, blemishes, pressure marks and superficial damage.

Fruit are mechanically graded for size and placed into plastic pocket tray packs and wrapped with polyliner [2] The average total weight of fruit in a tray is 3.6kg [2]. The plastic pocket tray provides protection to fruit from mechanical damage and the polyliner reduces fruit dehydration by ensuring a localized high humidity inside the tray [2]

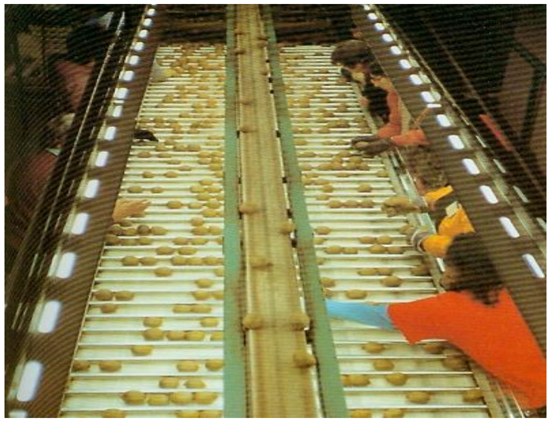


Figure 2.11: Grading table [2].

The packed trays are then placed onto pallets of about 174 trays and strapped tightly [2]. Once the fruit are packed into cartons and palletized, the pallets are precooled, stored and transported to the export market based on demand. Precooling is the rapid cooling of fruit before cool-storage, shipping or processing [2]

2.2.2.4 Cool-Storage

A cool-store is also known as a buffer store. The optimum storage requirements for cool-storage currently recognized by the NZ Kiwifruit Industry are [2; 17]:

- no ethylene in the surrounding air (ethylene gas scrubbers are used to maintain ethylene free atmosphere) [23],
- relative humidity of 90-95% in the air surrounding the fruit,
- fruit temperature of 0°C ±0.5°C.

With above storage conditions, a storage life of 4-6 months can be achieved depending on the cultivar and harvest maturity [2; 24; 25]. Bins are normally stacked on top of each other up to 14 bins high in cool stores [4]. Various studies on the storage softening of kiwifruit have reported the excessive softening of kiwifruit in coolstorage to be the major reason for postharvest quality loss [19; 24].

Softening in refrigerated storage at 0°C can limit the marketing period of kiwifruit resulting in huge economic loss [19]. Temperature is the main factor determining the post harvest storage quality of kiwifruit [2]. If coolstorage temperature is increased the rate of ripening, respiration, decay and moisture loss increases, resulting in the loss of storage life [2]. The harvesting firmness of Hayward and HORT16A varieties are between 60 -110 N and 40-50 N respectively[26]. Industry requires export fruit to have a flesh firmness of more than 10 N at the time it is shipped as fruit at 5 -8 N are ripe for eating and can reach an eatable state during shipping [2].

2.2.2.5 Controlled Atmosphere

Controlled atmosphere storage is used for bulk storage in wooden bins. This is done in order to extend the packing season [2]. Controlled atmosphere storage (CA) is a process where kiwifruit can be stored for several months after harvest under controlled conditions of temperature, oxygen and carbon dioxide [21]. CA storage has been proved to considerably decrease the rate of fruit softening and maintaining the fruit at an acceptable eating quality [2; 24; 27; 28].

The CA storage requirements vary for green and gold kiwifruit. For green, storage atmosphere containing 1.5-2.0% O_2 with 4.5-5.0% CO_2 are used. For gold, 1.2-2.0% O_2 with 1.5-2.0% CO_2 is considered best [2; 29]

2.3 Kiwifruit Waste and Rejection

Waste or reject kiwifruit can be defined as fruit rejected at the packhouses during various stages of inspection and packaging. A recent study carried out by Scion suggested that 16–18 % of the total kiwifruit production is rejected each year in New Zealand [30]. In addition, 95% of the waste kiwifruit is sold to farmers to be used as animal food at a minimum of 0 - $10 per ton [30]. In 2007 alone, 49920 tons of this vitamin packed kiwifruit was wasted [30]. According to a food waste study, kiwifruit wastes comprise 30% of the total kiwifruit production [31].

In order to understand some of the factors which could be responsible for the large kiwifruit waste, it is essential that the kiwifruit handling and production system be examined. Before kiwifruit get to the grading table they are in direct contact with the bin material during transit and storage. The New Zealand Kiwifruit Industry has always used wooden harvesting bins but increased kiwifruit production and rising waste rates have raised issues about wood as a bin material. Mechanical damage to kiwifruit from wooden bins is a cause of concern as it adversely influences the growers, the packhouses and most importantly the New Zealand economy.

Many countries already use plastic bins for apples and pears. Due to rising production and rejection numbers it is critical to review the bin material of the kiwifruit bins used in New Zealand.

2.3.1 Criteria for Fruit Damage

At pack houses, fruit are graded based on size and defects [2]. There are three classes of fruit, class 1(export fruit), class 2 (local fruit and some for the Australian market) and class 3 (reject fruit/animal food). Class 1 fruit is required to be of supreme quality and damage free. Slight damage is acceptable for local fruit. There are many reasons for fruit rejection such as surface damage, pest or disease infestation, flesh damage, superficial damage, flat fruit and non-pathogenic causes [2].

Major pest rots in kiwifruit have been found to be Botrytis, Botryosphaeria, Cryptosporiopsis and Phomopsis [32]. It must be noted that the focus of this work was on mechanical damage however, some other damages have also been discussed in this section. In the following section, various types of defects would be discussed.

1. **Flats:** A flat kiwifruit would have a greater width (diameter) than its length (Fig.2.13). For class 1 fruit, a ratio of 0.8 for max/min is acceptable. For class 2 fruit ratio of 0.7 for maximum/minimum is acceptable [32].

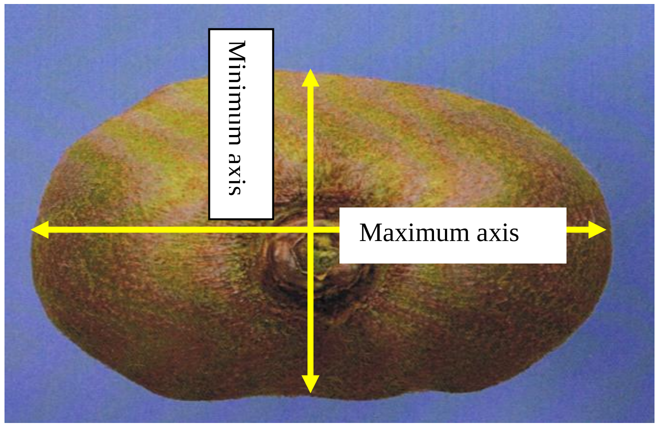


Figure 2.12: Flat kiwifruit [32].

2. **Dropped Shoulder:** When fruit shoulders are uneven. A sloped angle of 15° is considered the limit for the export market.

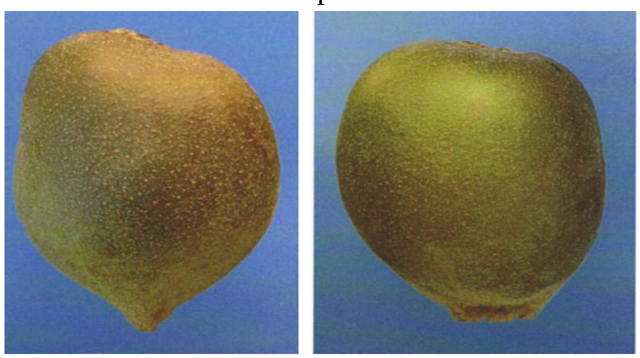


Figure 2.13: Dropped shoulder defect [32]

3. **Blemishes:** A mark or a scar on the fruit skin which could be due to healed physical damage, hail damage, healed fungal damage, skin rub or skin burn. For class 1, a blemish area ≤ 1 cm^2 is acceptable. For class 2, a blemish area ≤ 2 cm^2 is acceptable. For both classes, the scar must merge with fruit skin and should not affect the fruit appearance [32].

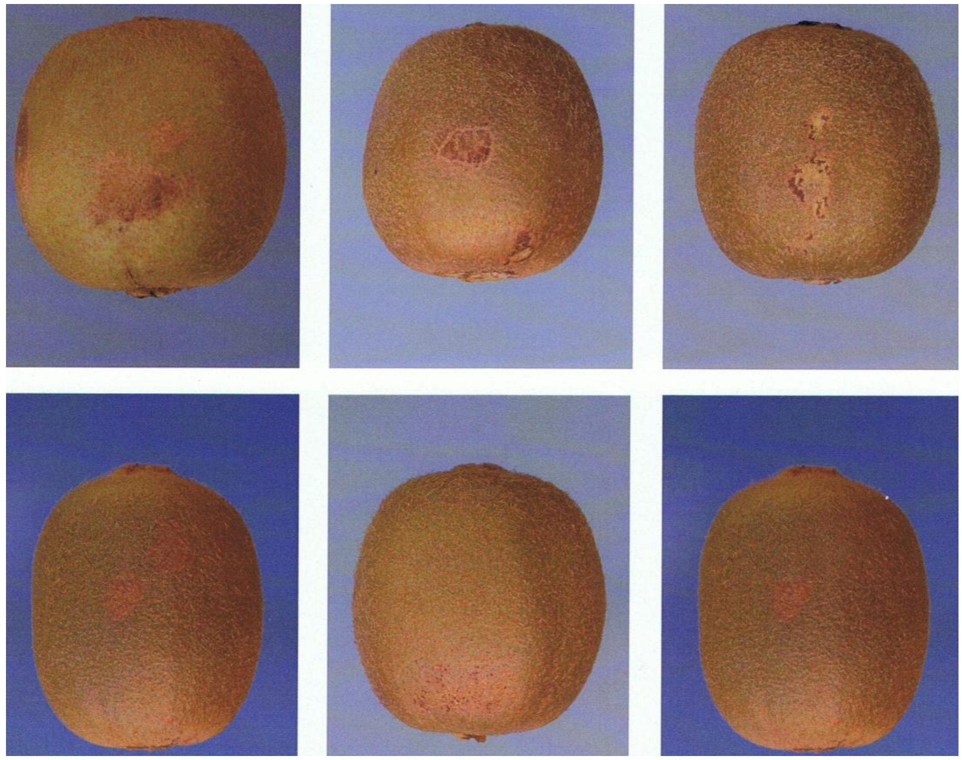


Figure 2.14: Blemishes on fruit skin [32].

4. **Hayward mark:** It is a line running down the side of a fruit which sometimes end as a beak or hook.

Figure 2.15: Hayward mark on the gold variety [32].

For class 1, fruits with one or two fine Hayward marks with no beaks are acceptable. Hayward beaks can cause cuts on neighboring fruits in bins.

5. **Flesh Damage:** Damage penetrating into the fruit skin. This type of damage could be due to cuts, broken beaks and punctures during or after harvest. Dry exposed flesh with diameter ≤ 1 mm is acceptable for both classes. Kiwifruit are highly susceptible to puncture damage late in the season when they have significantly lower firmnesses [33]

Figure 2.16: Flesh damage on gold variety [32].

6. **Superficial damage:** Surface damage which does not penetrate into fruit skin such as scuffing. For class 1 fruit, two superficial scuffs with ≤ 2mm diameter per scuff is acceptable. For class 2 fruit, two superficial scuffs with ≤ 4mm diameter per scuff is acceptable [32].

Figure 2.17: Superficial damage on gold fruit [32].

7. **Bin and pressure marks:** External visible damage due to fruit subjected to sustained pressure in a bin during storage. Pressure marks on kiwifruit can be visibly identified as bruising, indentation on fruit surface and compression.

For both classes, pressure marks which are not dark in color and not soft are acceptable. Pressure marks may soften over time and cause storage breakdown disorders.

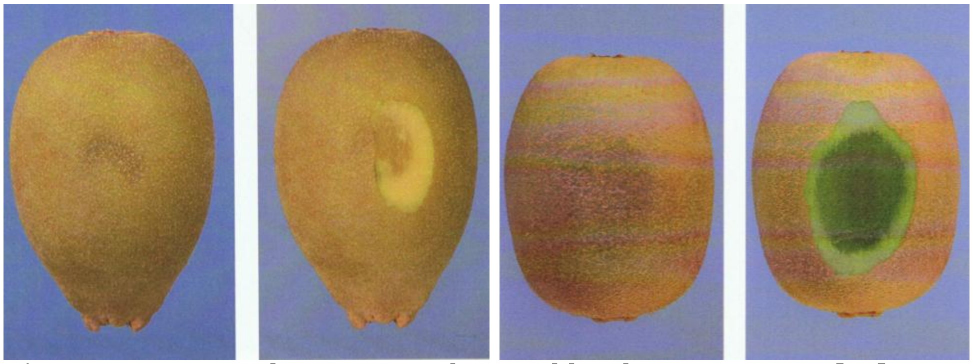


Figure 2.18: Bin and pressure marks in gold and green varieties [32].

8. **Dehydrated fruit:** Long term contact with wood could cause dehydration in fruit giving it spongy appearance. Visible shriveling becomes evident after as little as 4-6 weeks storage and is usually obvious after 3-4 % weight loss [2]. Dehydrated fruit are not allowed at all in both classes. Polyethylene liners are used in bins as wells plastic pocket trays to prevent fruit dehydration and to maintain high humidity [2].

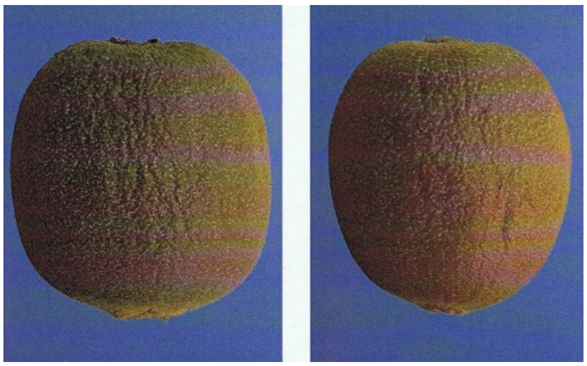


Figure.2.19: Dehydration damage in green kiwifruit [32].

9. **Botrytis rot:** it is a storage rot which develops at the stem end of the fruit [34]. The rotten area can easily be identified by its deep green color and could also develop from physical damage [32].

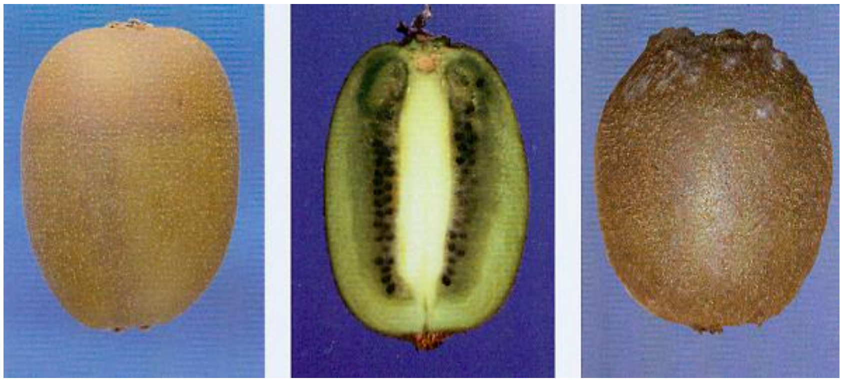


Figure 2.20: Botrytis rot in green kiwifruit [32].

10. **Softs :** Kiwifruit with any area/part softer than 10 Nis considered to be a soft and is not suitable for export [34]. A critical factor in determining the suitability of kiwifruit for export market and consumption is the flesh firmness [14]. According to the New Zealand Kiwifruit Industry standards export fruit flesh firmness levels must meet the export threshold value of 12 N [14; 35; 36].

11. **Pitting :** pinhead sized pits or small purple indentations on kiwifruit skin which altogether must not cover >1cm^2 area per fruit [34].

Figure 2.21: Pitting damage on kiwifruit [32].

2.3.2 Reject Fruit Analysis

Reject analysis is carried out by the quality control departments of pack houses to study the extent of each type of damage. A randomly selected sample of rejected fruit is analyzed individually and its rejection cause noted. Reject analysis is carried out every 2 hours whilst grading. A typical reject analysis sheet used by one of the kiwifruit pack houses is shown in Table.2.1 (numbers have been omitted).

Damage types are classed into different groups namely: blemish, shape, surface deposits and physical damage. In light of assessing damage due to contact with harvesting bins, only physically damaged fruit and some storage defects are relevant. Soft fruit and dehydration are mainly found in cool stored or CA stored fruit. Physically damaged fruit include:

- softs,
- cuts,
- pressure marks,
- broken Hayward,
- juicy and punctured fruit,
- storage defects include softs, dehydrated, juicy and pressure marked fruit

Table 2.1: Sample reject analysis sheet [29].

Grower:	Name:	Date from:	Class:				
Pack run:	**Matarea:**	**Grader:**	**Variety:**				
Packhouse:	**Date to:**	**Reject type:**	**Grow Method**				
Details	Count	Surface Deposit	Count	Physical damage	Count	Totals	Count
Blemish		**-dirt**		**-broken Hayward**		**Blemish**	
-skin rub		**-bird lime**		**-cuts**		**Shape**	
-water stain		**-juice**		**-scuffs**		**Surface deposit**	
-colour		**-sooty mould**		**-puncture**		**Marks**	
-sun burn				**-pressure marks**		**Pests**	
-healed insect		Marks				**Physical damage**	
-hail		**-proximity**		Storage defects		**Other**	
-fungal		**-Hayward**		**-bot rots**		**Storage defects**	
				-other rots			
Other		Pests		**-softs**		Total	
-undersize		**-scale**		**-storage stain**			
-export fruit		**-leaf roller**		**-pitting**			
		-fullers rose weevil		**-juice**			
		-other		**-dehydration**			

2.3.4 Kiwifruit Production and Rejection Statistics

A proportion of the NZ kiwifruit production is rejected each year mainly due to surface damage (surface blemishes) and incorrect size or shape as it fails to meet the specifications for the export quality fresh fruit [2]. Table 2.2 presents the New Zealand kiwifruit production from 1971 to 1986.

Table 2.2: New Zealand kiwifruit production from 1971 to 1986 [2]

Year	Total production	Exports		Available for domestic market	Used for making processed food
		No of trays	Tonnes		
	tonnes	x 10^3	tonnes	tones	tonnes
1971	2338	206	765	1573	-
1972	2799	264	978	1746	75
1973	3709	367	1359	2250	95
1974	5608	738	2734	2794	80
1975	4486	735	2724	1648	114
1976	6651	1387	5136	1364	151
1977	8044	1675	6204	1062	778
1978	9616	2158	7992	324	1300
1979	18650	4028	14919	1205	2526
1980	17965	4143	15285	712	1968
1981	28806	6214	22960	2992	2854
1982	25353	4668	17037	3765	4551
1983	48801	10541[2]	39041	n.a.	n.a.
1984	62500	13736[2]	49411	n.a.	n.a.
1985	108800	23520[3]	87037	9763	12000[4.6]
1986	146296	31600[5]	117037	15259	14000[6]

Since 1986 to 2007, production has increased to approximately 85 million trays. [37] With rising export demands, the New Zealand kiwifruit market has to find better technology to increase kiwifruit production. Along with an increase in production, the NZ Kiwifruit Industry has suffered from huge increases in fruit rejection mainly due to the postharvest handling of significantly higher volumes of fruit. In 1984, about 13,000 tonnes of kiwifruit were rejected rising to 74,000 tonnes 1992 [2]. The New Zealand Kiwifruit Industry suffered a loss of nearly $50m in the years 1989 - 1990 due to storage losses [34].

In addition to investigating kiwifruit production and rejection figures nationally a production and reject analysis at two packhouses was also conducted.

Table 2.3: Kiwifruit production over a three year period for two kiwifruit packhouses, percentages are presented individually for green and gold variety [29]. "-"means the particular variety of kiwifruit was not produced.

	2007			**2008**			**2009**		
Packhouse 1	Green (%)	Gold (%)	Total (tonnes)	Green (%)	Gold (%)	Total (tonnes)	Green (%)	Gold (%)	Total (tonnes)
	9.2	8.1	1157	12.35	16.09	1784	-	14.05	288
Packhouse 2	Green (%)	Gold (%)	Total (tonnes)	Green (%)	Gold (%)	Total (tonnes)	Green (%)	Gold (%)	Total (tonnes)
	9.05	-	1251	7.6	-	1443	10.05	-	2256

Over the 3 years considered, kiwifruit production from both packhouses has increased significantly (Table 2.3). Based on this information, it can be believed that production from other kiwifruit packhouses would also accelerate with time. For proprietary, actual names of packhouses 1 and 2 cannot be disclosed.

Table 2.4 shows the amount of kiwifruit waste from packhouses 1 and 2 respectively, where the fraction PDF (physically damaged fruit) is calculated based on total fruit rejected. Reject fruit analysis sheets, as seen in Table 2.1, were requested from 2 packhouses. Reject analysis sheets are not always preserved, and consequently

Packhouses 2 was only able to supply reject analysis sheets for 2007, 2008 and 2009, while packhouse 1 could only supply data for 2 growers in 2009.

Table 2.4: Kiwifruit waste over a period of 3 years for packhouse 1 and 2 [29].

	2007		2008		2009	
Pack House 2	reject fruit	% PDF	reject fruit	% PDF	reject fruit	% PDF
	292047	**6.45**	335422	**4.66**	19879	**4.71**
Pack House 1					reject fruit	% PDF
Grower 1					376	**24.5**
Grower 2					664	**18.2**

As suggested by Scion, with 16 -18% fruit rejection, packhouse 2 contributed about 1% to the total fruit rejection. Even though the NZ Kiwifruit Industry has been suffering from higher kiwifruit wastes in recent years, the issues with wooden bins have not been paid enough attention which could be the prime factor in increased fruit losses.

