Effect of Harvest Time, Post-harvest Storage and Ripening Temperature on Fruit Quality of Reed Avocado Cultivar

by

Kingsly Shikwambana

MINI-DISSERTATION

Submitted in fulfillment of the requirements for the degree of

Master of Science

in

Agriculture (Horticulture)

in the

FACULTY OF SCIENCE AND AGRICULTURE

(School of Agricultural and Environmental Sciences)

at the

UNIVERSITY OF LIMPOPO

Supervisor: Prof TP Mafeo

Co-supervisor: Dr N Mathaba

2016

TABLE OF CONTENTS

	Page
DECLARATION	v
DEDICATION	vi
ACKNOWLEDGEMENTS	vii
LIST OF TABLE	viii
LIST OF FIGURES	ix
LIST OF APPENDICES	xi
ABSTRACT	xiii
CHAPTER 1	1
INTRODUCTION	1
1.1 Background	1
1.2 Problem statement	2
1.3 Motivation for the study	2
1.4 Aim and objectives of the study	3
1.4.1 Aim	3
1.4.2 Objectives	3
1.5 Hypotheses	3
CHAPTER 2	4
LITERATURE REVIEW	4
2.1 Introduction	4
2.2 Work done on the research problem	4
2.2.1 Fruit maturity and moisture content	4
2.2.2 Post-harvest storage	5
2.2.3 Electrolyte leakage	7
2.2.4 Vascular browning	8
2.2.5 Ripening physiology	8

2.2.6 Effect of ripening temperature on avocado fruit quality 9
2.2.7 Post-harvest quality attributes 9
2.2.8 Pathological and physiological disorders 12
2.3 Addressing the identified gaps 13
CHAPTER 3 14
MATERIALS AND METHODS 14
3.1 Experimental sites 14
3.2 Experimental design, treatment and procedures 14
3.3 Data collection 14
3.3.1 Determination of moisture content 14
3.3.2 Determination of weight loss 15
3.3.3 Measuring of firmness 16
3.3.4 Determination of respiration rate 16
3.3.5 Determination of colour 17
3.3.6 Determination of tissue electrolyte leakage 18
3.3.7 Determination of physiological and pathological disorders on ripe 'Reed' avocado fruit 19
3.4 Data analysis 20
CHAPTER 4 21
RESULTS 21
4.1 Moisture content 21
4.2 Weight loss 21
4.3 Fruit firmness 22
4.4 Respiration rate 24
4.5 Ripening percentage 26
4.6 Colour parameters 27
4.7 Electrolyte leakage 33

4.8 Chilling injury 33
4.9 Vascular browning 34
4.10 Stem-end rot 35
4.11 Body rot 36
4.12 Correlation between parameters 37
CHAPTER 5 41
DISCUSSIONS 41
5.1 Moisture content 41
5.2 Fruit weight loss 42
5.3 Fruit firmness 42
5.4 Respiratory rate 43
5.5 Ripening percentage 44
5.6 Colour parameters 45
5.7 Chilling injury and electrolyte leakage 46
5.8 Vascular browning 47
5.9 Stem-end rot and body rot 47
CHAPTER 6 49
SUMMARY, RECOMMENDED FUTURE RESEARCH AND CONCLUSION 49
6.1 Summary 49
6.2 Recommendation and future research 49
6.3 Conclusion 50
REFERENCES 51

DECLARATION

I declare that the mini-dissertation hereby submitted to the University of Limpopo, for the degree of Master of Science in Agriculture (Horticulture) has not previously been submitted by me for a degree at this or any other University; that it is my work in design and execution, and that all material contained herein has been duly acknowledged.