2.4 Role of Harvesting Bins in Fruit Quality

Wooden bins have been the Industry standard since 1957 because of their low cost and availability [5]. A typical wooden bin used in the New Zealand Kiwifruit Industry is seen in Figure 2.25. Wooden bins are of no standard shape or size and different packhouses use different footprints and heights based on their understanding gained over the years [2]. However, plastic bins would have a standard footprint, 1200 x 1200 x 510 mm, and a standard bin height customized for the New Zealand market [16].

U.S, Australian and European horticulture industry started using plastic bins more than 40 years ago due to additional benefits of using plastic and the demand for plastic bins has been increasing since [5]. According to a research conducted by Agriculture Victoria, fruit harvested and stored in plastic bins showed a reduction in chemical costs and less fruit waste [12].

A comparison of the properties and features of traditional wooden bins and plastic bins has been provided in Table 2.5.

Table 2.5: Comparison of wooden and plastic bin properties [6; 38; 39]

Wooden Bin	**Plastic Bin**
Absorption of chemicals	Non absorption of chemicals
Absorption of moisture	Non absorption of moisture
Porous i.e. poor sanitation	Non porous
Weathering	Resistant to weathering
Non-recyclable	Recyclable
Inadequate air circulation around	Better air circulation and less scald
Variable design	Standard Industry design
Non hygienic	Hygienic
Difficult to clean	Easy to clean
High maintenance cost	Low maintenance cost
Rough surface	Smoother surface
Cost ~$80	Cost ~$(150-250)
Life max 10 years	Life ~30 years
Capacity ~250kg	Capacity ~(300-350)kg
Weight between 53-68 kg	Weight <40kg
Nails and splinters	No nails, rust, paint chips and splinters

On the left in Figure 2.22 a Nally mega bin, widely used in the Australian horticulture is shown. On the right a typical wooden harvesting bin currently used in New Zealand, is shown.

Figure 2.22: Nally Megabin manufactured by Viscount Australia is used widely in the Australian horticulture market and a wooden harvesting bin used in New Zealand.

Injection molded plastic harvesting bins (single piece bin construction) are exploited world-wide by fruit and vegetable industries [9]. They are light weight, tough and are designed to reduce product waste [9; 40]. Plastics bins are made from recyclable polypropylene or HDPE plastic material and meet standards for food product handling [9].

Nally Megabin manufactured in Australia by Viscount Plastics is used extensively in the Australian markets. The Nally bin is food grade approved, fully recyclable and UV stabilized [41]. The abrasiveness to product as compared to wooden bins is completely eliminated by multiple vents, smooth internal surfaces and rounded internal corners [41]. Figure 2.23 shows an isometric image of the Plastic bins which would be manufactured by Viscount Plastics in New Zealand.

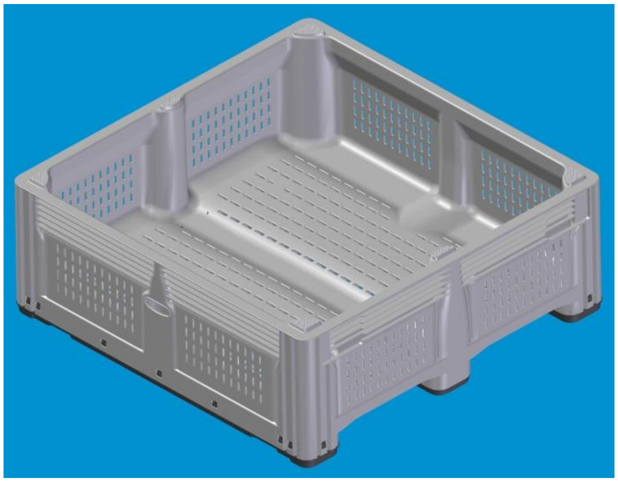


Figure 2.23: An isometric view of the proposed plastic bins to match the needs of the New Zealand Industry [42].

Major manufacturers of plastic bins worldwide are Viscount Plastics (Australia), Moreno Global Plastics (Australia), MACX Harvest bins (Dubois Agrinovation), CHEP pallets (U.S), CEVA and Macroplastics (U.S) [9; 10]. Apple industries from all over including New Zealand already use plastic bins replacing the traditionally used wooden bins. In New Zealand, Viscount Plastics is leading the way by bringing this technology to kiwifruit packhouses and orchards.

2.4.2 Advantages of Plastic Bins

Wood is porous and absorbent material and can support fungal growth. It could also cause contamination problems by moisture and chemical uptake. Various disease causing organisms can be harbored in the wood which can affect the fruit quality over long term storage [5; 6; 12].

According to the World Intellectual Property Organization patent on agricultural containers, a wooden bin may absorb 12 pounds of water in the first three months of CA storage [6]. Moisture absorbed by a bin is extracted from fruit in the bin. This results in fruit losing a significant amount of moisture and becoming shriveled [6]. In addition, dry wooden bins can also absorb moisture from the surrounding air reducing the surrounding relative humidity which can result in further weight loss of the stored fruit [5].

Harvesting bins are subjected to various temperature conditions in their life cycle sometimes stored in coolstores, under covered sheds, in open in packhouses and orchards. Plastic bins do not take up moisture and don't alter in weight [10]. Plastics bins weigh up to 40% less than wooden bins [9; 43], can withstand temperatures between +60°C to -40°C and are resistant to UV degradation [38]. Due to this feature, they can be stored inside or outside. However with wooden bins, due to their porous nature, they can suffer from flexure or deflection.

In a research carried out by Agriculture Victoria, puncture levels were found to be three times higher in fruit harvested into wooden bins than plastic equivalents [12]. Like wooden bins, plastic bins can also be manufactured with either solid or vented walls. Vented bins are believed to be better than solid sides as venting allows for higher open air, better cooling around the fruit and improved air circulation impedes the growth of bacteria and molds [38; 44].

Wooden bins have, on average, an open area (venting) of 1.5 % however, plastic bins have higher open area between 7-11% [5; 9]. Therefore, wooden bin construction does not permit the recommended 8% - 11% free air space on the bottom and sides [6]. Lesser open air area in wooden bins results in slower cooling of fruit inside the bin and makes it difficult to maintain low temperatures during coolstorage [6]. Ventilation in vented plastic bins allows for cooling at twice the speed of a wooden bin thus maintaining a better shelf-life of the product [11].

The analysis in Section 2.3.4 showed that a significant portion of kiwifruit production is rejected each year in New Zealand. It has been indentified that a major part of the reject fruit could be due to physical damage to fruit from the bin material. In order to understand where in the harvesting process this damage could occur, it is essential to comprehend how physical damage arises in the harvesting processes. The following chapter provides and insight into various physical damage mechanisms.

Chapter 3: Characterization of Physical Damage

3.1 Introduction

Mechanical damage on kiwifruit results in a significant decline in its market value. Mechanical injury to fresh fruit and vegetables can occur during harvesting, pack house operations, handling and transit with most damage occurring during handling and transport [45]. The nature of the bin surface plays a huge role in determining the extent of mechanical damage [45].

Various studies have shown that fruit such as mangoes, papayas and apples are rejected at consumer markets due to mechanical injuries (causing bad appearance) [46; 47]. Literature suggests that kiwifruit is highly susceptible to mechanical damage especially early in the season when skin is less tough and fruit firmnesses is higher [33]. It has been suggested that most apparent mechanical injuries (scuffing and impacts) are due to small drops during picking, moving fruit from one container to another and fruit rubbing together or against the bin surface [33].

On the vine kiwifruit can get damaged by abrasion, bruising and punctures by being in contact with neighboring fruit and vine branches [45]. Mechanical damage begins when fruit comes in contact with the bin surface during picking, loading-unloading, transporting and pack house handling [45].

Several studies have identified mechanical injury to be the main concern to fruit quality. Timm et al. (1997) identified excessive handling impacts and excessive compressive forces to be the two major causes of mechanical damage to fruit and vegetables during postharvest handling [48]. Another study by Burton et al. (1998) quantified mechanical damage to apples during orchard picking and transport, and found most damage to apples was due to impact and sliding vibration against rough sides of wooden bins [48].

Mechanical damage can prove detrimental to fruit quality as any physical damage occurred whilst harvesting could develop into a storage rot during bulk storage. In a study of impact damage to apples, it was suggested that postharvest pathogens such as Bortrytis can infect the healthy fruit tissue and can damage the whole fruit by entering through the damaged tissue [45]. Early damage to fruit during picking could therefore cause rotting during storage.

3.2 Classification of Mechanical Injury

Mechanical injury to kiwifruit can be classified based on its occurrence during harvesting and further into damage mechanisms. Figure 3.1 is a flowchart of physical damage to kiwifruit during post harvest handling.

.

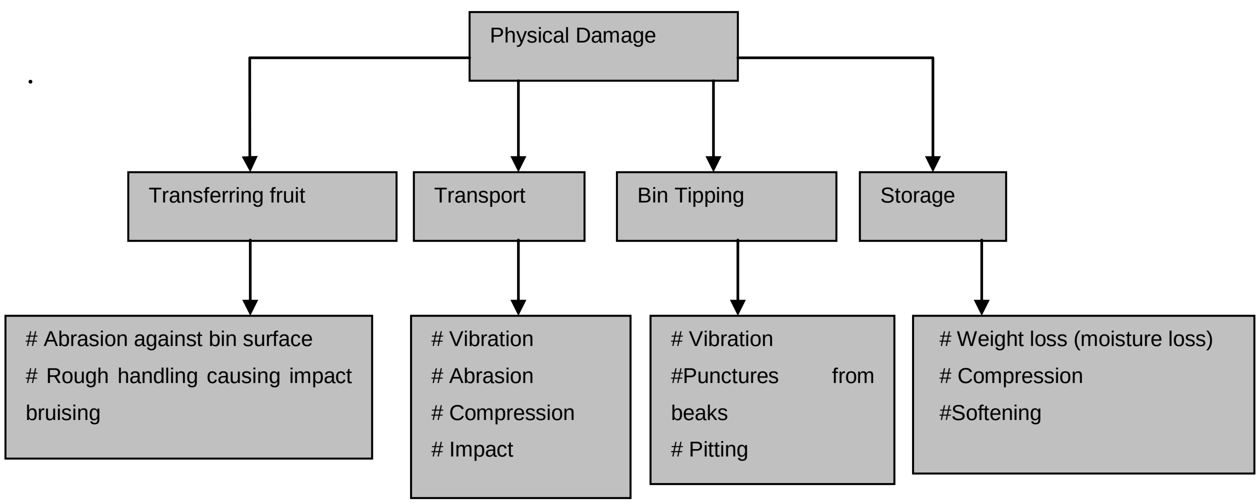


Figure 3.1: Breakdown of physical damage to

The first instance where fruit damage can occur is during harvesting where fruit is transferred from picking bags to harvesting bins and is caused by rough handling. Damage is a result of impact bruising and fruit skin abrading on rough bin surfaces.

At packhouses, during bin tipping, fruit can get damaged by vibration and punctures from beaks of neighboring fruit. Impact damage to kiwifruit during bin tipping was studied by Bollen and Dela Rue (1990) and it was found that most damage occurred when the first lot of fruit is released from the bin [49].

During transport, almost all damage mechanisms could be significant. Vibration from road conditions such as roughness, bumps and pot holes could cause small impacts. The combined effect of vibration and rough wooden bin surfaces could cause scuffing and flesh damage. Compressive forces could cause pressure points on fruit at the bottom and side panels of the bins.

During storage, fruit in the bottom few layers can get permanent compression damage under the dead weight of fruit above them. Moisture loss from fruit from long term contact with wood could also result in fruit rejection due to dehydration [46].

Premature softening of kiwifruit during storage could result in huge losses to the Kiwifruit Industry. In 1991, approximately 70% kiwifruit was wasted due to premature softening [14; 50]. It has been reported that the softening of the kiwifruit flesh could be related to two major physiological changes: cell wall breakdown and decrease in moisture content [14; 51]. Moisture loss and cell breakage have been related to pectin solubilisation and degradation of hemicelluloses [14].

The relation between fruit softening, moisture loss and use of wooden bins has been completely neglected in the Kiwifruit Industry that there could be a. Wood, as pointed out earlier, can absorb moisture from fruit over months of storage. As a result of moisture loss, fruit could become prematurely soft due to cell wall breakdown.

3.3 Identification of Mechanical Injury

Mechanical injury to kiwifruit according to the Zespri grade standards has been described as the presence of soft patches, cuts, scuffs, punctures, pressure marks, Hayward mark, overall soft fruit and juice leakiness in fruit [32].

Mechanical injury as a result of compression damage can be identified in the form of localized pressure marks, bruising (water soaking of fruit flesh), flattening of fruit skin, soft patches and fruit dehydration, either localized or whole [52; 53]. Water soaking can be explained due to fluid leaking from cell membranes as a result of compression damage [52; 54].

Impact damage cannot be identified directly after picking and only becomes visible following cool storage in the form of bruising and darkened skin. Skin at the point of impact becomes dark green due to bruising of flesh underneath.

A soft patch can be defined as an area more than 1 cm^2 anywhere on the surface, where flesh firmness is below 10 N [52]. Soft patches are not easily identified on kiwifruit before cool storage or C.A storage; however, it becomes obvious after several weeks or months in storage.

Bruising can be identified as browning of flesh under the fruit skin and can happen cumulatively during post harvesting processes [55; 56]. The phenomenon behind bruising can be explained by the breakage of the cell membranes resulting in the browning of the flesh when cytoplastic enzymes act on sequestered substrates [57]. Bollen et al. (1999) suggested fruit bruising to the most significant symptom of mechanical damage [55]. In a study by Sargent et al. (1987) on damage assessment of apples during harvest and transport, it was found that 93% of all apples were bruised during harvesting and transit to pack houses [48].

Any type of mechanical injury to kiwifruit during harvesting could result in premature softening during storage. The root cause of premature fruit softening (overall or soft patches) has been identified to be mechanical injury due to compression or impact during postharvest handling [53; 58]. It was found in a study on the susceptibility of kiwifruit to mechanical damage during post harvest handling and storage that premature softening contributes to about 70% fruit loss [52; 54]. Premature fruit softening promotes premature ripening of the damaged as well as undamaged neighboring fruit by release of ethylene.

Many studies have related fruit damage to mechanical handling issues (suspension system, structural integrity of the bin design and bin floor stiff) however, little work has been done to quantify the magnitude of damage that can be attributed directly to the bin material [20]. The main factors determining how forces are transmitted from the bin to fruit inside are the bin material and bin design [20]. Studies have shown that damage (bruising, cuts) in a bulk bin during transport in and around the orchard, as well on the road, can be related to the shock forces (bumps or ruts), bin material fruit are exposed to during transit [20].

In this chapter, physical damage has been categorized into different types. Each type has been explained based on visible symptoms, its occurrence in the life cycle of kiwifruit bins and how they lead to fruit rejection. Physical damage to kiwifruit can be broken down in following modes:

- compression damage
- vibration damage
- impact damage
- abrasion damage

3.3.1 Compression Damage

During post-harvest handling, physical damage to fruit and vegetables can be mainly divided into two categories: compressive forces during bulk and packaging and impact forces during harvesting, grading and transportation [8]. Studies have shown that although kiwifruit are hard at the time of harvest, they do get damaged by compression [53].

Fruit are subjected to continuous static compression forces during storage [56]. Kiwifruit are under compressive forces when handled in bulk in harvesting bins or in single layer trays, which may be stacked into pallets (58 trays high) [53]. In addition to bulk compression, kiwifruit also gets damaged from small compressive forces in single layer and tri-layer trays [52]. These are either static loads during storage or dynamic compressive forces during bin handling and transit [8]. In a study by Ivan et al. (1992), kiwifruit were exposed to compression forces in the range of 0 N to ~30N [54]. Studies on compression damage in apples have suggested a load of 21 N on each fruit on the base of the bin [8; 56]. Kiwifruit are often stored in bulk bins (275kg) or in single layer trays which are stacked two pallets high (58 trays) for 4-6 months [2; 6]. Bulk storage can result in a considerable load on fruit at the bottom layer of the bins.

A study on mechanical damage to apples during transport in wooden crates proved that greatest damage to apples occurred in the lower fruit layers at the base of the bin [46]. This work also suggested that damage is higher in lower layers because of the mechanical forces caused by the weight of fruits on top [46]. A study on compressive forces on apples suggested serious compression damage is confined mainly to fruit in contact with the base (floor) and the sides of the bin [8]. Under the influence of continuous vibrations during bulk transport, fruit get tightly packed which in turn raises the incidence and severity of compression injury especially in fruit in direct contact with wooden boards [59].

Work carried by G. Hopkirk in 1983 showed that this type of compression injury can result in severe visible damage [6]. Principal damage symptoms include external flattening of the fruit skin and water-soaking of the flesh [6; 8].Water soaked flesh can easily be observed once the fruit has ripened giving that part of the flesh a dark appearance [6].

Compression damage can change physiological properties such as, fruit firmness and rate of ripening. It has been suggested that not all compressed fruit with externally flattened areas show signs of water soaking, however, they do ripen more quickly as compared to undamaged fruit at 20°C [52; 54].

Bin material could significantly influence compression damage to fruit. Timm et al. (1997) studied damage to apples from compressive forces in various bulk bins and found that plastic bins caused less bruising than hardwood or plywood bins [48]. Moisture content of bins, even within different boards of the same bin, can vary significantly depending on the humidity of surrounding air. This could result in a wooden bin to respond differently when full of fruit. Loss or gain of moisture could cause joints in wooden bins to loosen and the bin could lose rigidity. In addition, boards could bow out slightly when bins are full. When handled with forklifts, boards could then bend inward exerting pressure on the fruit [33]. A study on bin strength of seven harvesting bins (six wooden and one plastic) for apples, explored structural aspects based on wall bow, wall shear deformation and floor deflection. This work suggested that plastic, collapsible bins to be the stiffest among all designs studied [7].

Compression damage on kiwifruit in bulk bins can never be completely eliminated. By careful selection of an appropriate bin material, it could potentially be managed.

3.3.2 Vibration Damage

Vibration of a system can be defined as trembling, shaking or backwards and forwards movement in some way [2; 52]. Vibration forces can also be visualized as smaller shock forces occurring continuously [60]. Vibration during transit is considered as a randomly vibrating system as the motion is unpredictable [2].

The fruit and bin system is subjected to random excitations as the road conditions and driving speed change. For instance, a truck carrying full bins, going over a speed bump or a pot hole, would be subjected to higher vibrations than over a smooth road surface.

The extent of vibration damage to fruit depends on many factors such as bin material, shock absorption system, truck speed and road conditions. Armstrong et al. (1992) studied bruising in apples during transport in bulk bins and have found less bruising in fruit in air cushioned suspension systems as compared to steel spring systems [61]. Studies on vibration damage in fruit have shown that single big bumps are enough to cause significant damage to fruit [33]. Air suspension systems are considered to be ideal irrespective of distances travelled [33]. Work conducted on apples has shown that instances such as bumps and potholes are more critical than the distance travelled.

Symptoms of vibration damage to fruit include scuffing, bruising, overall softening and soft patches on the fruit skin or internal damage which is only noticeable if the fruit is cut open [59]. Vibration damage can be identified as water-soaking of the fruit flesh as shown in Figure 3.2. Moreover, vibration damage changes the physiological properties of fruit causing increased ethylene production [59]. A transportation vibration damage study with apples in wooden crates revealed bruise damage to be in the order of 45% [46]. In another study, transportation vibration damage to fruits reported that greatest damage occur in the range 5-10 Hz [62].

Figure 3.2: Water soaking of the flesh indicating vibration injury on kiwifruit.

3.3.3 Impact Damage

Impact injury can develop into a soft patch over time during storage in coolstores and binstores (CA). This not only results in rejection of the individual fruit but can also accelerate the ripening of neighbouring fruits. Wood is not a force absorbing material and hence results in all impact being absorbed by the fruit in the form of bruises.

Studies regarding damage to apples have shown that they experienced impacts (shocks) during picking, transit and handling [60]. Because kiwifruit is hardy, it is generally assumed not to get impact damaged during picking; however, studies have shown that they do get injured by impact on hard surfaces [49]. A study on the susceptibility of kiwifruit to physical damage by Finch and Hopkirk in 1987 showed kiwifruit can be readily damaged by impacting/dropping even though the visible symptoms are not immediately noticeable unlike others fruits such as apples and nectarines [58].

Impact damage initiates during picking if fruit are dropped carelessly onto hard surfaces of the wooden bins. Kiwifruit can also get damaged if subjected to harsh impacts during post harvest handling [49; 58].

Studies by Finch and Hopkirk (1987) on kiwifruit impact damage have showed that impact damage does not show any immediate external symptoms such as bruising or skin rub, but it affected physiological properties [49]. As a result of impact injury, softening rate were increased as well as pre-initiation of ethylene production and water soaking of the flesh [49]. In their work, impact onto 4 mm foam from a height 300 mm resulted in a 10% reduction in the time to produce ethylene while a 100 mm drop onto steel resulted in 30% reduction [49].

Current literature revealed that the extent of impact damage is dependent on the speed, height and the physical characteristics of the impact surface [46]. It is understood that harder impact surfaces lead to greater damage and the degree of damage decreased by covering the impact surface with a soft material [46].

Finch and Hopkirk (1987) used time to ethylene production as an indicator of impact damage on kiwifruit [58]. They suggested that impacted fruit began producing ethylene a lot earlier than un-impacted fruit. Typical impact damage bruise in kiwifruit is seen in Figure 3.3.

Figure 3.3: Impact damage in kiwifruit.