--　　　　　　　　　　　-------------------------------

Shikwambana, K (Mr)　　　　　　　　　　　　　　　　　　Date

DEDICATION

I would like to dedicate this study to my exquisite daughter

(Akelo Kylie Shikwambana)

ACKNOWLEDGEMENTS

I would like to express my sincere gratefulness towards the following people and organisations:

- My supervisory team Prof TP Mafeo and Dr N Mathaba for their guidance, encouragement and constructive criticisms throughout the study and for introducing me to the world of scientific writing.
- My grateful acknowledgement also goes to my late father (Ntshunani Benneth Shikwambana) and my mother (Mawewe Agnes Shikwambana) for giving me a start in life and for providing me with the opportunity to study.
- My siblings (Tlangelani Cliff, Musa Torrence and Lucky Nkanteko Shikwambana), for their everlasting inspiration, unwavering support and encouragement during my study.
- My wonderful wife, Rhulani Beauty Shibambu, for her patience throughout this study, moral support and companionship throughout my University study.
- Agricultural Research Council (ARC) and National Research Foundation (NRF) for financial support.
- Most importantly, all thanks to the Almighty God for His Grace and the privilege of studying and completing my research work.

LIST OF TABLE

		Page
Table 4.1	Correlation coefficients (R^2) between 'Reed' avocado quality parameters after removal from lower (2.0ºC) and higher (5.5ºC) cold storage temperatures to ripening at 16, 21 and 25ºC during both mid- and late harvest time	40

LIST OF FIGURES

		Page
Figure 3.1	Weighing scale measuring flesh sample mass **(A)** and oven drying fruit flash of 'Reed' avocado fruit **(B)**	15
Figure 3.2	Sinclair IQ™ automated desktop firmness machine used to measure fruit firmness of 'Reed' avocado fruit	16
Figure 3.3	Infrared gas analyser measuring CO_2 evaluation **(A)** and individual 'Reed' avocado fruit incubated in 1 L plastic jar **(B)**	17
Figure 3.4	Chromameter used to measure colour parameters (Lightness (L *), a * and b * values)	18
Figure 3.5	Electrical conductivity (EC) meter used to measure electrolyte leakage	19
Figure 4.1	Moisture content percentage of 'Reed' avocado fruit at mid- and late harvest time	21
Figure 4.2	Effect of harvest time, post-harvest storage, ripening temperature and ripening time on the fruit weight loss of 'Reed' avocado fruit	22
Figure 4.3	Effect of harvest time, post-harvest storage, ripening temperature and ripening time on the firmness of 'Reed' avocado fruit	24
Figure 4.4	Effect of harvest time, post-harvest storage, ripening temperature and ripening time on the respiration rates of 'Reed' avocado fruit	25
Figure 4.5	Effect of harvest time, post-harvest storage, ripening temperature and ripening time on the ripening percentage of 'Reed' avocado fruit	27
Figure 4.6	Effect of harvest time, post-harvest storage, ripening temperature and ripening time on the fruit lightness (L *) of 'Reed' avocado fruit	28
Figure 4.7	Effect of harvest time, post-harvest storage, ripening temperature and ripening time on the chroma (C *) of 'Reed' avocado fruit	30

Figure 4.8	Effect of harvest time, post-harvest storage, ripening temperature and ripening time on the hue angle (*h*°) of 'Reed' avocado fruit	31
Figure 4.9	Effect of harvest time, post-harvest storage, ripening temperature and ripening time on eye colour of 'Reed' avocado fruit	32
Figure 4.10	Effect of harvest time and post-harvest storage on electrolyte leakage of 'Reed' avocado fruit	33
Figure 4.11	Effect of harvest time, post-harvest storage and ripening temperature on chilling injury of 'Reed' avocado fruit	34
Figure 4.12	Effect of harvest time, post-harvest storage and ripening temperature on incidence of vascular browning on 'Reed' avocado fruit	35
Figure 4.13	Effect of harvest time, post-harvest storage and ripening temperature on incidence of stem-end rot on 'Reed' avocado fruit	36
Figure 4.14	Effect of harvest time, post-harvest storage and ripening temperature on incident of body rot on 'Reed' avocado fruit	37
Figure 4.15	Correlation between chilling injury and electrolyte leakage after withdrawal from lower (2.0ºC) and higher (5.5ºC) cold storage temperatures during mid- and late harvest time	39