3.3.4 Abrasion Damage

Fruit movement in bulk bins can be related to the tribological phenomenon of wear. Tribology is the science of interacting surfaces in motion. Wear (abrasion) on kiwifruit is the rubbing of fruit skin against the rough bin surface and also with surrounding fruit. Wooden bulk bins can result in cuts, scuffing and bruises on fruit skin [63]. Literature suggested that abrasion damage on fruit skin (skin rub or scuffing) can be treated as a form of vibration damage. In addition, vibration damage also results in loss of hair from the fruit skin [59]. Figure 3.4 shows images of rough surfaces from wooden bins. Abrasion damage could happen anywhere from picking through when fruit are in contact with the bin surface.

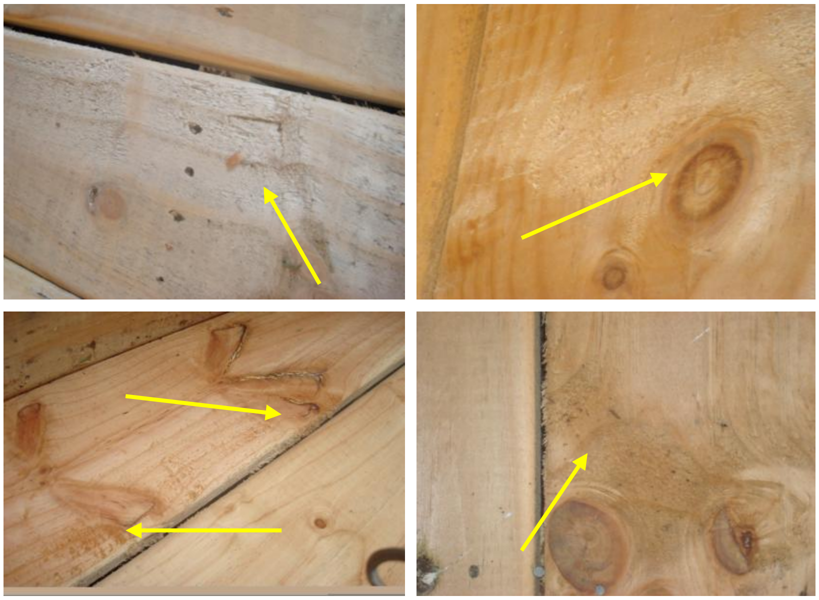


Figure 3.4: Rough surfaces of wooden bins.

Chapter 4: Experimental Work

4.1 Materials Used

4.1.1 Fruit

The two types of kiwifruit used in this study were A. deliciosa 'Hayward' (green) and *A. chinensis 'HORT 16'* (gold). Kiwifruit of two different firmnesses were used, 10 and 25 N respectively. 10 N fruit were soft and eatable and 25N fruit were slightly harder, indicative of 6 months of coolstorage. 10 N soft fruit were 7 months old fruit from controlled atmosphere storage. Kiwifruit are harvested rock hard, with firmnesses of green and gold fruit approximately 85 and 45 N respectively. 25 N fruit were obtained by artificially ripening rock hard harvested fruit. Fruit used were of similar size, regular shape and free of defects. Mean fruit diameters were 45 mm.

Method for artificial ripening

In order to artificially ripen harder fruit (85 N green and 45 N gold) to 25 N firmness, fruit were placed in a large plastic bag. The bag was sealed with a small open hole. A 30 second shot of ethylene gas, supplied by BOC gases, was applied and the bag sealed for 12 hours. After that, fruit were removed and held under ambient conditions. Fruit firmnesses were monitored every 24 hours using a hand held penetrometer. About 30 fruit were selected randomly from the bag at a time. When fruit reached average firmness of 25 N they were immediately placed in the coolstore.

4.1.2 Bin Material

Wood of Radiata pine with moisture content in the range of 10 to 20% was used in this study. Plastic sheets made from polypropylene (PP) of grade ExxonMobil PP7033N were used and were supplied by Viscount Plastics. Tests were conducted on both flat and vented wooden and plastic surfaces. As seen in Figure 4.1, bin materials used included flat and vented surfaces made from wood and plastic. For wood, vents were made by joining two wooden boards together with an appropriate gap.

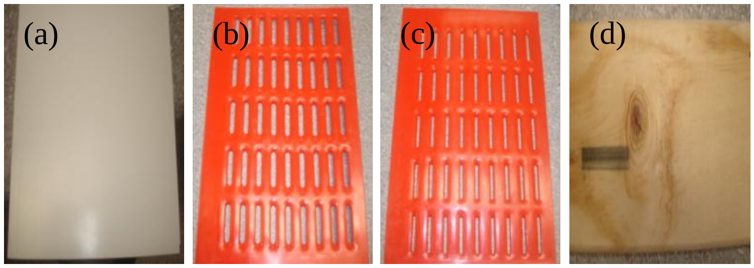


Figure 4.1: Materials used in testing. (a) Flat PP plastic sheet (b) & (c) plastic sheets with 10 and 6mm vent (d) typical wooden board

4.2 Analysis of Physical Damage

Physical damage was analysed based on visible signs of damage, percentage mass loss, percentage deformation, average firmness at compression area, percentage compressed area, percentage bruised fruit and percentage bruised area.

4.2.1 Visible Symptoms of Damage

1. Compression area/pressure marks due to external flattening of fruit skin as a result of continues loading [6]. Pressure marks can lead to fruit rejection if it is either soft or dark green in color.
2. Water soaking of the flesh at the point of compression causing bruised appearance [6]. Water soaking can be related to the leaking of cell contents as a result of mechanical damage. When kiwifruit is subjected to physical injury, fluids leak from cells resulting in gas-filled intercellular space to be filled with liquids; hence a water soaked appearance [58; 64]. A major portion of leakage is thought to be starch which did not convert to sugar during ripening, as it does in unaffected tissue [64].
3. Softening at the point of damage (compression or impact) quantified as firmness. Damaged fruit generally get softer at points where damage occurred

(fruit and wood/plastic face) and softened overall more quickly than uncompressed fruit [6].

4. Signs of dehydration at point of contact between fruit and bin.

4.2.2 Assessment Criteria

The assessment criteria for fruit rejection primarily included of visible damage. For the analysis of physical damage, mass and deformation (diameter) was measured before and immediately after the tests. However, bruised area, compressed area and firmnesses were measured only after 30 days of holding period following the test period.

4.2.2.1 Measurement of Flesh Firmness

Flesh firmnesses of fruit were measured by Lloyd (LR 100K) instrument fitted with a 7.9 mm (5/16 in) plunger. The plunger was penetrated to a depth of 10 mm into the peeled face (a thin slice of skin was removed). The firmness was recorded as the maximum force needed to penetrate 8 mm into the flesh and reported as the average peak force (N) of 10 kiwifruit.

Firmness was measured on two peeled faces of fruit at right angles to one another for undamaged fruits. Firmnesses were measured after 30 days holding period and on the face which was in contact with the bin material. For e.g. for compression tests, firmness were measured on the fruit wood/plastic compression face.

4.2.2.2 Measurement of Percentage Mass Loss

Percentage mass losses of fruit were measured using gravimetric methods. Fruit masses were measured before and after each test and percentage mass loss calculated.

4.2.2.3 Measurements of Percentage Deformation

Percentage deformations of fruit were measured by measuring fruit diameters before and after each test and percentages calculated. Diameters were measured with the use of vernier calipers.

4.2.2.4 Measurement of Percentage Bruised Area and Compressed Area

Bruised and compression areas were measured using IQ materials analysis package. Compression area was caused due to compression and is apparent as a pressure mark on fruit skin visible immediately after compression however, bruises in fruit flesh were apparent only after 30 days of holding period.

The technique used for calculating bruised and compressed area is shown in Figures 4.2 and 4.3 respectively. Figure 4.2 shows a bruised fruit following compression on flat wood and 30 days holding period. As seen, the area was measured as a percentage of the projected area. P1 is the pixel area of the bruised region and P2 is the pixel area of the fruit projection. Using P1 and P2, percentage projection area of the bruised region was calculated.

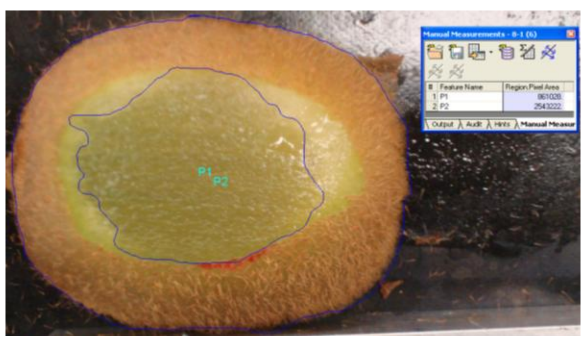


Figure 4.2: Projected bruised area on kiwifruit

As seen in Figure 4.3, compression area was calculated as a percentage of projected fruit area. This image was taken immediately after compression of gold kiwifruit on 6 mm wooden vents. P1 and P2 are the region pixel areas of the two compressed parts, while P3 is the region pixel area of the fruit projection. Percentage compressed area was calculated using P1, P2 and P3.

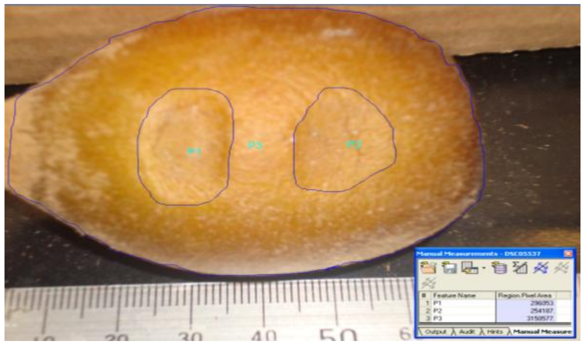


Figure 4.3: Projected compressed area on kiwifruit.

4.2.2.5 Criteria for Visible Damage Rejection

A visible damage reject analysis was carried out where fruit were checked for rejection based on surface damage. Methodology used for visible damage reject analysis was that set out by Zespri grade standards. Rejection was mainly based on presence of pressure spots, signs of dehydration and flesh damage.

A dark spot of any size on fruit skin is called a pressure spot. It could either be present as a flat area (compressed on flat surface) or an indent (if fruit has been sitting on a vent). Any pressure mark or indent is considered to be a reject if it appears dark green in color or soft (<10 N) [32]. Fruit were also checked for any signs of dehydration and damage penetrating into flesh.

4.3 Experimental Design

4.3.1 Compression Damage

Compression experiments were carried out at ambient temperatures (10-21 °C) for 48 hours and in a coolstore at < 1°C for one month. Tests at ambient were used to replicate 24 - 48 hour curing and long term tests were aimed at bin storage.

In addition to compression tests, equivalent compression controls were also carried out. A control can be defined as an uncompressed fruit resting on a bin surface. Controls were also run for 2 days in ambient and one month in a coolstore. Controls were carried out in order to single out the affect of compression and the bin material; that is to see if damage is more pronounced due to the actual compression or the bin material.

Figure 4.4 shows the plan for compression tests which were conducted on wood and plastic surfaces, both flat and vented at ambient and in coolstore. At the end of each compression test, fruit were taken out and held for one month in a coolstore at <1°C to allow for damage to develop. This period is referred to as a holding period. At the end of the holding period, fruit were taken out and firmnesses measured.

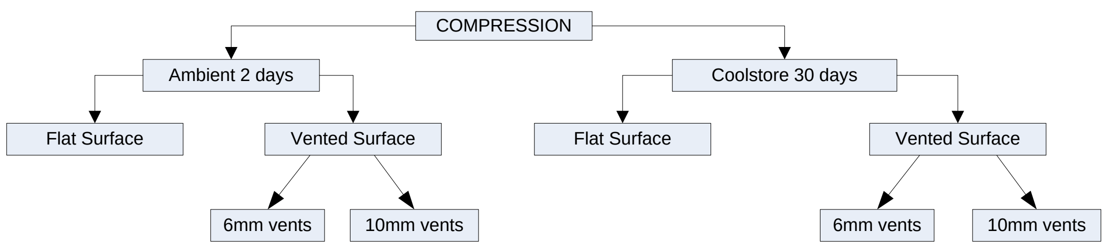


Figure 4.4: Summary of compression tests.

Each fruit was compressed under a load of 7 N (refer to the calculation provided later in this section). Stationary weights were used for compressing fruit as shown schematically in Figure 4.5.

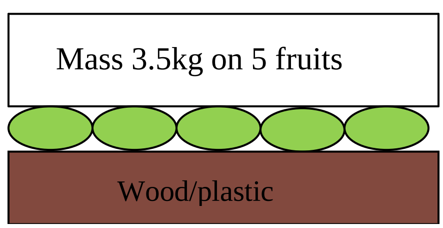
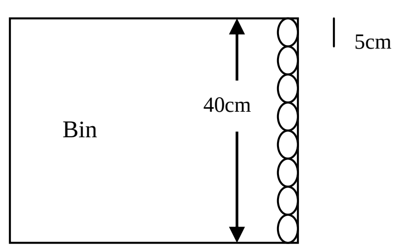


Figure 4.5: Compression test set up.

Assumptions for compression tests

- Average weight of a kiwifruit = 100 g
- Load exerted by 1 kiwifruit = 1 N



- Average internal height of a bin = 40 cm
- Average diameter of a kiwifruit = 5 cm
- Assuming fruit are uniformly packed in a bin, fruit stacked along the height (40/5) = 8 fruit
- Therefore, load on a single fruit in the bottom layer of a bin (that has 7 fruit on top of it) = (7 X 1N) = 7 N, i.e. 0.7 kg.

4.3.2 Impact Damage

Impact tests were carried out in order to study the effect of the nature of the impacting surface on damage to kiwifruit. It is understood that harder the surface, higher the damage. Figure.4.6 outlines the impact work carried out as part of this research. Fruit were dropped from 500 mm on to flat and vented wooden and plastic surfaces.

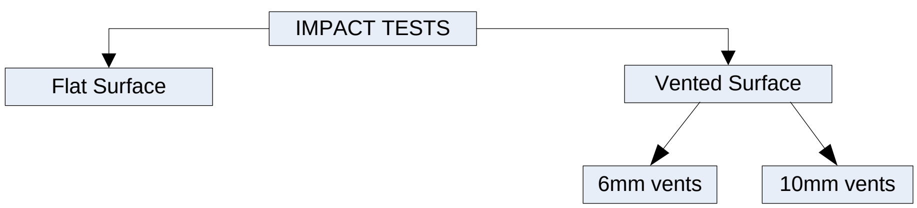


Figure 4.6: Summary of impact tests

For some earlier impact experiments, fruit were swung in a pendulum arrangement from a known height onto a vertical impacting surface (wood or plastic) as seen in Fig.4.7. However, it was observed that this arrangement was not ideal due to many reasons. The thickness and the shape of the plastic and wooden boards used were different, plastic was thinner than wood. The shape of the plastic sheet was different from that of an actual plastic bin. This could contribute to unequal comparisons and therefore it was decided to drop fruit in actual bins as the deflection and flexural behaviours of vertical boards would be different from that of an actual bin.

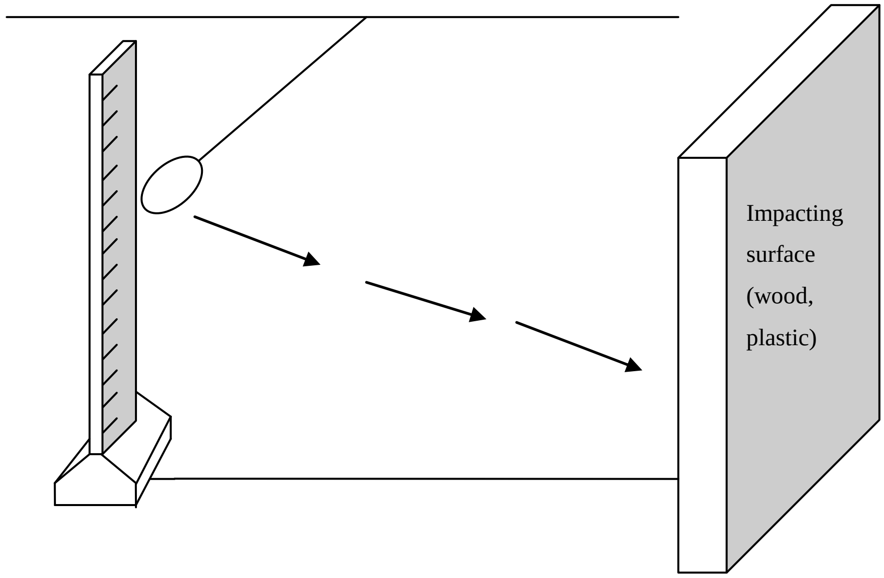


Figure 4.7: Schematic of the pendulum apparatus used for impacting kiwifruit in early experiments.

Figure 4.8 shows the bins used for conducting impact tests. The arrangement used for impacting fruit in bins is shown below in Figure.4.9. As seen, fruit were held in a copper wire such as two holes would fit in to nylon treads on the sides. The fruit were dropped form a known height onto the bin surface.

Figure 4.8: Nally Megabin manufactured by Viscount Australia is used widely in the Australian horticulture market and a wooden harvesting bin used in New Zealand.

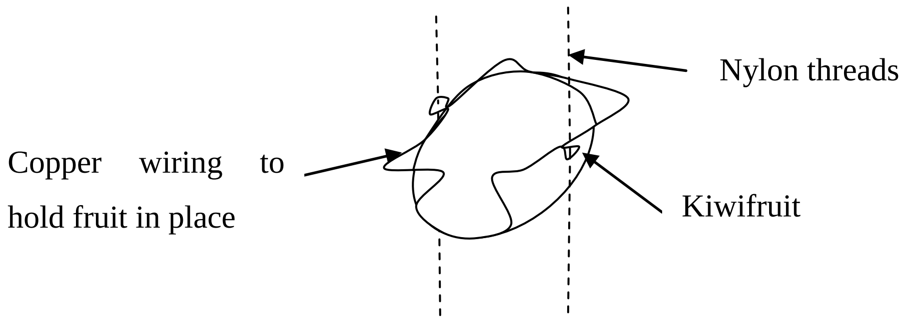


Figure 4:9: Schematic of fruit drooping in bins.

4.3.3 Abrasion Damage

Abrasion (scuffing) is a superficial damage mechanism. In order to investigate abrasion damage to kiwifruit from wood and plastic, a scuffing tool was built as shown in Figure.4.10. Kiwifruit were given a constant rub with wood and plastic pieces for 5 minutes under a dead load of 7 N. A scuffing distance of 20 mm and speed of 0.01 m/s was used. Because fruit were given a continuous rub this was treated as a test to study the relative difference between wood and plastic. This test was one off work and analysis was carried out with softer 10 N fruit.

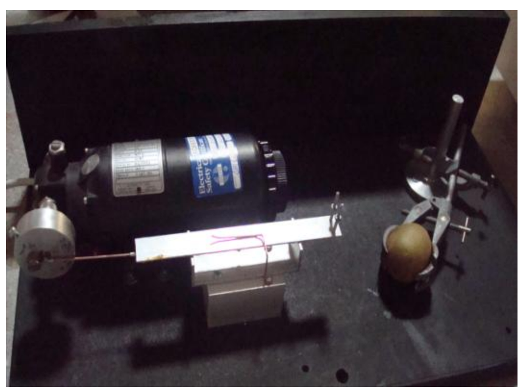


Figure 4.10: Abrasion tool used for scuffing fruit.

In addition to controlled abrasion tests, macro-scale roughness of wooden and plastic boards used in the study were measured. It is understood that roughness of the bin material has a significant effect on physical damage to fruit. For all damage mechanism discussed above, damage gets transferred to fruit through the bin surface i.e. rougher & harder the contact surface, higher the mechanical injury. Roughness measurements were used to study the difference in the roughness of the two materials.

The Surface Profilometer used to study the surface qualities and measuring roughness measurements is shown in Figure.4.11.

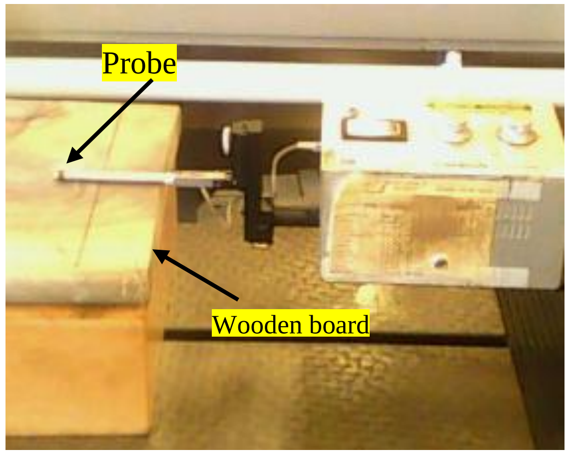


Figure 4.11: Surface Profilometer.

The roughness parameters R_a, centre line average roughness or the arithmetic mean of the departures of the roughness from the mean line were measured. It is expressed in microns. A sampling length of 2.5 mm was used. About 50 measurements were made each for wood and plastic.

4.3.4 Moisture Uptake

In order to investigate the affect of varying moisture in wood on fruit loss, fruit were compressed on wooden boards with different moisture content in them. Three moisture levels were chosen 0, 3-4 and 45-47 % respectively. A wood moisture meter was exploited to measure the moisture content of the boards. Nine wooden boards of size 25 X 18 X 2 cm were weighed individually. On average, their initial weight was 450 g. Three boards were put in an oven at 60 °C, three in a condition chamber at 20 °C and 50% relative humidity and three in a water bath. Mass of wooden boards was recorded every two days. When their masses reached equilibrium, i.e. when they reached a constant mass, they were taken out and compression tests were set. All three boards had reached their equilibrium within two to three weeks. Compression tests were then set up in a coolstore 0 ± 2.0 °C on each board for one month. At the end of one month fruit were taken out and held for one month in coolstore. Figure 4.12 shows the experimental plan for moisture uptake work.

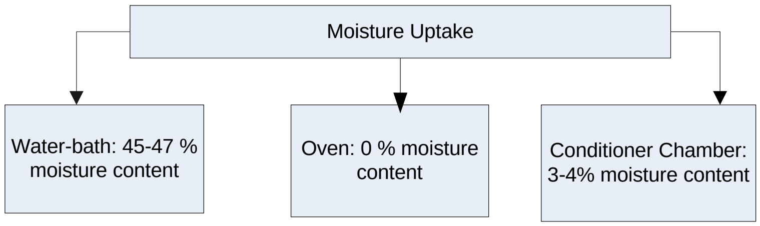


Figure 4.12: Summary of Moisture uptake experiments

4.3.5 Accelerated Transport Damage

An ERPMA Rocking Platform mixer (orbital shaker) as shown in Figure.4.13 was used to subject kiwifruit to transport damage fruit. Fruit were vibrated acceleratory in small laboratory scale wooden and plastic bins of dimensions 3.4 X 3.4 X 2 cm at shaker speed of 100rpm for 15 minutes in a circular motion of 3cm radii.

Figure 4.13: Orbital shaker.

It was noted in some earlier runs that higher damage from wood could be due to the friction of wooden bin might be grabbing the fruit inside and causing them to impact the bin sides. In order to mitigate this, trials were carried out by padding the four sides with cushioned foam.

Chapter 5: Results and Discussion

In this chapter the results from experimental work is discussed in three parts: firstly, results from preliminary work is discussed and it is how the results influenced subsequent experimental work. Secondly, results from compression and impact testing are discussed, followed by an economic analysis of the benefit of using plastic harvesting bins.

5.1 Preliminary Experiments

Preliminary experiments were designed to determine the appropriate parameters used in compression and impact testing trials.. Scoping trials included transportation damage, abrasion damage and effect of wood moisture content on fruit damage.

5.1.1 Moisture Content of Wood

Wood is porous and can absorb moisture, causing swelling. It is well known that the moisture content of wood is dependent on the humidity of ambient air. It could potentially be responsible for drawing moisture from fruit in contact with wood during storage. The objective of this experiment was to assess the extent to which wood moisture content influences fruit damage during storage. Only 10 N firmness fruit were used.

Figure 5.1 shows the percentage mass loss of green and gold kiwifruit compressed on wood at different moisture contents. Values are based on an average of 10 fruit per test. Fruit were compressed under a load of 7 N per fruit for 30 days in a coolstore. From Figure 5.1 it can be seen that low moisture content in wood leads to a significant moisture loss in kiwifruit as previously described by Woodward et al. [14; 51]. It can be seen that mass loss of green kiwifruit is lower than that of gold. This is due to the fact that skin of green kiwifruit is generally more resistant to moisture loss.

Figure 5.2 shows the final firmnesses of green and gold kiwifruit after compression. It can be seen that dehydrated wood only caused slightly higher loss of firmness than hydrated wood; however, the effect of storage compression is greater than that of wood moisture content. High mass loss and a decrease in firmness are related as compression may lead to cell breakage and a consequent loss of fluids; similar affects have also been observed by other researchers [14]. It is important to note that the observed drop was more severe for the gold variety. This can be expected due to the more delicate nature of the fruit’s flesh compared to that of the green variety.

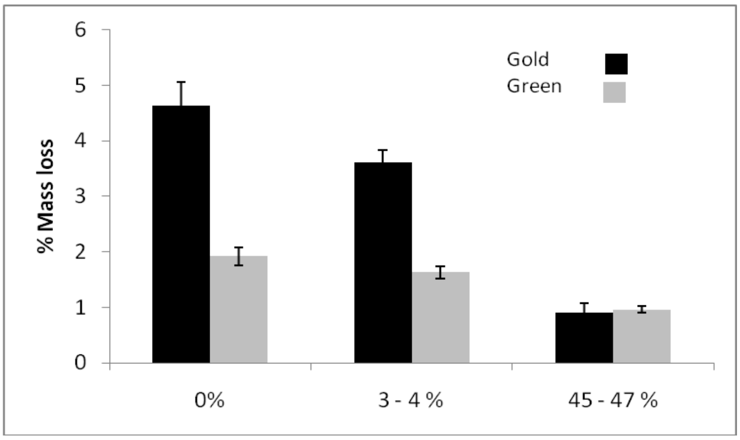


Figure 5.1: Percentage mass loss of green and gold kiwifruit on wooden boards with different moisture content.

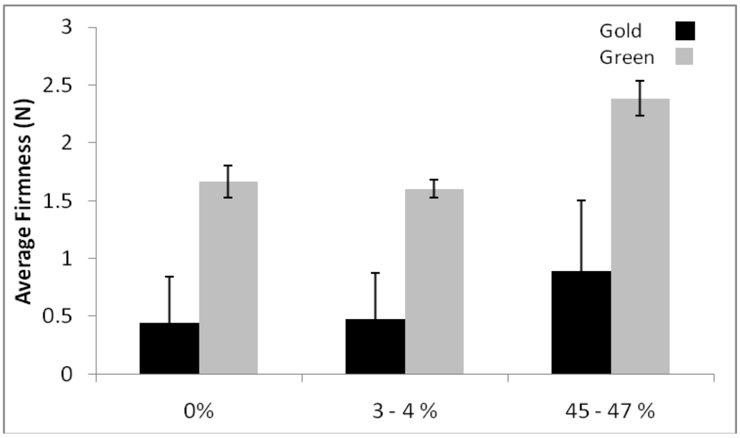


Figure 5.2: Average firmness of green and gold kiwifruit on wooden boards with different moisture content.

Long term contact of fruit with drier wood resulted in lower firmness and significant mass loss which can result in fruit shriveling, as seen in Figure 5.3. Fruit shriveling was quantified as percentage deformation. It can be seen that higher deformation is observed for fruit compressed on dehydrated wood

In addition to these tests, fruit were also assessed for visible damage as seen in Figure 5.4. Reject fruit, based on visible damage, were counted and shown next to typical visible damage in Figure 5.4. Severe dehydration and skin darkening can be observed in fruit compressed on completely dried wood. Slight dehydration circles can be seen on fruit from 3-4 % wood. However, fruit compressed on wood at 45-47 % moisture content showed signs of excessive darkening of skin indicating bruising.

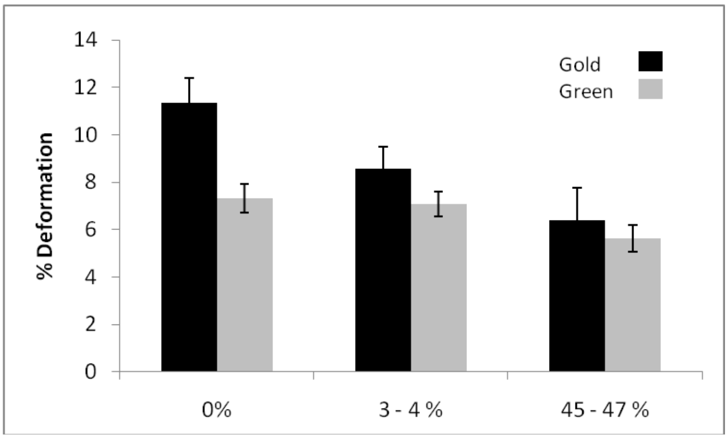


Figure 5.3: Percentage deformation of green and gold kiwifruit on wooden boards with different moisture content.

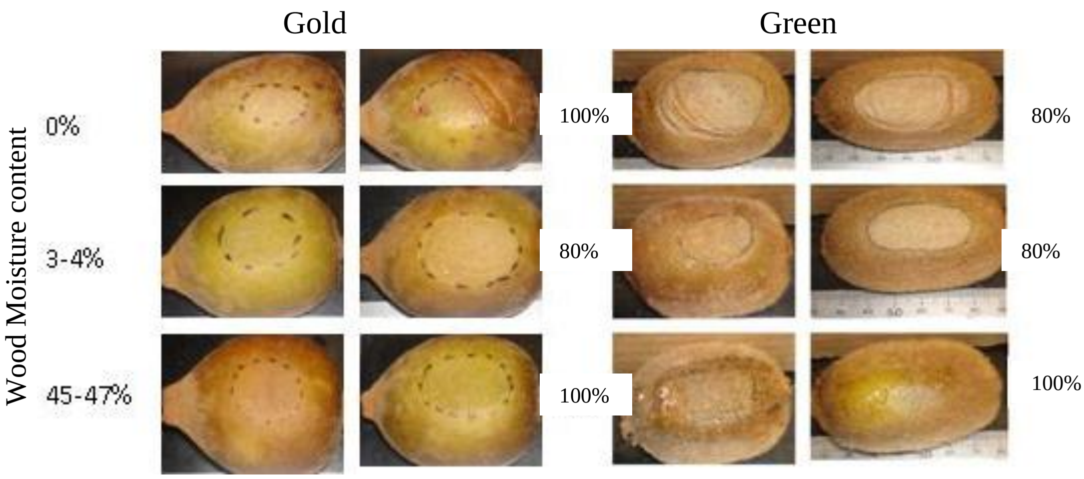


Figure 5.4: Visible damage of green and gold kiwifruit on wooden boards with different moisture content. Numbers on right are percentage reject fruit.

Based on this work, it was decided to do further compression tests on wooden boards with moisture content in the range of 10-20% to mitigate excessive dehydration and over hydration. Commercial wooden bins are never dehydrated and have a general moisture content of about 10-20% and it is therefore acceptable to ignore the effect of dehydrated wood. It was also decided to include controls in the compression test to isolate the effect of ageing on the measured parameters during compression.

5.1.2 Accelerated Transportation Damage

In order to simulate transport of kiwifruit in an orchard they were subjected to the circular motion of an orbital shaker. This test was designed to accelerate and exaggerate damage caused by transport. Although the test did not simulate actual conditions, the results were used as a comparison between fruit damage when in contact with wood or plastic.

Figure 5.5 shows typical visible damage in kiwifruit after the accelerated transportation damage of 15 minutes with padded bin sides. Severe damage is evident in gold variety, with broken beaks and fluid loss from fruit in contact with wood. However, fruit from plastic bins were dry with no leakage or beak breakage.

Green kiwifruit however, did not show severe surface damage except for hair loss. When cut open, damage became apparent as significant softening was detected in fruit in contact with wooden bins. As discussed earlier, vibration damage is characteristic of water soaking of flesh, as shown in Figure 5.5.

Figure 5.5: Fruit following accelerated transport damage in small laboratory scale wooden and plastic bin. Numbers of right are percentage number of reject fruit.

It can therefore be concluded that as a material, wood causes far more damage to kiwifruit. Small repetitive impacts can prove to be detrimental, especially on a hard surface, such as wood. Therefore, normal impact tests were considered to be more appropriate for comparing fruit damage in actual practice and conducted on both flat and vented surfaces.

5.1.3 Abrasion Damage

Roughness is a measure of surface texture. Rough surfaces can be expected to cause higher wear damage to kiwifruit. A surface profilometer was used to measure the surface roughness of wood and plastic surfaces used in this study. The surface roughness of wood was found to be between 220 to 759 and plastic between 33 to 88 micro inches.

Figure 5.6 shows typical scuffing damage after contact to wood and plastic bin surfaces. Fruit were continuously abraded against solid surfaces according to methods described earlier. However, in actual harvesting practices fruit never suffers from continuous and cyclic abrasion and this test was used only for the purposes of assessing relative differences between wood and plastic surfaces. Visible abrasion damage consisted of pressure marks, flesh damage and small cuts from rougher areas.

Figure 5.6: Visible damage in gold and green kiwifruit after abrasion tests. Numbers of right are percentage number of reject fruit.

Abrasion damage in these experiments was exaggerated to show visible damage to kiwifruit from wood and plastic. It was found that 5 minutes abrasion of wood caused more severe abrasion damage compared to plastic.

5.2 Damage Caused by Wood or Plastic Surfaces

Based on the preliminary experiments, and consideration of the process of harvesting, it was decided to only consider damage as a result of:

1. Short term compression under ambient (refer to section 4.3.1).
2. Long term compression under coolstore conditions (refer to section 4.3.1).
3. Impact damage

All of these mechanisms were explored in light of the effect of:

1. Bin material (wood and plastic)
2. Fruit type (gold and green)
3. Fruit firmness (10 N and 25 N)
4. Bin design, or vent size (6 and 10 mm)

In all cases, damage was assessed in terms of percentage mass loss, percentage deformation, fruit firmness; percentage bruised fruit, percentage bruise and compression areas as well as visible damage.

5.2.1 Compression Damage

5.2.1.1 Green Kiwifruit

Two day compression under ambient conditions

In this section, results from green kiwifruit subjected to compression damage on wood and plastic surfaces after two days under ambient conditions will be discussed. In addition, uncompressed fruit (controls) were considered to isolate the effect of fruit ageing, without compression. Fruit with starting firmness of 10 and 25 N were used to investigate the effect of whole fruit firmness on compression damage.

Fruit damage was characterized in two steps:

1. Damage was measured directly after compression in terms of percentage mass loss, deformation, fruit rejection and compressed area.
2. In order to assess internal damage a 30 day holding period was required following compression testing. Internal damage was characterized as flesh firmness at the compressed area, percentage bruised fruit and bruised area. Flesh firmness at the compressed area does not relate to whole fruit firmness, but only to that of the damaged area.

As seen in Figure 5.7A, two day compression under ambient conditions did not lead to any significant mass loss over natural ageing using wood or plastic surfaces for both fruit firmnesses.

No significant differences in mass loss were observed between any of the wooden surfaces tested. A similar trend was observed for vented plastic surfaces. However, it can be said with 99% confidence that unvented plastic surfaces lead to less mass loss compared to vented surfaces, for both firmnesses. It was thought that this was mainly due to the fact that vented surfaces promoted diffusion of moisture from fruit. It was concluded that, for both firmnesses, plastic surfaces consistently resulted in less mass loss than wooden surfaces.

From Figure 5.7B, a significant difference between percentage deformation for tests and controls were detected, except for tests on 10 mm vents using fruit of 10 N firmness. This suggested that softer fruit, under their own weight, deformed more than firmer fruit. It was concluded that any plastic surface tested were better than flat wood surfaces, but, the surface material was not significant as soon as vents were introduced.

In addition to percentage mass loss and percentage deformation, damage from wood and plastic was also quantified in terms of percentage reject fruit. In Figures 5.8 and 5.9 respectively, fruit directly after compression are shown; these were used to determine percentage rejection, as presented in Figure 5.7C. Criteria used for fruit rejection were discussed in Chapter 4. It was observed that, plastic surfaces lead to far less rejected fruit than any wooden surfaces. For both 10 and 25 N firmness, 10 mm plastic vents resulted in least fruit rejection. Vented wood lead to more fruit rejection than flat wooden surfaces, for both firmnesses, where 10 mm vents in plastic reduced fruit rejection slightly.

Figure 5.7D shows the percentage compression area on fruit directly after testing, using images of damaged fruit shown in Figures 5.8 and 5.9 respectively. For both fruit firmnesses, 10 mm vents on plastic surfaces lead to smallest compressed area. This suggested that using a wider vent reduced the pressure on fruit surfaces in contact with the bin material.

Figure 5.10A shows the average firmness of fruit, measured at the compressed area after 30 days of holding. It can be seen that compression did not lead to any significant drop in flesh firmness for either wooden or plastic surfaces, as evident from no significant differences between tests and controls.

For 10N fruit, flesh firmnesses at the compressed area for wood and plastic were higher when using flat surfaces. However, for 25N fruit vented surfaces had no effect, this would suggest that softer fruit were more prone to compression damage, especially at the edges of vents which acted as stress concentration points. It is most important to note that plastic surfaces consistently resulted in higher flesh firmness than wood in all cases. Plastic bins would therefore be preferred to prevent fruit damage in this case.

Figure 5.11 shows typical bruising damage in green kiwifruit after a 30 day holding period. It can be observed from Figure 5.10B, that for both firmness fruit, plastic lead to significantly less bruised fruit compared to wooded surfaces. No bruising was observed on 25N fruit following compression on 10mm plastic vents.

As seen in Figure 5.10C, percentage bruised area was found to be considerably lower using plastic surfaces, as compared to wood for both fruit firmnesses. It was also observed that using 25N firmness fruit, on both flat wood and plastic surfaces did not lead to any significant bruising. This is most likely due to the increased fruit firmness that can resist deformation for longer periods. Fresh fruit would therefore be less prone to compression damage. It can also be suggested that any plastic surface would lead to negligible damage with firmer fruit.

From above discussion on compression of green kiwifruit under ambient conditions it can be concluded that using plastic as bin construction material would be superior to using wood. Fruit were firmer and showed significantly less visible damage on plastic surfaces. It was also found that 10 mm vents were best under ambient compression conditions. Data from mass loss and flesh firmness suggested that the effect of the bin material is more significant than the effect of compression relative to ageing. In other words, damage would be less on plastic surfaces regardless of fruit being compressed or not during storage at ambient conditions.

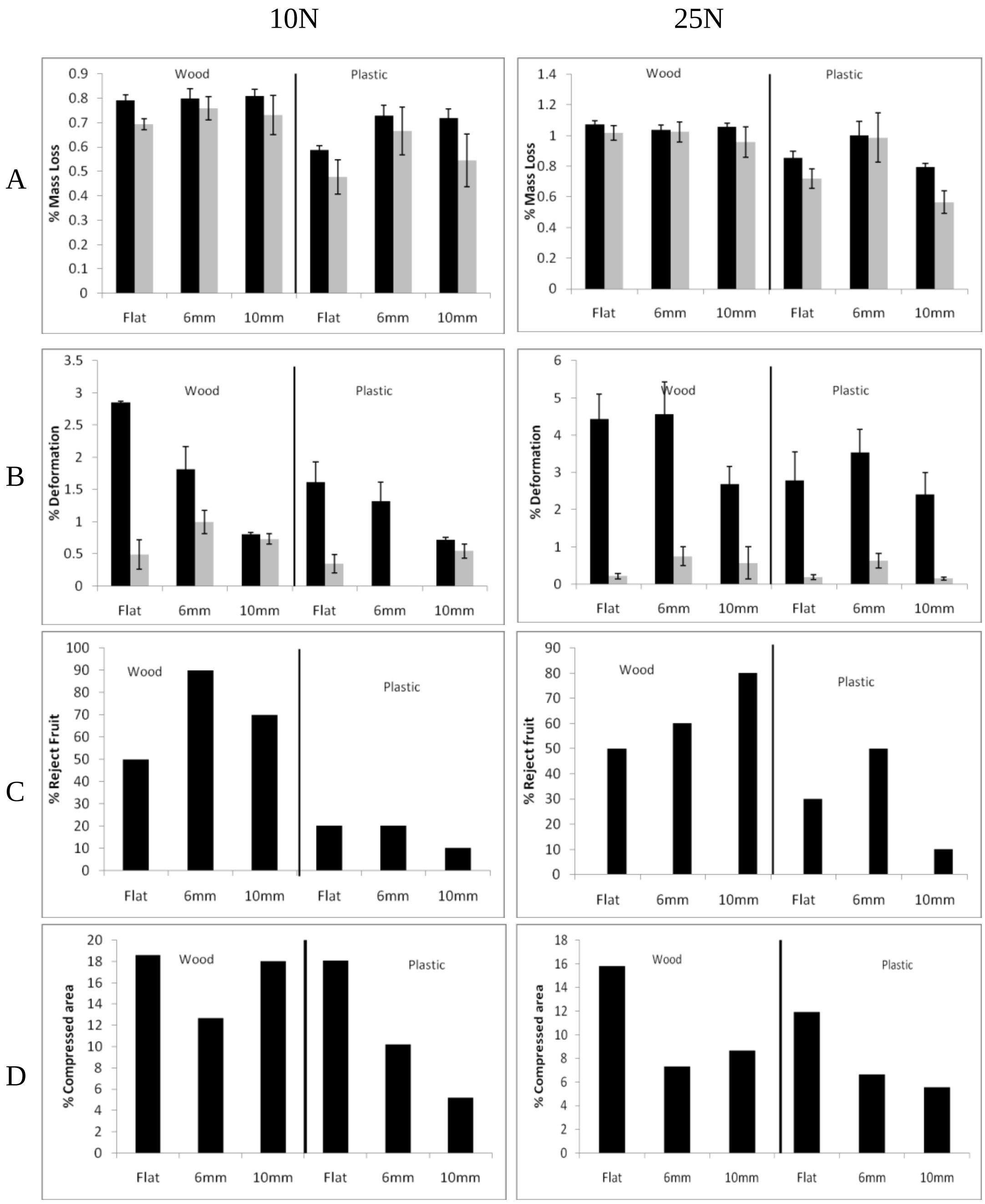


Figure 5.7: Damage to green kiwifruit measured directly after two days of compression under ambient conditions. A: % mass loss; B % deformation; C: % rejected fruit; D: % compressed area.