LIST OF APPENDICES

		Page
Appendix 1	ANOVA table for moisture content of ‘Reed’ avocado fruit at mid- and late harvest time	67
Appendix 2	ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on the fruit weight loss of ‘Reed’ avocado fruit	68
Appendix 3	ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on the fruit firmness of ‘Reed’ avocado fruit	69
Appendix 4	ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on the respiration rate of ‘Reed’ avocado fruit	70
Appendix 5	ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on the ripening percentage of ‘Reed’ avocado fruit	71
Appendix 6	ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on the fruit lightness (L *) of ‘Reed’ avocado fruit	72
Appendix 7	ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on the chroma (C *) of ‘Reed’ avocado fruit	73
Appendix 8	ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on hue angle (h°) of ‘Reed’ avocado fruit	74
Appendix 9	ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on eye colour of ‘Reed’ avocado fruit	75
Appendix 10	ANOVA table for effect of harvest time and post-harvest storage on electrolyte leakage of ‘Reed’ avocado fruit	76
Appendix 11	ANOVA table for effect of harvest time, post-harvest storage and ripening temperature on chilling injury of	76

	'Reed' avocado fruit	
Appendix 12	ANOVA table for effect of harvest time, post-harvest storage and ripening temperature on incidence of vascular browning on 'Reed' avocado fruit	77
Appendix 13	ANOVA table for effect of harvest time, post-harvest storage and ripening temperature on incidence of stem-end rot on 'Reed' avocado fruit	77
Appendix 14	ANOVA table for effect of harvest time, post-harvest storage and ripening temperature on incidence of body rot on 'Reed' avocado fruit	78

ABSTRACT

‘Reed’ avocado is a late season cultivar introduced to South Africa from California. The cultivar has shown good adaptation and produces quality fruit with export potential. Its pre-harvest adaptation and production aspects have been researched and documented. However, the effect of harvest time, post-harvest storage and ripening temperature has not been comprehensively studied on this newly introduced ‘Reed’ avocado cultivar. Therefore, the aim of this work was to investigate the effect of different harvest time, post-harvest storage and ripening temperature on the quality of late season ‘Reed’ avocado fruit. Matured ‘Reed’ avocado fruit were harvested based on moisture content indexing in December (2015) and January (2016). The experiment was carried out in a factorial, arranged in a completely randomised design (CRD) with three replicates. Treatment factors were: 2 x harvest time (mid-and late), 2 x post-harvest storage (2.0 and 5.5°C), 3 x ripening temperature (16, 21 and 25°C) and 5 x ripening day (0, 2, 4, 6 and 8). Fruit were stored at 2.0 and 5.5°C for 28 days, thereafter, ripened at 16, 21 and 25°C until fully ripe. During ripening, fruit were evaluated for weight loss, skin colour, firmness, respiration rate, physiological and pathological disorders. Mid-harvest fruit had higher moisture content when compared with late harvest fruit. However, harvest time, post-harvest storage, ripening temperature and ripening time (days) significantly influenced fruit weight loss, firmness, respiration rate, ripening percentage of ‘Reed’ avocado fruit during ripening. Moreover, fruit firmness decreased faster at higher temperatures (25 and 21°C) with fruit ripening within 4 and 6 days, respectively. In addition, ripening at a lower temperature (16°C) was slower with fruit fully ripened within 8 days after withdrawal from cold storage at both harvest times. ‘Reed’ avocado fruit respiration rate followed a climacteric pattern, however, significantly higher rate at higher temperature (25°C) when compared with lower temperature (16°C) after withdrawal from cold storage during both harvest times. Interestingly, mid-harvest fruit showed high electrolyte damage after withdrawal from 2.0°C when compared with late harvest fruit at the same temperature. Furthermore, mid-harvest fruit stored at 2.0°C and ripened at 21°C showed higher chilling injury when compared with fruit ripened at 16 and 25°C. High electrolyte leakage positively correlated (R^2 = 0.242) with high chilling damage for mid-harvest fruit stored 5.5°C. Treatment factors had a significant effect (P < 0.05) on lightness (L *) and hue angle (h°) but no significant effect (P > 0.05) on chroma (C *) and eye colour of 'Reed' avocado fruit during ripening, irrespective of harvest time. Overall results showed a visual change in 'Reed' avocado skin colour, with eye colour changing from green to bright yellow. Furthermore, late harvest fruit showed high post-harvest pathological diseases after removal from high temperature (5.5°C) when compared with mid-harvest fruit stored at low storage temperature (2.0°C). Ripening at a higher temperature (21 and 25°C) resulted in higher incidence of stem-end rot and body rot when compared with lower temperature (16°C) for both harvest times. Late harvest fruit showed a higher incidence of vascular browning at higher ripening temperatures (21 and 25°C) when compared with lower temperature (16°C) after withdrawal from cold storage. Moreover, overall results showed that harvest time, post-harvest storage and the ripening temperature had a profound influence on the quality of 'Reed' avocado fruit. In conclusion, 'Reed' avocado fruit can be harvested during mid- or late season and stored at recommended low temperature (2.0°C); and thereafter, ripened at either 16 or 21°C. In addition, future studies should focus on identifying pre-harvest practices that promote higher post-harvest fruit quality for 'Reed' avocado fruit under South African production environment.