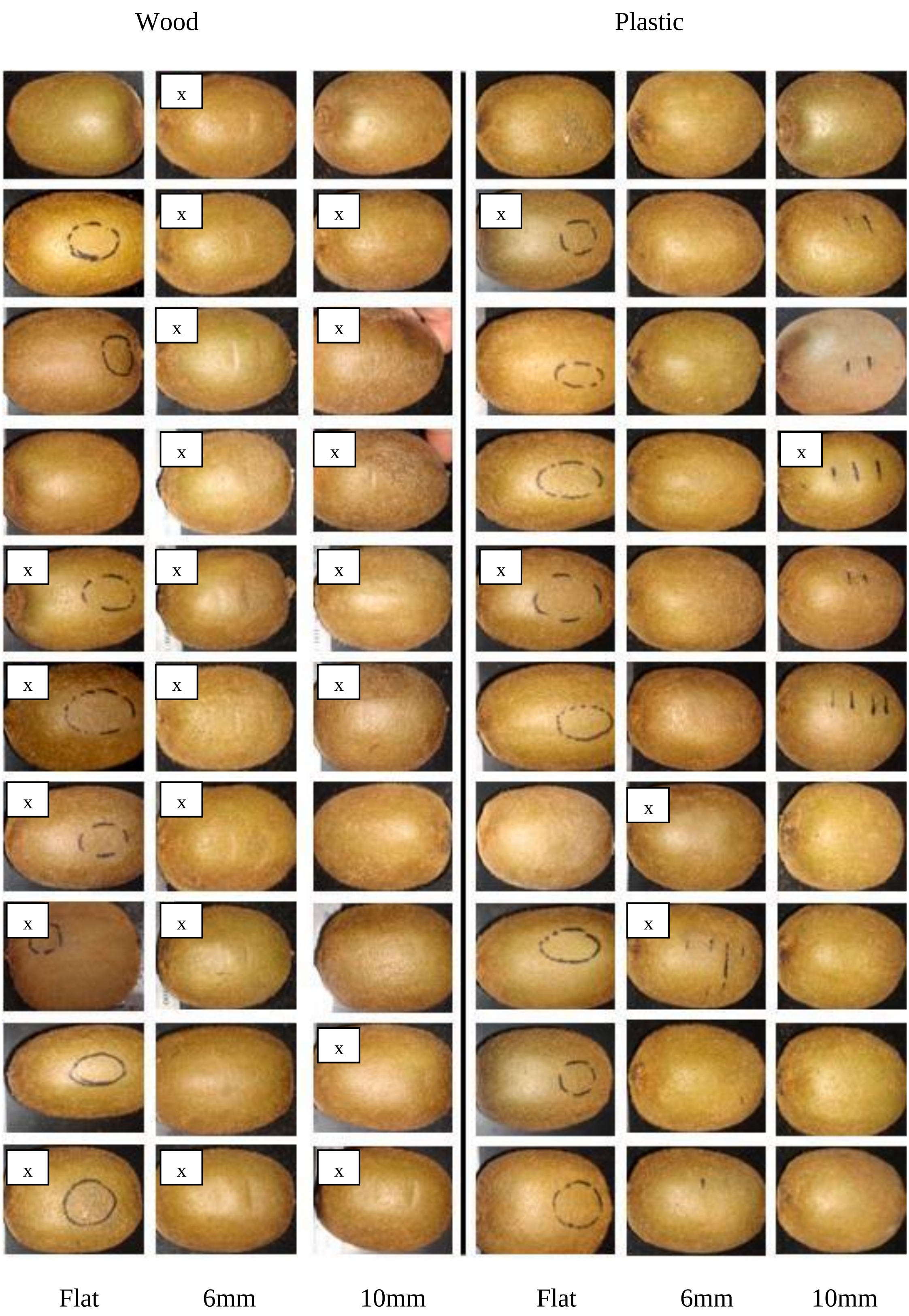


Figure 5.8: Visible damage to 10 N firmness green kiwifruit observed directly after two days of compression under ambient conditions for wood and plastic surfaces.

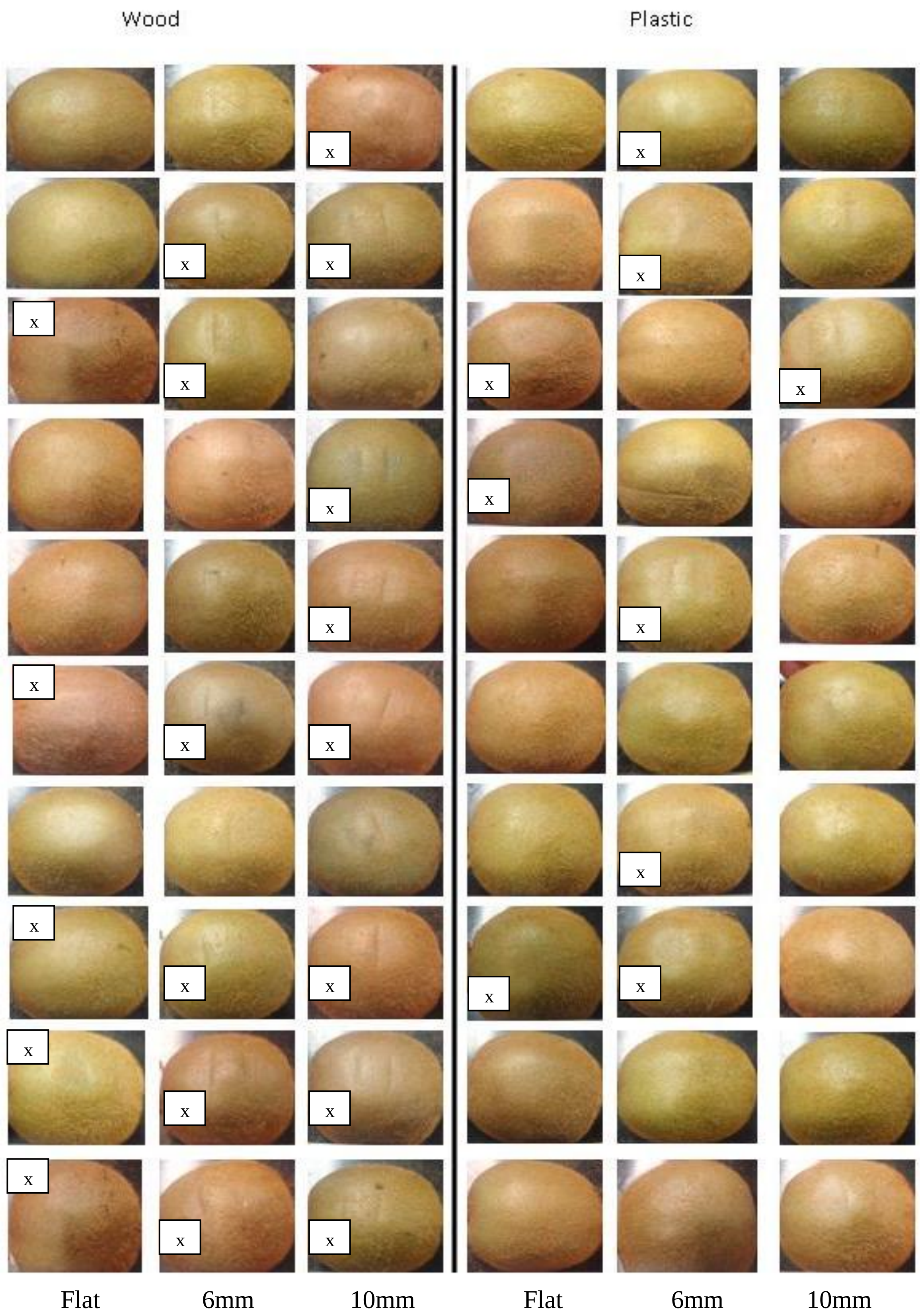


Figure5.9: Visible damage to 25 N firmness green kiwifruit observed directly after two days of compression under ambient conditions for wood and plastic surfaces.

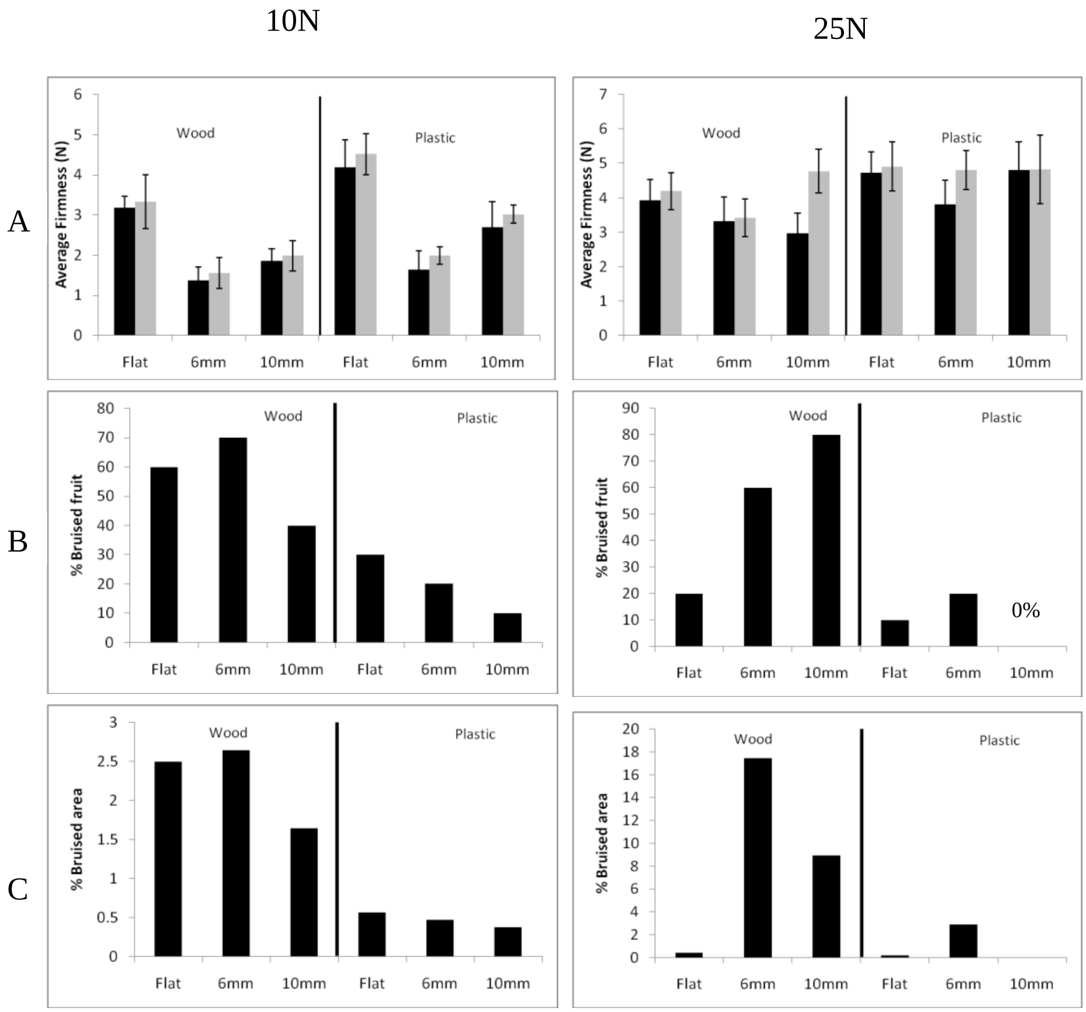


Figure 5.10: Damage to green kiwifruit measured after a 30 day holding period preceded by two days of compression under ambient storage. A: average firmness; B % bruised fruit; C: % bruised area.

Figure 5.11: Bruise damage in green kiwifruit after a 30 day holding period preceded by two day compression under ambient conditions.

30 day compression under cool storage

From Figure 5.12A, no statistically significant differences were found between mass loss of tests and controls for both firmnesses based on 99% confidence interval. An exception to this was compression of 25 N firmness fruit on flat wood, which showed that compression lead to significantly more mass loss than fruit just sitting under their own weight. Although not statistically significant at 99% confidence, the mass loss for 10 N fruit on flat wooded surfaces was also observed to be more than their corresponding controls. This would suggest that wood is at least partially responsible for withdrawing moisture from fruit during compression.

Statistical analysis revealed that mass loss differences within each surface type for each bin material were insignificant for both firmnesses except for the compression of 10 N soft fruit on flat plastic which showed significantly less mass loss on vented surfaces. This suggested that flat plastic surfaces prevented moisture loss more efficiently than other surfaces tested.

From Figure 5.12B, a clear difference in percentage fruit deformation between tests and controls were observed, for both 10 and 25 N fruit. Deformation on plastic was found to be less than wood for all surface types while individual surface types did not have a significant influence on deformation.

Visible damage on fruit is shown in Figures 5.13 and 5.14 respectively. These images were used to calculate percentage rejected fruit and is shown in Figure 5.12C. It can be seen that the extent of visible damage was significantly higher in fruit compressed on wood. Furthermore, vented wood surfaces lead to more fruit rejections that flat wood for 10 N firmness fruit. For 25 N fruit, all fruit compressed on wood were rejected irrespective of the surface type. Plastic surfaces consistently resulted less fruit rejection for both firmnesses, further improved by introducing 10 mm vents.

Considering the data presented in Figure 5.12D, it can be seen that larger compressed areas were observed in 10 N fruit. This can be expected as softer fruit would deform more than harder fruit under coolstorage. For 10 N fruit, compressed areas were about the same between different wooden surfaces. Compressed areas were lower using plastic surfaces, with 10 mm vents resulting in the best performance. When using 25 N fruit, introducing vents resulted in a significant drop in compressed area. It can be concluded that for all surface types and both firmnesses, plastic surfaces led to less damage compared to wooden surfaces.

From Figure 5.15A it can be observed that the affect of compression was negligible for both fruit firmnesses compared to the corresponding controls. However, compression of fruit on plastic surfaces consistently showed higher firmness than wooden surfaces. Furthermore, 10 mm vents further improved fruit quality.

It is apparent from Figure 5.15B and Figure 5.15C that for 10 N fruit, percentage bruised areas and percentage bruised fruit were significantly higher for wooden surfaces than any plastic surface. However, for 25 N firm fruit bruise damage was comparable to that of plastic surfaces and no bruise damage was visible for 10 mm vents.

Considering the above results, it can be concluded that 10 mm vents in plastic surfaces were the most efficient at maintaining fruit quality. The combined effect of wood causing moisture loss and sharp edges of vented wooden bins resulted in the superior behavior observed using plastic surfaces. The economic benefit of using plastic bins is presented in Section 5.3.

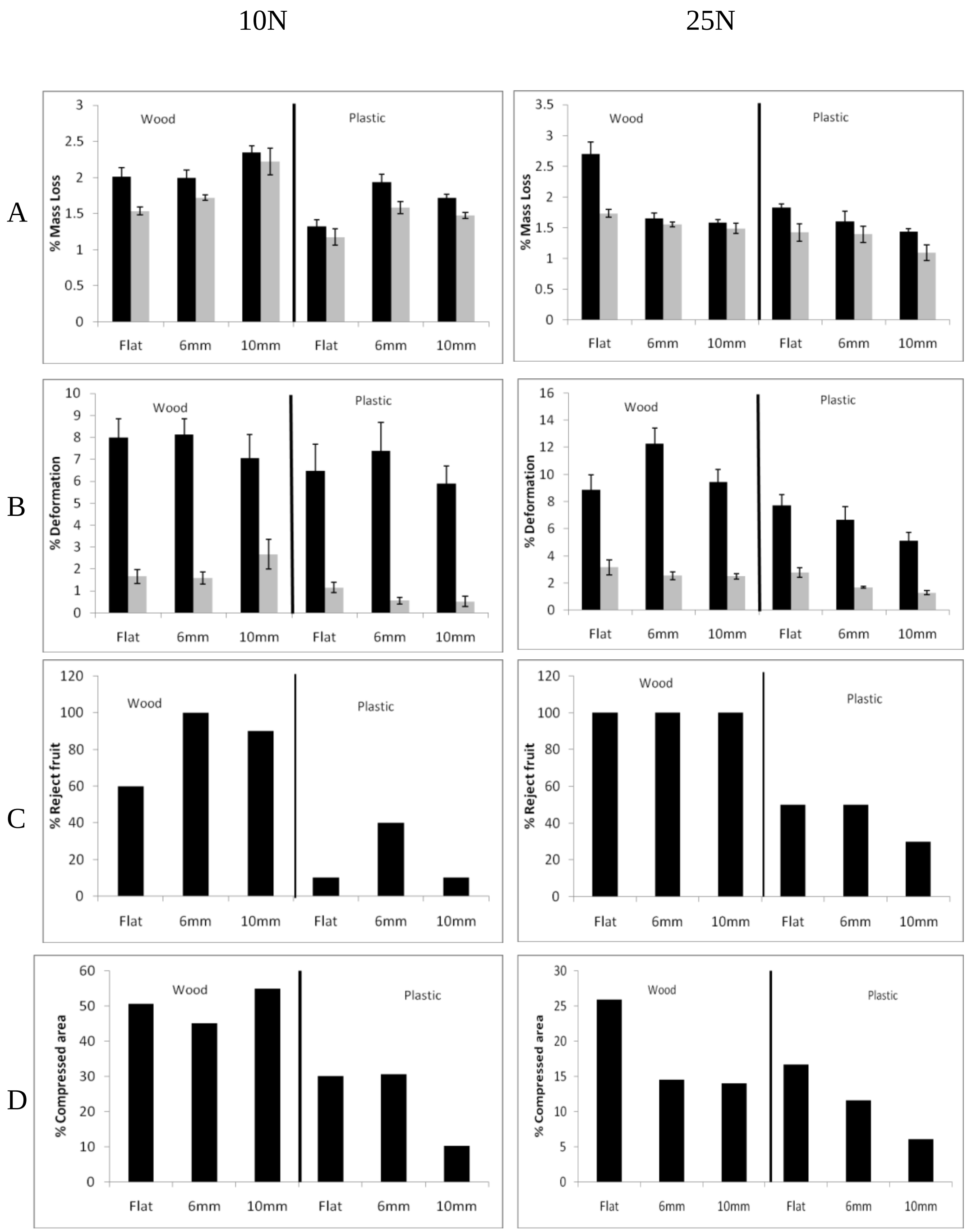


Figure 5.12: Damage to green kiwifruit measured directly after a 30 day compression under coolstorage conditions. A: % mass loss; B % deformation; C: % rejected fruit; D: % compressed area.

Wood Plastic

Flat 6mm 10mm Flat 6mm 10mm

Figure5.13: Visible damage to 10 N firmness green kiwifruit observed directly after 30 days compression under coolstorage conditions for wood and plastic surfaces.

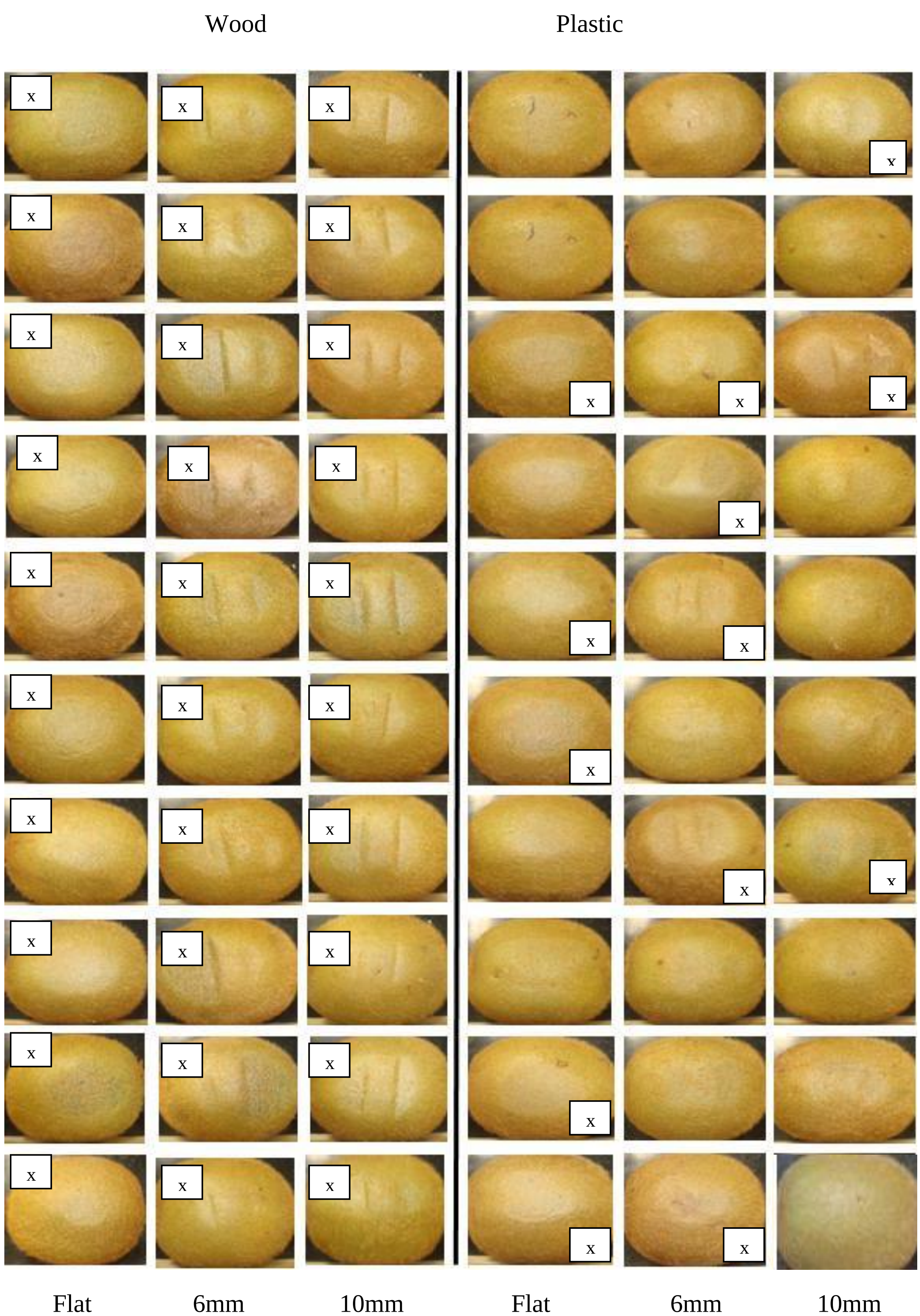


Figure5.14: Visible damage to 25 N firmness green kiwifruit observed directly after 30 days compression under coolstorage conditions for wood and plastic surfaces.