Keywords: *'Reed' avocado fruit; firmness; electrolyte leakage; respiration rate; stem-end rot; body rot; vascular browning*

CHAPTER 1
INTRODUCTION

1.1 Background

The South African Avocado Industry has lost revenue over a number of years, as a result of its inability to balance market supply and demand (Voster, 2001), and being largely export-orientated, the industry depends mainly on the European markets (Blakey, 2011). However, with increasing production potential and growing competition in Europe, the industry is currently introducing, breeding new germplasm and seeking new international markets. Moreover, owing to the climatic variations in the different growing regions of South Africa, avocado fruit are harvested over an extended period, from late February to early November, with the bulk of fruit from late March until the beginning of September (SAAGA, 2005; DAFF, 2010). This creates a gap of no available fruit for export and local market from October to February (DAFF, 2014). Therefore, industry has identified this gap as a challenge to increase their export market competitiveness (Farmer's Weekly, 2011). For a decade now, the industry has introduced promising germplasms from other countries such as 'Reed' cultivar from California, locally bred and selections of new cultivars. Several pre-harvest aspects of these new selections cultivars including 'Reed' are well researched and documented (Newett *et al.,* 2002). However, less has been done on their post-harvest behaviour to meet ever-changing quality and phytosanitary requirements of importing countries.

Harvest time plays a very important role in maturation, expected storage and shelf-life of avocado fruit; while the temperature is a key factor to consider during post-harvest storage and associated with ripening physiological processes (Gamble *et al.,* 2010). Therefore, the focus needs to be placed on the effect of harvest time, in conjunction with post-harvest storage and ripening temperatures on 'Reed' cultivar fruit quality. Such information would assist in closing the identified gap, lead to the registration of 'Reed' cultivar; and enable the industry to access major export and new market (China and the USA) during the late season.

1.2 Problem statement

In South Africa, avocado production is export-oriented, with the European and Middle East as the primary markets. The South African avocado harvest season begins in the middle of March to October, with the bulk of the crop from late-March until the beginning of September (SAAGA, 2005; DAFF, 2010). This creates a gap of no available fruit for export and local market from October to February (DAFF, 2014). The South African Avocado Industry has since identified this gap as a challenge to increase the export market competitiveness. For a decade now, the industry has introduced promising germplasms such as ‘Reed’ cultivar from California, locally bred and selected new cultivars. Several pre-harvest aspects of these new materials are well researched and documented. However, less was done on their post-harvest behaviour to meet ever-changing quality and phytosanitary requirements of importing countries.