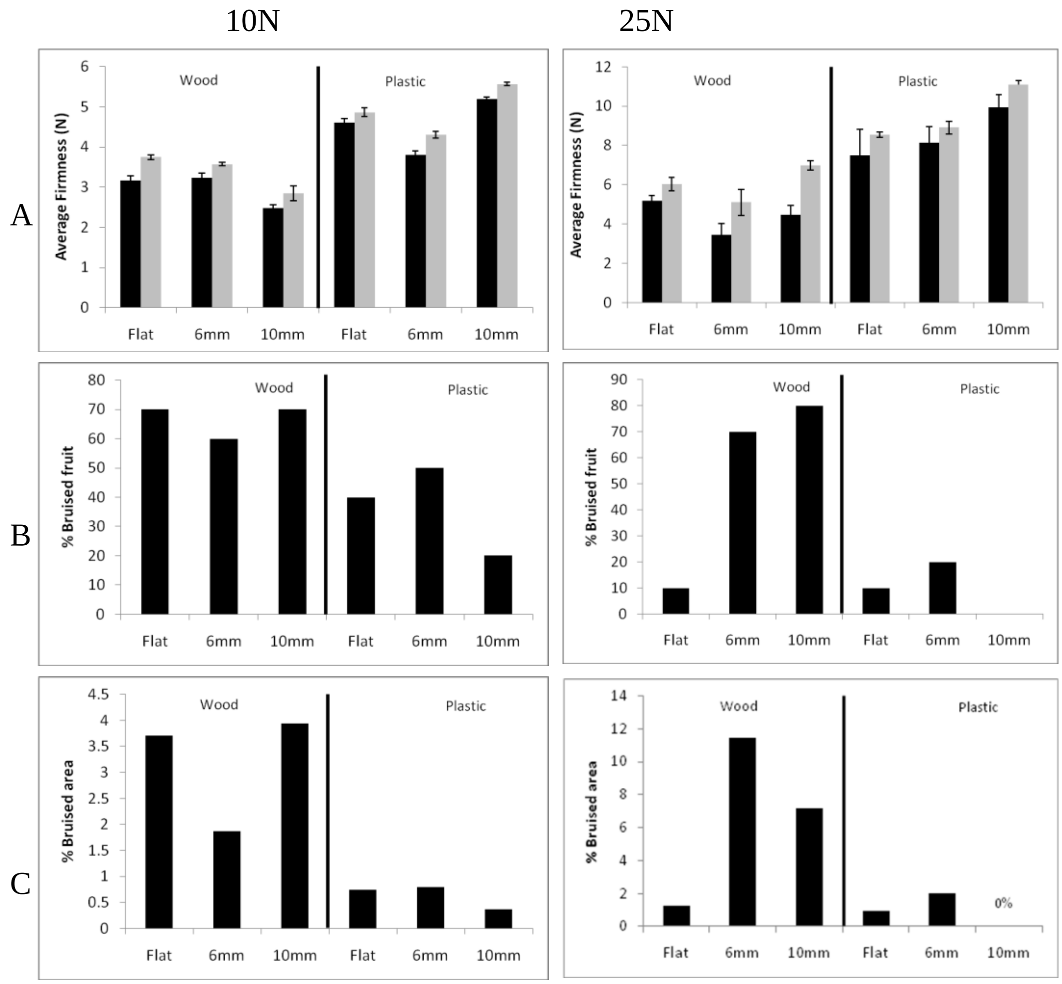


Figure 5.15: Damage to green kiwifruit measured after a 30 day holding period preceded by 30 days of compression under cool storage. A: average firmness; B % bruised fruit; C: % bruised area.

5.2.1.2 Gold Kiwifruit

Two day compression under ambient conditions

From Figure 5.16A, it can be seen that for 10 N firmness fruit, mass loss calculated after compression was not significantly different compared to uncompressed controls. Only minor differences were observed between plastic and wooden surfaces.

Mass loss on vented wood surfaces for harder 25 N fruit was found to be significantly more compared to uncompressed fruit, based on a 99% confidence interval. It was found that the effect of surface material (i.e. wood or plastic) was more significant than surface type (vented or flat) and plastic surfaces were best.

From Figure 5.16B, a clear difference in fruit deformation between tests and controls can be observed. For 10 N fruit, deformations were quite similar for same surface types between wood and plastic. It could be due to the fact that softer fruit deform more easily and deformation is less influenced by the bin material. However, for 25 N fruit, fruit deformation was found to be less on plastic.

From Figure 5.16C, it can be seen that fruit rejections from wood were significantly higher than plastic surfaces. Flat plastic was found to best in both firmnesses. However, from Figure 5.16D, a clear difference in compressed area between wood and plastic can be observed and was lowest using 10 mm vented plastic. Flat surfaces lead to higher compressed areas; however fruit are only rejected if skin showed signs of darkening and softening.

From Figure 5.19A, it can be seen that the firmness of compressed fruit were very similar to controls in all cases. For 10 N fruit, bin material was found to have an insignificant influence on fruit firmness, using any surface type. However, for 25 N fruit, using flat and 10 mm vented plastic showed to reduce the loss in fruit firmness over that of using wood.

Figure 5.20 shows typical bruise damage in gold kiwifruit from wooden and plastic surfaces and were used to calculate percentage bruised fruit and bruise areas for the different surfaces tested (Figure 5.19B and Figure 5.19C). It was found that minimum bruised fruit and bruise damage occurred in fruit compressed on 10 mm vented plastic surfaces.

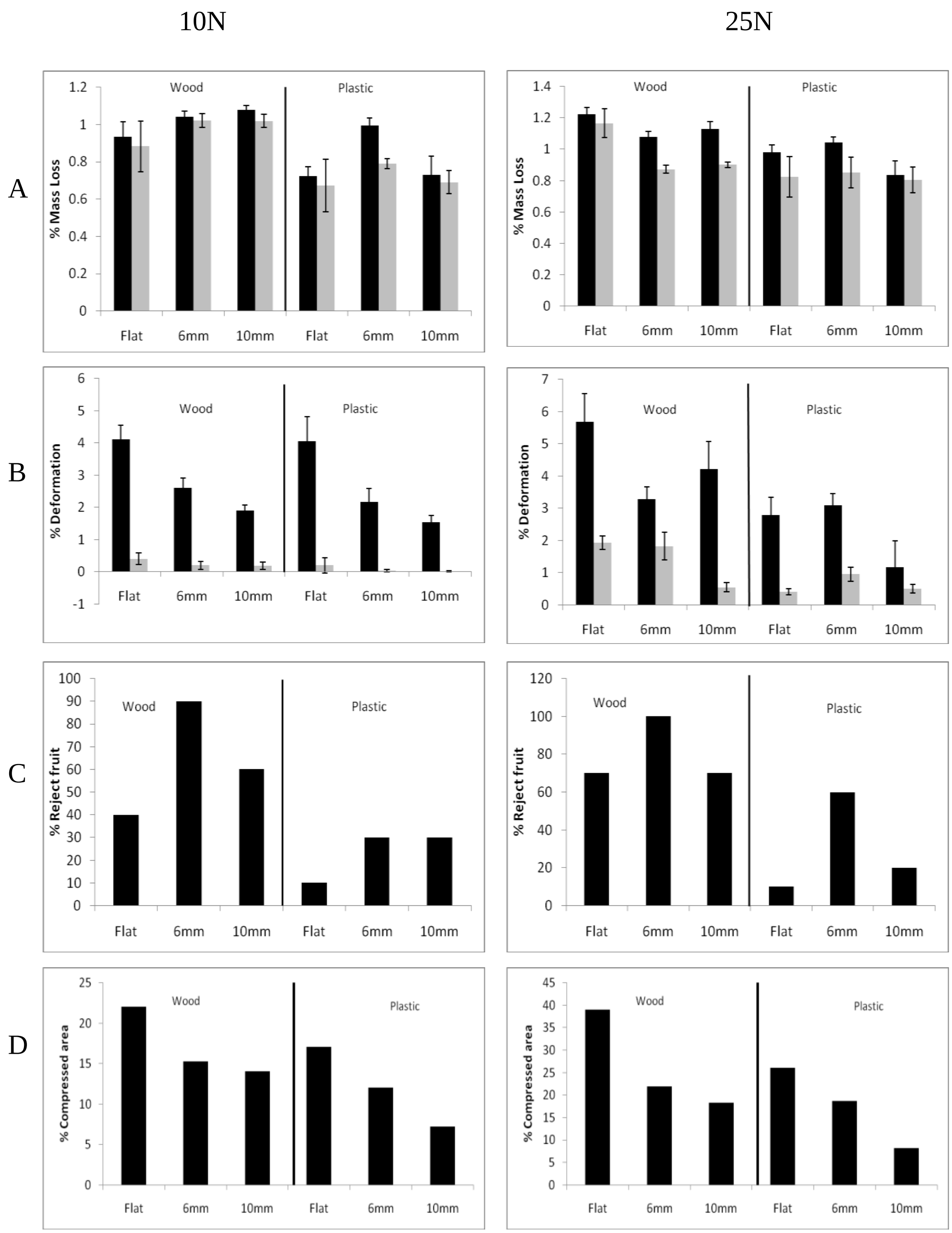


Figure 5.16: Damage to gold kiwifruit measured directly after two days of compression under ambient conditions. A: % mass loss; B % deformation; C: % rejected fruit; D: % compressed area.

.

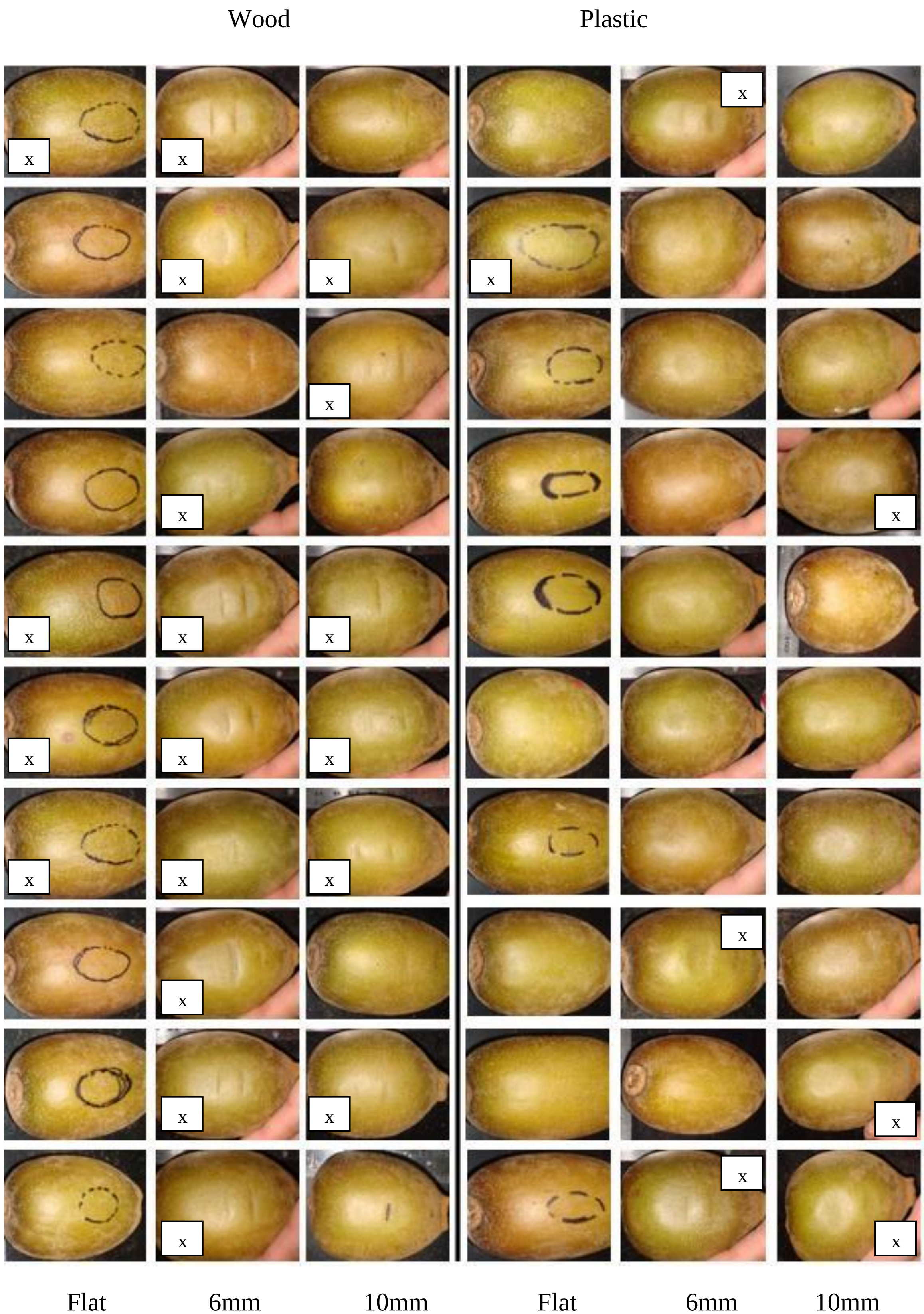


Figure 5.17: Visible damage to 10 N firmness gold kiwifruit observed directly after two days of compression under ambient conditions for wood and plastic surfaces.

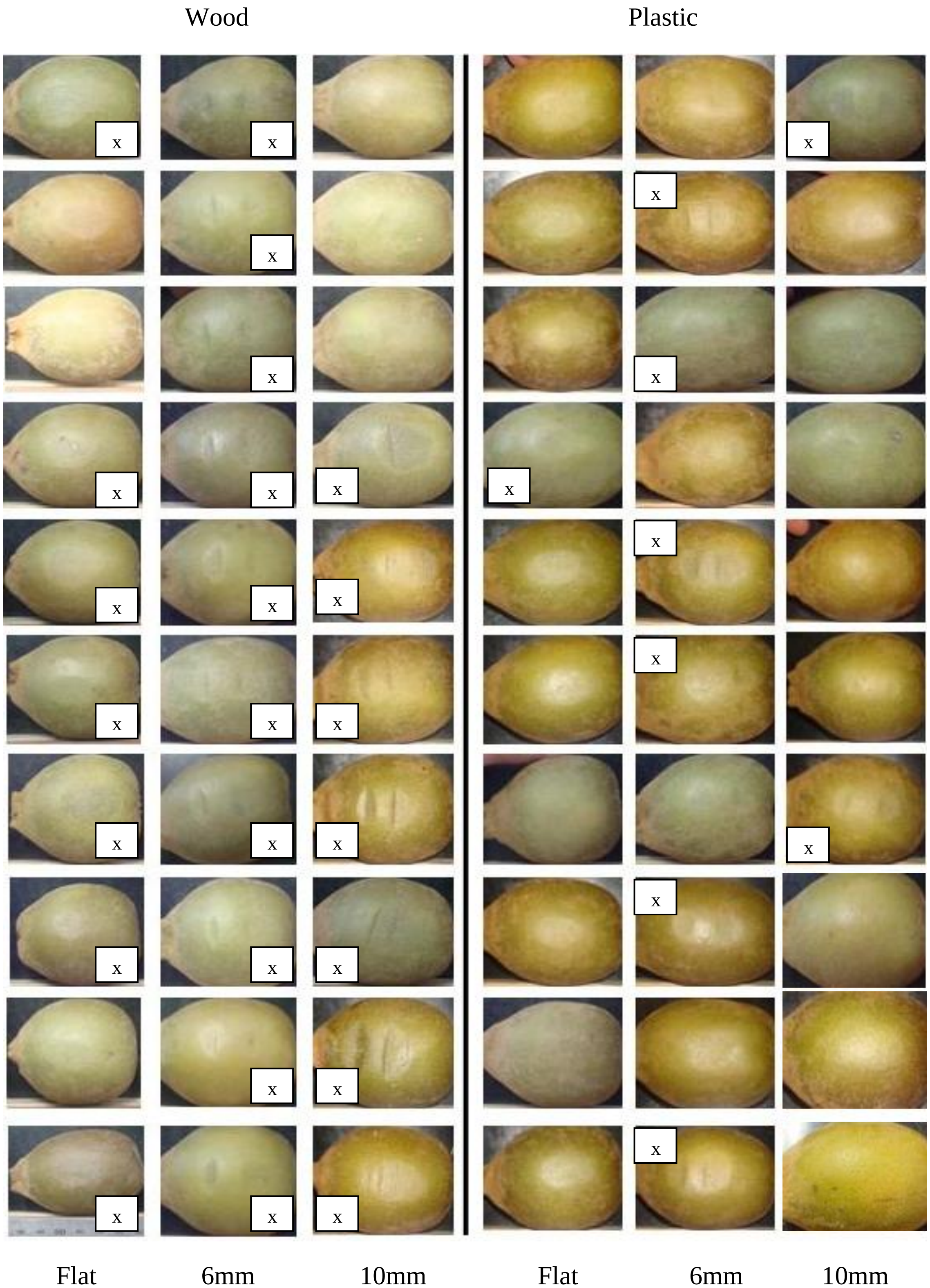


Figure 5.18: Visible damage to 25 N firmness gold kiwifruit observed directly after two days of compression under ambient conditions for wood and plastic surfaces.

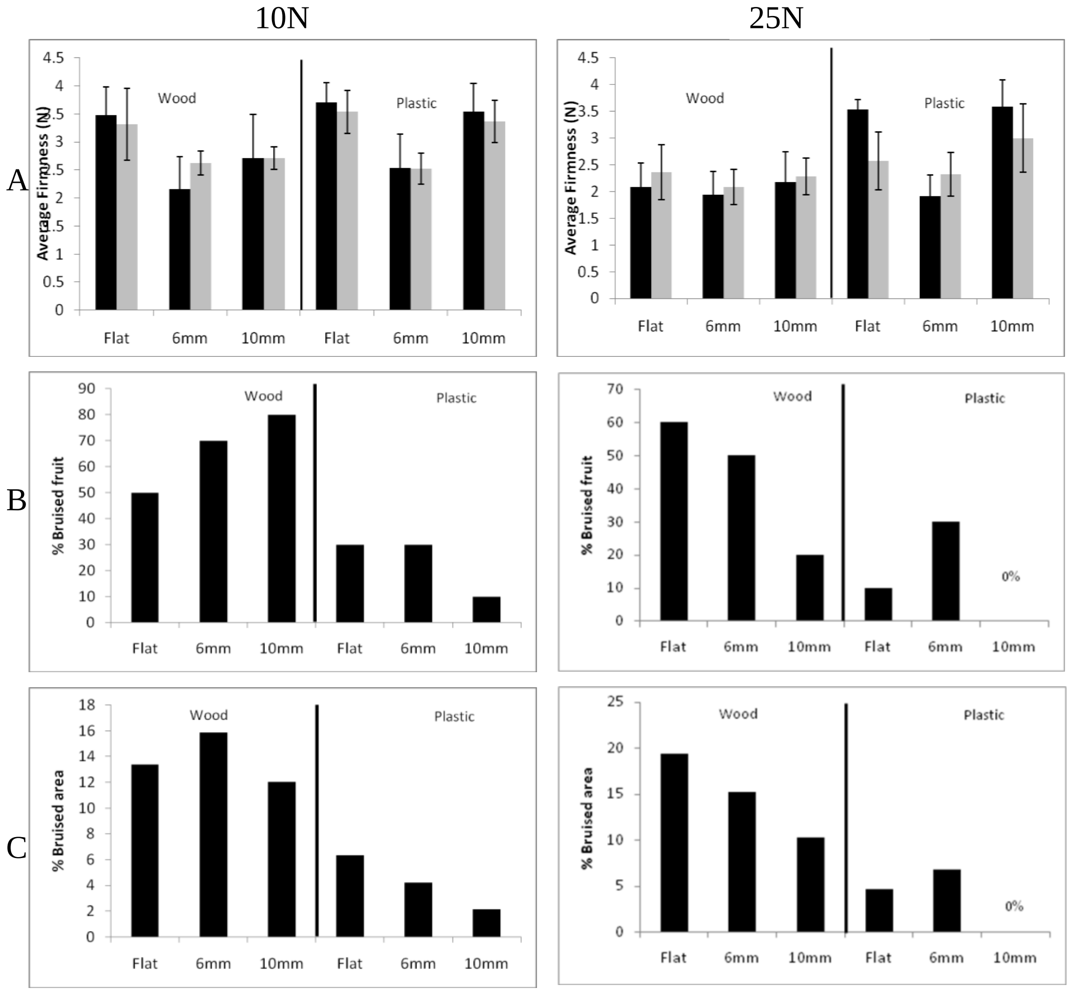


Figure 5.19: Damage to gold kiwifruit measured after a 30 day holding period preceded by two days of compression under ambient conditions. A: average firmness; B % bruised fruit; C: % bruised area.

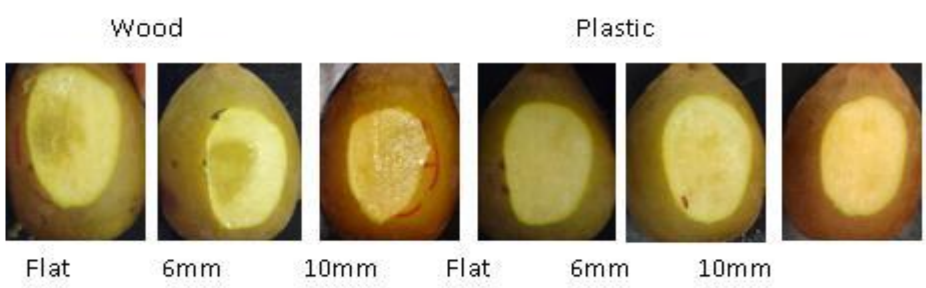


Figure 5.20: Bruise damage in gold kiwifruit after a 30 day holding period preceded by two day ambient compression.

30 day compression under cool storage

From Figure 5.21A it can be seen that using plastic surfaces did not lead to any significant reduction in mass loss for any surface type. In addition, no significant mass loss differences were observed between tests and controls for both firmnesses except for the compression of hard fruit on flat surfaces. This suggested that the affect of actual compression is less important than the material in contact.

Significant deformation differences were observed between tests and controls for both fruit firmnesses, as shown in Figure 5.21B. Fruit deformation was found to be consistently lower on flat and 6 mm vented plastic, using fruit of 10 N firmness. However, no significant differences were observed between wood and plastic surfaces using 25 N fruit, although 10 mm vents were best in both cases.

Figure 5.21C shows that compression of 10 N firmness fruit on plastic surfaces led to less fruit rejection compared to wood surfaces. However, for 25 N fruit, fruit rejection from plastic surfaces was only slightly less than wood surfaces. In addition, Figure 5.21D revealed that for both firmnesses, 10 mm plastic vents led to smaller compressed areas. It was found that the difference between wood and plastic surfaces was most pronounced using softer fruit. In addition, venting reduced contact pressure on fruit surfaces, resulting in less damage.

It was concluded from Figure 5.24A that for both fruit firmnesses, compression under cool storage did not show any significant difference between tests and controls. Although there were apparent differences between tests and controls for 10 N firmness fruit compressed on vented surfaces, these were found to be statistically insignificant. It can be said with 99% confidence that significant differences existed between firmnesses of 25 N firmness fruit compressed on vented wood and plastic. No other tests showed differences between wood and plastic due to larger deviations in data.

Between plastic surfaces, flat plastic showed highest firmness for softer fruit and 10mm vented plastic showed the highest firmness for 25 N firmness fruit.

Figure 5.24B shows that the percentage bruised fruit were about the same for all wooden surfaces using either 10 or 25 N firmness fruit. Plastic lead to significantly less bruised fruit compared to wood for all surfaces investigated. In addition, percentage bruised area was found to be noticeably lower using plastic surfaces as compared to wood for both firmnesses tested (Figure 5.24C). The lowest percentage bruised area was observed for 10 mm vented plastic surfaces.

From above discussion, it can be concluded that using plastic lead to less visible damage compared to using wood. It was found that among all surfaces and bin materials investigated, 10 mm plastic vents preserved fruit firmness better and also resulted in less bruised fruit and that the effect of bin material is more important than the effect of compression.

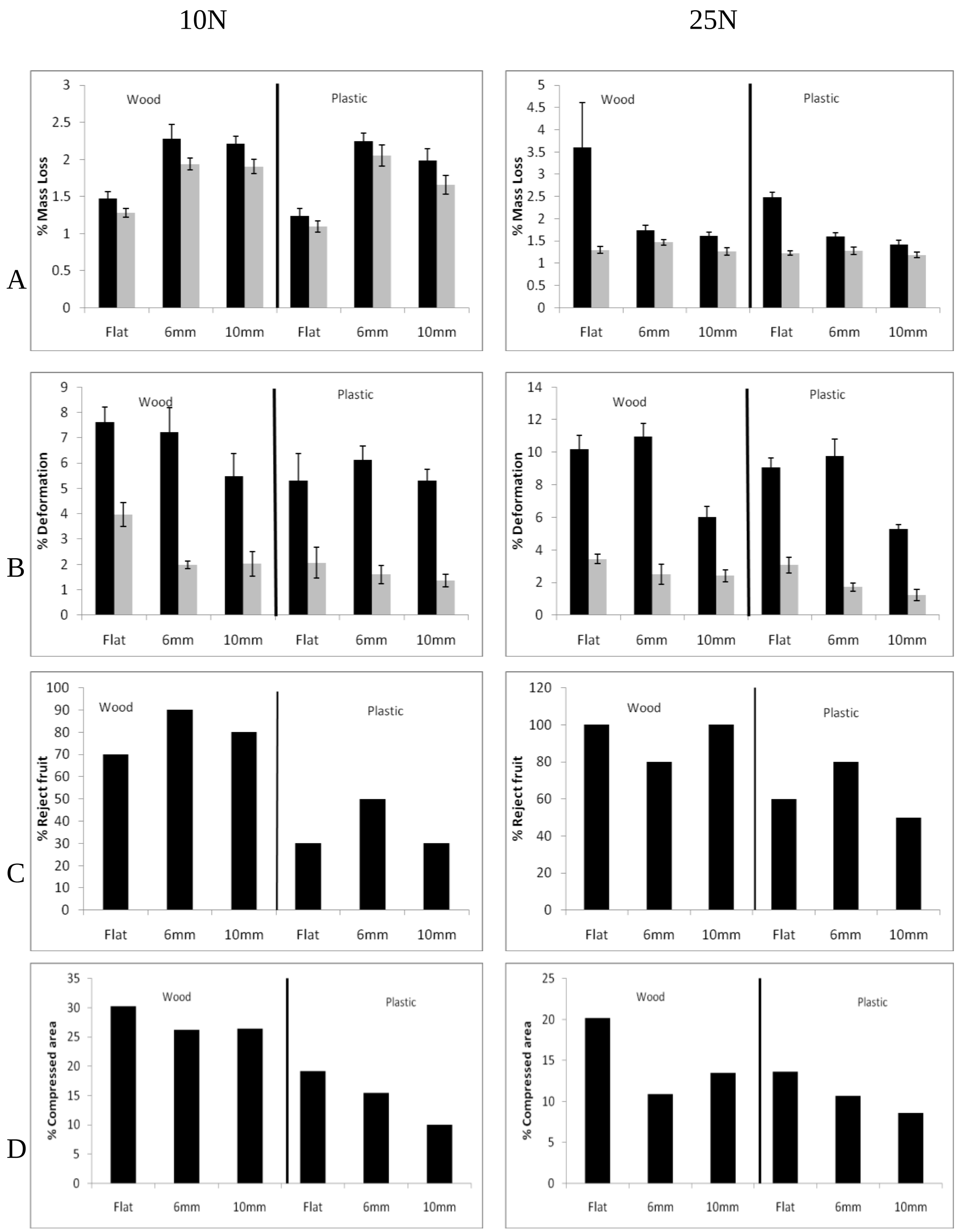


Figure 5.21: Damage to gold kiwifruit measured directly after a 30 day compression under coolstorage. A: % mass loss; B % deformation; C: % rejected fruit; D: % compressed area.

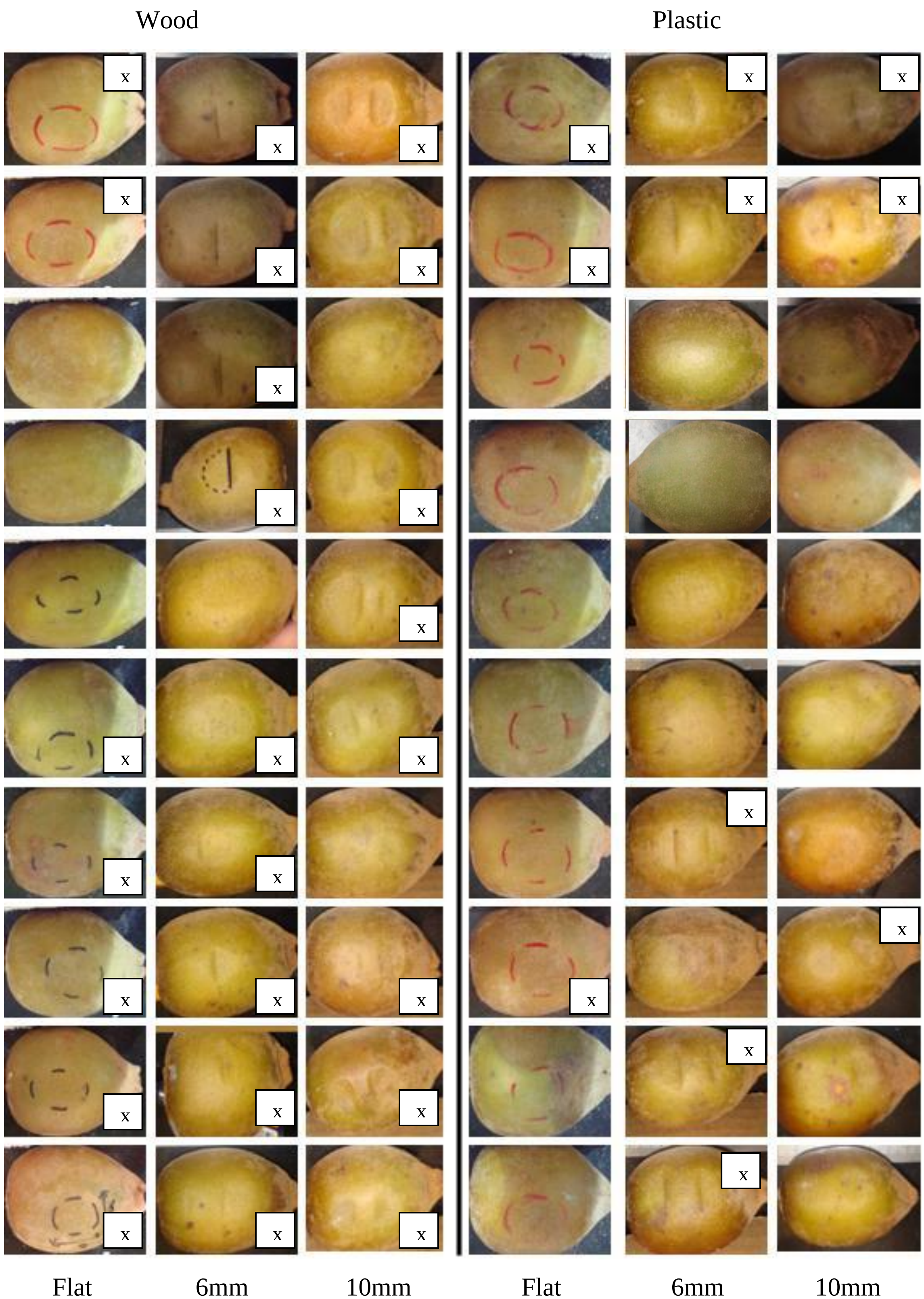


Figure 5.22: Visible damage to 10 N firmness gold kiwifruit observed directly after 30 days of compression under coolstorage conditions for wood and plastic surfaces.

Figure 5.23: Visible damage to 25 N firmness gold kiwifruit observed directly after 30 days of compression under coolstorage conditions for wood and plastic surfaces.

10N 25N

A

B

C

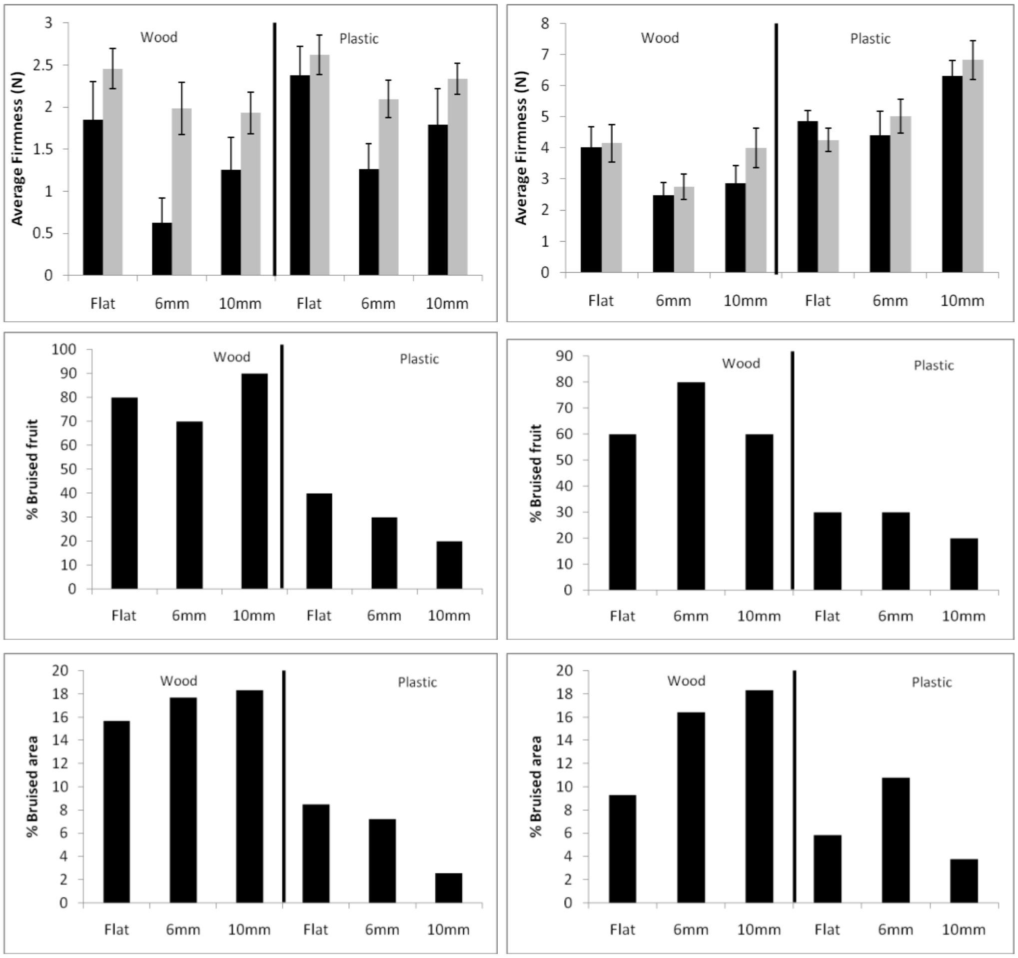


Figure 5.24: Damage to gold kiwifruit measured after a 30 day holding period preceded by 30 days of compression under cool storage. A: average firmness; B % bruised fruit; C: % bruised area.

In the light of the compression tests, it can be concluded that the choice of bin material had a huge effect on physical damage to fruit and consequent fruit rejection. It was found in almost every test that plastic resulted in less damage.

It can be concluded from these experiments that that visible damage was greater in both green and gold varieties over long term compression under cool storage. However, it was also observed that for softer fruit, two-day compression at ambient conditions could be seriously detrimental to fruit firmness, even more than 30 days in cool storage (Figures 5.7C, 5.12C and 5.21C).

10 mm vents on plastic caused significantly less visible damage, bruising, compressed areas, percentage mass loss, percentage deformation and loss of fruit firmness. This can be explained by two factors: air circulation around a fruit on 10 mm vented plastic could help preserve fruit quality. Secondly, larger, rounded vents resulted in less contact area between fruit and plastic, which prevented severe pressure spots.

5.2.2 Impact Damage

In order to assess damage to fruit, mostly as a result of dropping into bins during picking, impact testing was performed on fruit of a starting firmness of 10 and 25 N. Damage will only become evident after a 30 day holding period in cool storage.

5.2.2.1 Green Kiwifruit

From Figure 5.25A, it can be seen that the average firmness of fruit compressed on plastic surfaces were found to be consistently higher than any of the wood surface types. However, no statistically significant differences in fruit firmnesses were observed between vented and flat surfaces.

In Figure 5.26B and Figure 5.26C typical bruising in green kiwifruit after impact tests are shown. Percentage bruised fruit was found to be higher on flat surfaces as compared vented surfaces for wood and plastic. No bruising was found in kiwifruit impacted on plastic vents. In general, bruising on flat plastic surfaces was comparable to vented and flat wooden surfaces for both 10 and 25 N fruit.

Considering the nature of the impact tests used in this study, one has to consider the fact that fruit was carefully aimed to impact the surface across a vent. This would imply a smaller contact area between the fruit and the relevant surface. One would therefore expect that damage be highly localized resulting to more damage. However, the results indicated that damage on flat surfaces were much more significant. This could suggest that damage in fruit impacted on vented surfaces are simply too localized to be detected or requires a longer hold time to become evident.

5.2.2.2 Gold Kiwifruit

From Figure 5.27A no clear trend in the difference between damaged caused by vented and flat surfaces were observed for 10 N fruit. Although the differences were statistically significant, the trends are not consistent with other observations regarding damage (Figure 5.27B and Figure 5.27C). As a general observation, fruit impacted on plastic surfaces showed higher firmness than those impacted on wood. Statistically, significant differences were found only for 25 N firmness fruit compressed on 6mm plastic and wooden vents.

In regards to visible damage, no bruising was found in gold kiwifruit impacted on 6 and 10 mm plastic vents (Figures 5.27B and Figure 5.28). Percentage bruised fruit were higher in 10 N as compared to 25 N fruit, which is expected as firmer kiwifruit is generally less prone to impact damage.

Overall, it can be concluded that vented plastic surfaces did not cause any significant bruise damage to fruit. However, impact damage was found to be higher in 10 N fruit 10 mm plastic vents were found to be the best among all surfaces, suggesting that well rounded edges, further apart is more effective at preventing damage than smaller vents or flat surfaces.

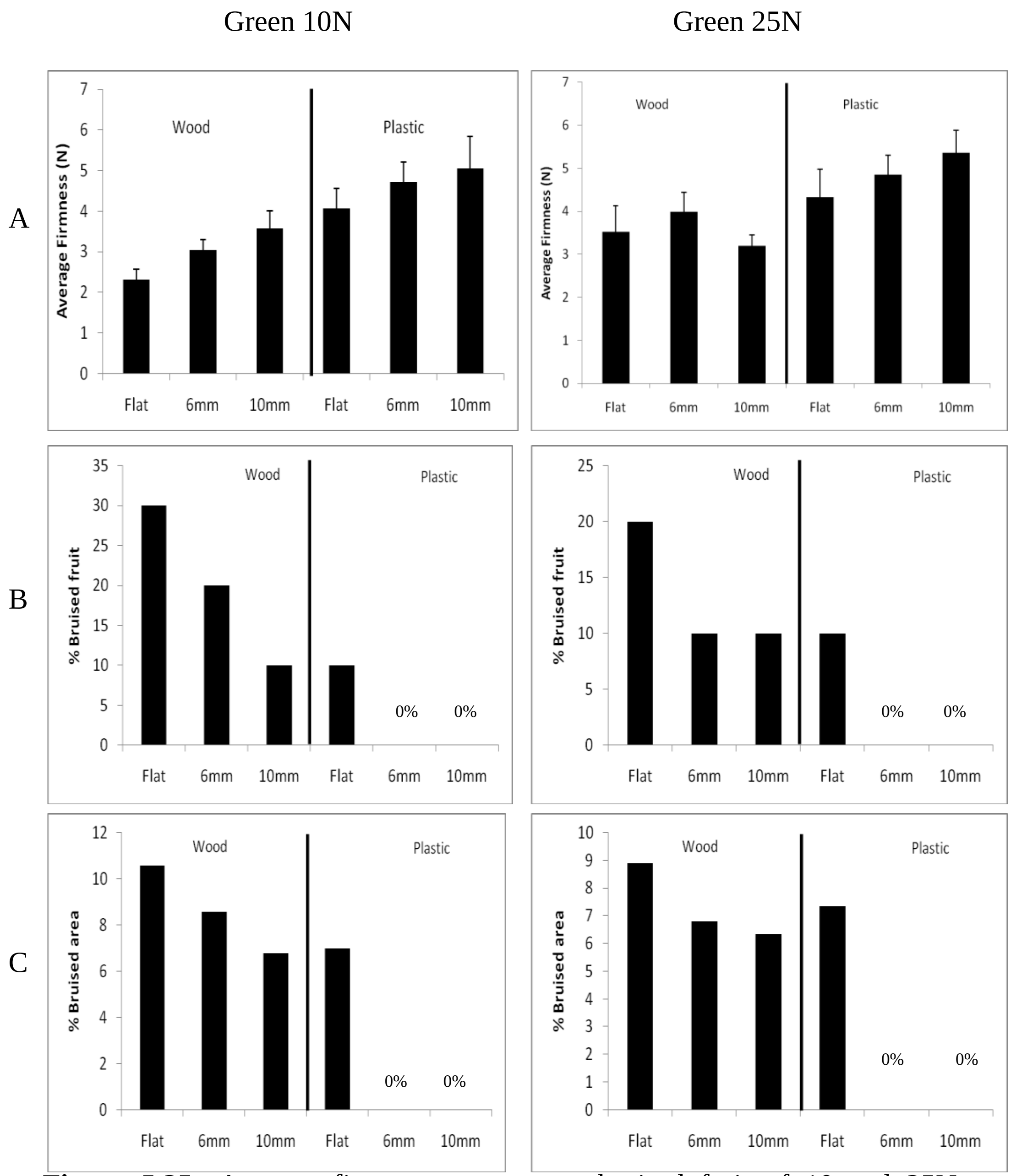


Figure 5.25: Average firmness, percentage bruised fruit of 10 and 25N Green kiwifruit following impacts tests.

Figure 5.26: Impact bruises in green kiwifruit.