1.3 Motivation for the study

The main avocado cultivars grown in South Africa commercially are ‘Hass’, ‘Fuerte’, ‘Ryan’ and ‘Pinkerton’ (Donkin, 2007). However, several cultivars have been introduced in the market either through importation or breeding, and selection. Currently, ‘Reed’ cultivar is classified as “other cultivars” under Standards and Requirements regarding control of the export of avocado fruit as per Agricultural Product Standards Act, 1990 (Act No. 119 of 1990). In California, ‘Reed’ cultivar is preferred for its late maturing, flesh quality and ability to crop under tropical conditions (Newett *et al*., 2002). The proposed study would contribute in documenting post-harvest storage potential, ripening and physico-chemical properties of mid-and late harvest ‘Reed’ avocado for the first time under South African growing conditions. Also the information generated from this study would assist in the registration process for ‘Reed’ avocado cultivar, closing the identified gap, and enable the industry to access major export and new markets (China and the USA) during the late season. Potentially, this would increase industry competitiveness and entry to international markets during late season, when avocado fruit demand is high.

1.4 Aim and objectives of the study

1.4.1 Aim

The aim of the study was to investigate the effect of different harvest time, post-harvest storage and ripening temperature on the quality of late cultivar ‘Reed’ avocado fruit.

1.4.2 Objectives

The study had two objectives, which were:

a. To evaluate effect of different harvest time on the quality of late cultivar ‘Reed’ avocado fruit.

b. To evaluate the effect of different post-harvest cold storage and ripening temperatures on quality of ‘Reed’ avocado fruit.

1.5 Hypotheses

The study consisted of two hypotheses, which were:

a. Different harvest time had no effect on quality variables of late ‘Reed’ avocado fruit.

b. Post-harvest cold storage and ripening temperatures had no effect on quality of ‘Reed’ avocado fruit.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The South African, avocado industry is a rapidly expanding, and largely export oriented. However, the industry is faced with challenges mainly; fluctuation of currency exchange rate, shipping delays, restricted access to high paying markets and competition from other exporting countries (Blakey and Bower, 2009). In respond to competition from other exporting countries, the industry has introduced a new cultivar 'Reed' from California with a good adaptation potential and produces large fruit with good quality. However, the registration process of this newly introduced cultivar for export market requires additional information such as; harvest time, maturity index, post-harvest storage and ripening temperature. Therefore, a literature review of this study would focus on work done and not yet done on the research problem.

2.2 Work done on the research problem

2.2.1 Fruit maturity and moisture content

Lee *at al.* (1983) defined avocado fruit physiological maturity as the phase of development, whereby, most internal physicochemical properties have reached final growth, such that, the fruit would undergo normal ripening after harvest. In avocado, determination of harvest maturity is important in identifying minimum maturity that assures acceptable eating quality and minimal post-harvest disorders (Hofman *et al.,* 2013). In avocado, fruit physiological maturity is determined based on the minimum standard for a specific cultivar, required storage life, transport duration and market price (Hofman *et al*. 2002). Furthermore, maturity at harvest is fundamental for determining storage-life and final fruit quality (Kader, 1992). Therefore, avocado fruits harvested before reaching physiological maturity are associated with irregular ripening, off-flavour and high risk of physiological disorders (Zauberman *et al*., 1977). Determination of physiological maturity allows for an early harvest in order to take advantage of an early season high prices and could also reduce the risk of weather damage (wind, hail or frost) (Blakey, 2011). However, early season fruits are more prone to physiological disorders, shriveling, mechanical injury and have poor quality when ripe (Lee *et al*., 1983). The need for minimum maturity standard has led to the discovery of some maturity parameters such as moisture content (Pearson, 1975).

In South African, moisture content at harvest is a preferred measure of physiological maturity (Blakey, 2011); and also considered simple and more practical when compared with oil content (Kruger and Claassens, 2001). According to Kruger *et al.* (1995), avocado fruit moisture content is known to decline from early to late season. The Perishable Products Export Control Board (PPECB) in association with the South African Avocado Growers' Association (SAAGA) had clearly defined and set the optimal fruit moisture content to assist growers and exporters in the correct application and interpretation (Eksteen, 2001). The maximum moisture content for avocado fruit depends on the cultivar (Mans *et al*., 1995). However, there is concern with the use of moisture content as a measure of avocado fruit physiological maturity due to the unreliability of the method; and therefore, not a dependable indicator of avocado maturity (Olarewaju, 2014). However, new advance, more reliable and non-destructive technologies such as magnetic resonance imaging (MRI) and near-infrared spectroscopy (NIR) have been used (Clark *et al.,* 2003; Blakey *et al.,* 2009; Magwaza and Tesfay, 2015).