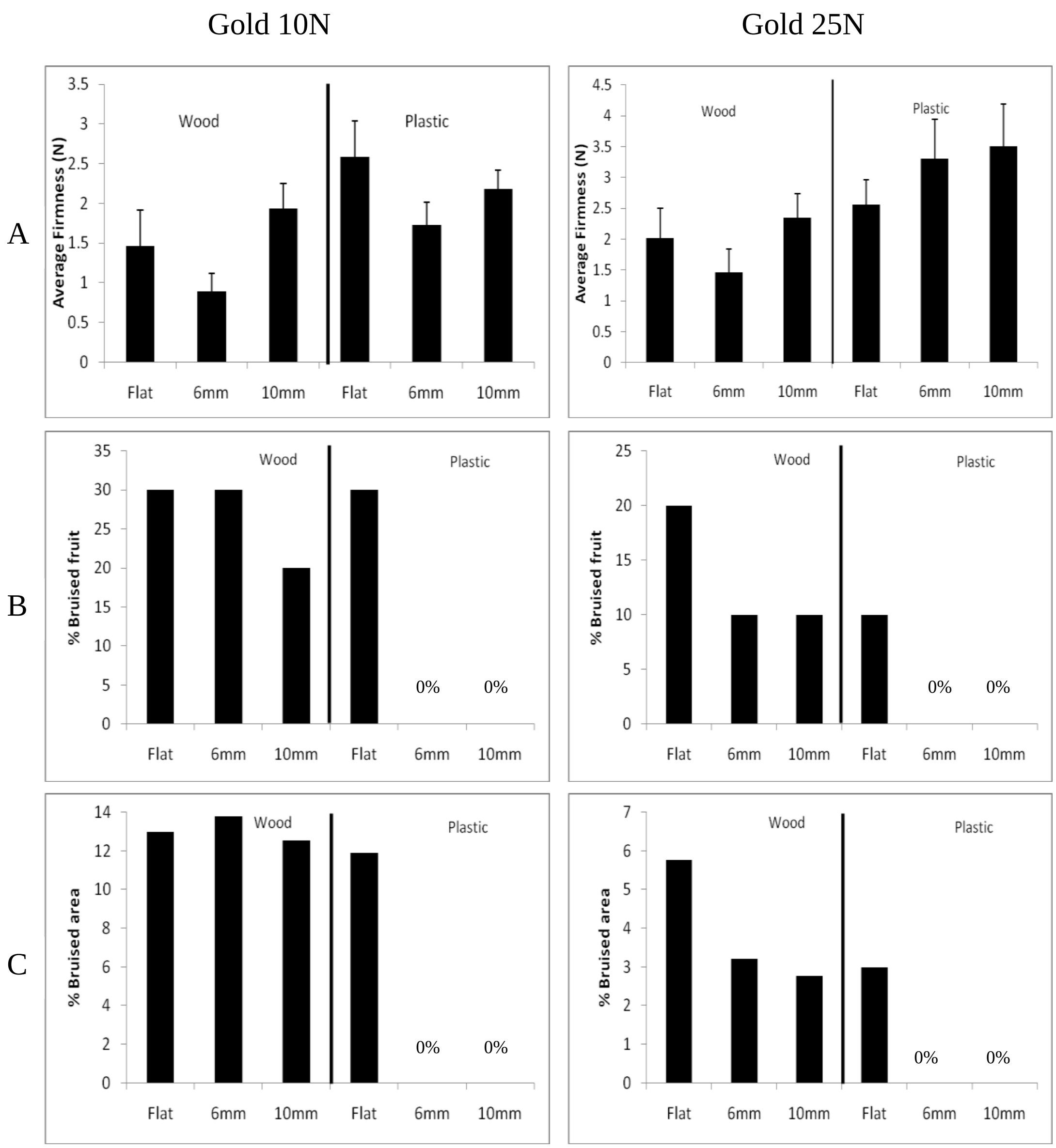


Figure 5.27: Average firmness, percentage bruised fruit of 10 and 25N Gold kiwifruit following impacts tests.

Figure 5.28: Impact bruises in gold kiwifruit.

5.3 Economic Analysis

In order to evaluate the benefit of using plastic bins, fruit damage had to be expressed in term of the financial impact of changing to plastic bins. Plastic bins are significantly more expensive than wooden bins and is typically sold for $ 200-250 while wooden bins are sold for $ 80-100. In order to justify the extra cost of plastic bins, the financial benefit of reduced fruit rejection should outweigh the additional cost of plastic bins. In kiwifruit packhouses, fruit are graded for visible damage and size. Any signs of physical injury on fruit will lead to fruit rejection. Mass loss following cool storage and controlled atmosphere storage is a major concern of the Kiwifruit Industry as fruit is sold on a mass basis.

Assuming, kiwifruit with an average diameter of 50 mm are tightly packed in a harvesting bin with an inner height of 400 mm, 8 layers of fruit can be packed in each bin. It is further assumed that compression damage is localized to the bottom layer of each, which would mean that a maximum of one eighth of each bin could be affected by compression damage. Also, only the first layer of fruit could be potentially damaged as a result of impacting with the bin surface during picking. An added complication is that not all fruit are stored under ambient conditions and cool storage. As explained in earlier chapters, fruit are typically cured for a day prior to direct shipping, cool storage or storage under controlled atmosphere. A summary of these parameters are shown in Table 5.1.

Table 5.1: Summary of parameters for assessing economic benefit

	Wooden bin	Plastic bin
Price	$ 80 – 100	$ 200 – 250
Capacity	250 kg	300 kg
Fruit on bottom layer	31.25 kg	37.5 kg

Only mass loss and percentage fruit rejection based on visual damage were considered in the economic analysis. Bruise area, percentage bruised fruit and fruit firmness are considered evidence of damage, but cannot be directly converted to fruit rejection.

The mass remaining in the bottom lays of a bin, after the combined effect of two day ambient compression and 30 day cool storage is calculated using Equation 1:

$$M_1 = M_B \times \left(100 - M_{c,2} - M_{c,30}\right)/100 \ldots \text{ (1)}$$

where:

M_1	= mass remaining in bottom layer after moisture loss
$M_{C,2}$	= % mass loss due to two day compression under ambient conditions
$M_{C,30}$	= % mass loss due to 30 day compression under cool storage

It was assumed that the mass loss due to two day compression and 30 day compression would be additive. In this study the effect of compression under ambient and coolstore conditions were explored individually. However, in actual practice, fruit in bins are kept under canopy and the same fruit are moved to cool storage. In other words, the same fruit are subjected to ambient and cool storage conditions. In addition, no significant differences in percentage mass loss was observed between softer and firmer fruit under ambient and cool storage conditions, it was therefore decided to use the more conservative 10 N firmness values.

Total mass loss as a result of damage is then calculated using Equation 2:

$$M_{total} = M_1 \times \left(R_I\right)/100 \ \ldots \text{ (2)}$$

where:

M_{total}	= total mass loss
M_B	= mass on bottom layer of bin
R_I	=maximum percentage rejection from impact, two day compression ($R_{I,2}$) or 30 day compression ($R_{I,30}$).

For impact damage, visible damage was not apparent immediately after testing; therefore, percentage bruised fruit have been used an estimate of rejected fruit.

Each bin is typically filled with fruit only once per season. If it assumed that green kiwifruit is sold for \$1.17 /kg and gold kiwifruit for \$2.03 /kg the payback period for switching to plastic bins can be calculated by using Equation 3:

$$P = \frac{(C_P - C_W)}{\left((M_{total})_{wood} - (M_{total})_{plastic}\right)} \times \frac{1}{S} \ldots (3)$$

where:

P	= payback period in seasons
C_p	= cost of plastic bin (\$225)
C_W	= cost of wooden bin (\$90)
M_{total}	= total mass loss in either wooden or plastic bins
S	= sale price of either green or gold kiwifruit (\$)

A summary of the payback periods calculated for the different bins options are shown in Table 5.2.

Table 5.2: Summary of payback periods for different bin options.

	Bin type		
	Flat	6mm	10mm
Green			
10 N	10.6	7.3	4.8
25 N	9.7	9.4	5.9
Gold			
10 N	6.4	7.3	5.0
25 N	8.2	13.8	5.5

From Table 5.2, it can be seen that the payback period is a minimum for plastic surfaces with 10 mm vents for both varieties and for both firmnesses. Furthermore, the payback period calculated for firmer fruit was slightly longer compared to softer fruit. As damage to firmer fruit was generally less than softer fruit, one can expect a slightly longer payback period when bins are exclusively used for firm fruit. It is important to note, that in almost all cases the payback period for changing to a plastic bin is within the expected life of a single wooden bin. That means that savings made by reduced fruit rejection by changing to a plastic bin would pay for the extra cost of a plastic bin within the expected life span of a wooden bin.

The payback period also do not reflect other benefits of using plastic bins, such as reduced cleaning cost, bin breakage and other forms of damage typically associated with wooden bins (e.g. rotting or fungal growth). It could therefore be expected that when those factors are considered, the payback period by be even shorter.

Chapter 6: Conclusions and Recommendations

Physical damage to kiwifruit from wooden and prospective plastic harvesting bins from various damage mechanisms during harvesting and storage was investigated and quantified. Significant damage mechanisms during harvesting and storage were identified from literature and included compression damage (storage) and impact damage. It was concluded that visible damage was the most important factor in determining fruit rejection.

In this study, it was shown that visible damage to kiwifruit from contact to wooden bins was higher compared to plastic bins. Introducing 10 mm vents in plastic bins were found to cause least amount of damage to fruit in both ambient and cool storage compression testing. However, the effect of compression was found to be insignificant compared to the effect of bin material. Therefore, just by changing to a better material, fruit damage can be reduced significantly. It was concluded that, both green and gold fruit are influenced in the same way by 10 mm plastic vents, i.e. 10 mm vented plastic surfaces were found to cause least visible damage to fruit.

From compression of wood on different moisture content wood, it was found that the effect of storage compression is greater than that of wood moisture content.

It was found that compression in cool storage resulted in more damage compared to compression under ambient conditions, mostly due to longer time over which fruit were compressed.

Vents in wood were found to cause more damage than flat wood surfaces, and it was concluded that this was mainly due to the sharp edges of vents leading to severe compression spots. Well rounded edges of vents on plastic surfaces were found to reduce visible damage.

It was found that the cost of using more expensive plastic bins could be recovered by the saving from reduced fruit rejection. It was found that using 10mm vented plastic bins would be the most suitable option with shortest payback period of 5.5 seasons.

Due to time restrictions, it was only possible to run cool storage compression tests for duration of one month. It is recommended that compression tests be run for longer durations in order to further highlight differences between wood and plastic surfaces.

In addition, to complete the analysis, tests have also been replicated in controlled atmosphere conditions; however this was not possible due to time limitations.

Only two initial fruit firmnesses were investigated, however, to be relevant for the industry, it is essential to conduct analysis on firmer fruit, to give a comprehensive overview of how the results are influenced by initial firmness, in addition to the bin's construction material.

References

[1] Jewett, T. (1996), *Thomas Jefferson: Agronomist,* viewed March 5th 2010

[2] Warrington, I. J. and Weston, G. C. (1990), *Kiwifriut Science and Management*, Ray Richards Publisher, Auckland.

[3] Parker, K., Weal, S. and Fernyhough, A. (2008), *Waste 2 Gold- Feasibility Study for Zespri: Final Report,* Scion, Auckland.

[4] Dew, D. (2008), *Eastpack Ltd- 'Where OGR is everything'*, Eastpack Ltd,

[5] Waelti, H. (1992), *Should we use Plastic Bins?*, Tree Fruit Postharvest Journal, 3 (4), 14-17.

[6] Hauff, A. F. (1995), Agricultural Container,

[7] Garder, G. M. (2001), *Bin Strength Evaluation*, Lincoln Technology,

[8] Bollen, A. F., Woodhead, I. M. and Dela Rue, B. T. D. (1995), *Compression Forces and Damage in Postharvest Handling System*, in (Eds) *Harvest and POstharvest Technologies for fresh Fruits and Vegetables*, Mexico, pp. 168-175.

[9] Macro Plastics *MacroPlastics Harvest Bins* viewed April 23 2010, http://www.producersupplyco.com/bins.php

[10] Moreno Global Plastics *Plastic Bins from Moreno Global Plastics,* viewed April 21 2010, http://www.fatcow.com.au/c/Moreno-Global-Plastics/Plastic-Bins-from-Moreno-Global-Plastics-p20630

[11] Asia-Pacific, C. *Vented Plastic Bins from CHEP,* viewed April 23 2010, http://www.ferret.com.au/c/CHEP-Asia-Pacific/Vented-Plastic-Bins-from-CHEP-p13022

[12] Macro Plastics (2000), *Wooden versus Plastic Bins - better for apples?,* viewed www.macroplastics.com/mp/newsPage.do?newsId=2

[13] Zespri Group Ltd (2009), viewed 18 May 2009, www.zespri.com

[14] Woodward, T. J. (2006), Variation in 'Hayward ' kiwifruit quality characteristics, Thesis, University of Waikato.

[15] Ministry of Agriculture and Forestry (2010), *Fruit and Vegetables,Kiwifruit Production in New Zealand,,* viewed 15 July 2009, http://www.maf.govt.nz/mafnet/sectors/hort/fruit.html

[16] Hilterman, N. S. (2009), *Kiwifruit Bin Report*, Viscount Plastics New Zealand Ltd, Auckland.

[17] Fisk, C. L., Silver, A. M., Strik, B. C. and Zhao, Y. (2007), *Postharvest quality of hardy kiwifruit (Actinidia arguta ' Ananasnaya' associated with packaging and storage conditions*, Postharvest Biology and Technology, 47 (2008), 338-345.

[18] Antunes, M. D. C. and Sfakiotakis, E. M. Z. (2001), *Chilling induced ethylene biosynthesis in 'Hayward ' kiwifruit following storage*, Scientia Horticulturae, 92 (2002), 29-39.

[19] Harvey, J. M. and Harris, C. M. Y. d. D. (1986), *In-storage softening of kiwi fruit: effects of delayed cooling*, International Journal of Refrigeration, 9 (6), 352-356.

[20] Bollen, A. F., Timm, E. J. and Dela Rue, B. T. F. (2009), *Relation of individual forces on apples and Bruising during orchard transport of bulk bins*, Applied Engineering in Agriculture, 17 (2),

[21] Harley, L., Errol, H., Lallu, N., Mulligan, P., Muller, M. and Snowball, D. h. (2007), *Fruit losses in kiwifruit 2006*, New Zealand Kiwifruit Growers Incorporated, Auckland.

[22] Schaare, P. N. and Fraser, D. G. (2000), *Compasrison of reflectance, interactance and transmission modes of visible -near infrared spectroscopy for measuring internal properties of kiwifruit (Actinidia chinesis)*, Postharvest Biology and Technology, 20 (2000), 175-184.

[23] Strik, B. C. (2005), *Growing Kiwifruit*, Oregon State University,

[24] Ben-Arie, R. and Sonego, L. d. D.-.-. (1985), *Modified-atmosphere storage of kiwifruit (Actinidia chinensis Planch) with ethylene removal*, Scientia Horticulturae, 27 (3-4), 263-273.

[25] Fisk, C. L., Silver, A. M., Strik, B. C. and Zhao, Y. d. D. j. p. (2008), *Postharvest quality of hardy kiwifruit (Actinidia arguta [`]Ananasnaya') associated with packaging and storage conditions*, Postharvest Biology and Technology, 47 (3), 338-345.

[26] MacRae, E. A., Stec, M. G. H. and Triggs, C. M. (1990), *Effects of postharvest treatment on the sensory qualities of kiwifruit harvested at different maturities*, Journal of the science of food and agriculture, 50 (4), 533-546.

[27] Harman, J. E. and McDonald, B. d. D.-.-. (1989), *Controlled atmosphere storage of kiwifruit. Effect on fruit quality and composition*, Scientia Horticulturae, 37 (4), 303-315.

[28] McDonald, B. and Harman, J. E. (1982), *Controlled-atmosphere storage of kiwifruit. I. Effect on fruit firmness and storage life*, Scientia Horticulturae, 17 (2), 113-123.

[29] Packhouse visits, Personal communication, 2009.

[30] Wabnitz, G. (2008), *Biogas from Kiwifruit Waste*, Maunsell Limited, Wellington.

[31] *FOOD WASTES*, (2009), viewed 1 January 2010, www.unido.org/fileadmin/import/32068_35FoodWastes

[32] Zespri *Zespri grade standards photo manual*,

[33] Zespri Group Ltd *Damage in 2008 Harvest-Got it sussed?*,

[34] Clark, C., Gravett, I., Hopkirk, G., Richardson, C. and Burt, P. d. (1992), *NZKMB 1990/49 Factors in the Orchard, Packhouse, and Coolstore affecting Postharvest Fruit Loss*, NZKMB, Auckland.

[35] Hopkirk, G., Snelgar, W. P., Horne, S. F. and Manson, P. J. (1989), *Effect of increased preharvest temperature on fruit quality of kiwifruit (Actinidia deliciosa)*, The Journal of horticultural science, 64 (2), 227-237.

[36] Lallu, N. (1997), *Low temperature breakdown in kiwifruit*, Acta Horticulturae, 444, 579-585.

[37] Campbell, H. and Haggerty, J. (1-Mar-09 2009), *Kiwifruit export earnings,* viewed http://www.TeAra.govt.nz/en/kiwifruit/1/4

[38] Decade Products, e. (2009), *The ultimate "shipper-friendly" container,* viewed 15 July 2009, www.decadeproducts.com

[39] Sambado, R. (2009), *Apple Orchard Crates,* viewed 5 January 2009, http://www.p2pays.org/ref/06/05055.htm

[40] *Harvest Bin-MacroPlastics Incorporated,* viewed April 23 2010, http://www.duboisag.com/catalog.php?lang=en&product_id=549

[41] Viscount Plastics *Nally Megabin Specifications,* viewed April 27 2010, http://www.viscount.com.au/downloads/Megabin%20Grid%20220408.pdf

[42] Crook, R. (2010), Isometric view of the proposed plastic bin (Unpublished jpg).

[43] Dubois Agrinovation *MACX Harvest Bins*, viewed April 21 2010, http://www.duboisag.com/catalog.php?lang=en&product_id=530

[44] Industries, D. o. P. (2006), *Potato Bin Hygiene,* viewed July 2009,

[45] Zeebroeck, V. M., Linden, V. V., Ramon, H., Baerdemaeker, D. J., Nicolai, B. M. and Tijskens, E. (2007), *Impact damage to apples during transport and handling*, Postharvest Biology and Technology, 45 (2007), 157-167.

[46] Acican, T., Alibas, K. and Ozelkok, I. S. (2006), *Mechanical Damage to Apples during Transport in Wooden Crates*, Postharvest Technology, 96 (2), 239-248.

[47] Chonhenchob, V. and Singh, S. P. (2005), *Packaging Performance Comparison for Distribution and Export of Papaya Fruit*, Packaging Technology and Science, 18, 125-131.

[48] Timm, E. J., Bollen, A. F., Dela Rue, B. T. and Woodhead, I. M. (1998), *Apple damage and compressive forces in bulk bins during orchard transport*, Applied Engineering in Agriculture, 14 (2), 165-172.

[49] Bollen, A. F. and Dela Rue, B. T. D. (1990), *Handling Impacts for Kiwifruit, Asian Pears and Apples*, in (Eds) *1990 International Summer Meeting*, Columbus, Ohio, pp.

[50] Banks, N. H. (1992), *Effects of handling damage on storage behaviour of kiwifruit*, New Zealand Kiwifruit special publication edn, New Zealand Kiwifruit special publication, Auckland.,

[51] Arpaia, M. L., Labavitch, J. M., Greve, C. and Kader, A. A. (1987), *Changes in cell wall components of kiwifruit during storage in air or controlled atmosphere*, Journal of the American Society for Horticultural Sciences, 112, 474-481.

[52] Hasey, J. K. (1994), *Kiwifruit growing and handling*, ANR Publications, California.

[53] Hopkirk, G. and Finch, G. R. (1987), *Susceptability of kiwifruit to physical damage- Compression damage*, Department of Scientific and Industrial Research, Auckland.

[54] Davie, I. J., Banks, N. H. and C.J., S. *Kiwifruit Susceptability of mechanical damage during postharvest handling and storage*,

[55] Bollen, A. F., Nguyen, H. X. and Dela Rue, B. T. (1999), *Comparison of Methods for estimating the bruise volume of Apples*, Journal of Agriculture Engineering Research, 1999 (00),

[56] Nelson, C. W. and Mohsenin, N. N. (1968), *Maximum allowable static and dynamic loads and effect of temperature for mechnical injury in apples*, Journal of Agriculture Engineering Research, 13 (4), 305-317.

[57] Lee, H. J., Kim, T. C., Kim, S. J. and Park, S. J. (2005), *Bruising injury of persimmon (Diospyros kaki cv.Fuyu) fruits*, Scientia Horticulture, (103), 179-185.

[58] Finch, G. R. and Hopkirk, G. H. (1987), *The susceptability of kiwifruit to physical damage-Impact damage*, Department of Scientific and Industrial REsearch, Auckland.

[59] Lallu, N., Rose, K., Wiklund, C. and Burdon, J. (1999), *Vibration Induced Physical Damage in Packed Hayward Kiwifruit*, HortTesearch, Auckland.

[60] Singh, P. S. (1993), *Bruising in Apples as a Function of Truck Vibration and Packaging*, Food and Process Engineering 9(5), 455-460.

[61] Armstrong, P. R., Schulte, N. L., Timm, E. J. and Brown, G. K. (1992), Bruising During Truck Transport of Apples in Bulk Bins, Paper presented at ASAEInternational Summer Meeting 1992, Charlotte, North Carolina, June 21-24, 1992.

[62] Fisher, D., Craig, W. L., Watada, A. E., Douglas, W. and Ashby, B. H. (1992), *Simulated in-trasnit vibration damage to packaged fresh market grapes and strawberries*, Applied Engineering in Agriculture, 8 (3), 363-366.

[63] Kusabs, N., Bollen, A. F. and Kemp, O. (2004), *Curing Optimisation for Hort16A- Report*, Zespri Innovation, Mt Maunganui.

[64] Max, S. and Luckman, A., Are they really little green bullets?