2.2.2 Post-harvest storage

Effect of low storage temperature on quality of avocado fruit

Low storage temperature is used during shipping of avocado fruit in order to reduce respiration rate, delay ripening, extend storage life and ensure high produce quality (Dixon *et al*., 2004; Lütge, 2011). In general, low storage temperature for avocado fruit ranges between 5.0-8.0°C. But, other research work were conducted at 2.0°C and found low storage temperature ranging between 2.0-8.0°C to extend storage life, maintain quality, therefore, facilitating fruit distribution to distant markets (Zauberman and Jobin-Decor, 1995). Dixon *et al*. (2004) also showed that low storage temperature reduced respiration rate, ethylene production, metabolic rate; thus, extended the storage life of 'Hass' avocado fruit stored at 4.0 and 6.0°C for 4 weeks. Furthermore, Hopkirk *et al*. (1994) found the storage life of 'Hass' and 'Fuerte' avocado fruit stored at 0 or 2.0°C to increase to 5 weeks. 'Hass', 'Fuerte' and 'Naval' avocado fruit metabolic rate was reduced under 6-8°C storage and fruit softness was retarded until transferred to 20°C (Zauberman *et al*., 1977).

Low storage temperature between 2.0-4.0°C maintained fruit firmness of 'Ettinger' avocado fruit when compared with higher storage temperature of 6.0-8.0°C (Mizrach *et al*., 2000). Zauberman and Jobin-Deccor (1995) reported full ripening of avocado fruit after 2 and 3 weeks of storage at 8.0°C, while storage was extended to more than 3 weeks at 5.0°C storage. Storage temperature of about 12°C reduced ethylene production of tomato fruit (Mutari and Rees, 2011). Van Rooyen (2006) reported that storage of 'Pinkerton' avocado fruit at 2.0°C had significantly reduced the severity of mesocarp discolouration when compared with 8.0 and 5.5°C. While, prolong exposure of 'Hass' avocado under storage temperature of 0 and 2.0°C affected ripening and duration, thereby, influencing the incidence and severity of pathological rots (Hopkirk *et al*.,1994). Low storage temperature is the main method used to slow down the deterioration of commodities based on consumers' perception and nutritional value (Zhang *et al.,* 2009; Cantín *et al.,* 2010). However, low storage temperature might results in the development of chilling injury symptoms during or after cold storage (Dixon *et al.,* 2003).

Chilling injury

Chilling injury (CI) could be defined as a permanent physiological damage to plant tissue, cell and organ, and associated with prolonging exposure to temperatures below the critical threshold for that species or tissue (Donkin, 1995). According to Lyons and Breidenbach (1987), the chilling temperature is any temperature below the critical threshold temperature that causes cellular damage. In avocado fruit, chilling injury symptoms are characterised by pitting, blackening of the exocarp and discoloration of mesocarp.

According to Kok (2011), chilling injury acquired by a particular commodity is dependent on the temperature, duration of exposure to low temperature, cultivar and maturity stage. According to Van Rooyen (2005), the longer duration of exposure to low temperatures below a critical threshold, the higher is the severity of the chilling injury. Zauberman *et al.* (1977) found 'Nabal' and 'Hass' avocado fruit to be more resistant to chilling injury when compared with 'Fuerte' cultivar under low storage temperature of 6.0 and 8.0°C. However, Swarts (1980) stated that the severity of chilling injury varies with physiological maturity. Early season fruit are more sensitive to chilling damage when compared with late harvested (Adato and Gazit, 1974).

Effect of chilling injury on avocado fruit quality

In general, avocado fruits are subtropical crops, therefore, chilling-sensitive when stored at low temperatures (Fuchs *et al.,* 1995). The optimum storage temperatures for avocado fruit range between 4.4 to 12.8°C with a critical threshold temperature of 8.0°C (Lutz and Hardenburg, 1968; Lyons, 1973). Under chilling temperature, various physiological and biochemical alteration and cellular dysfunctions occur, particularly for chilling-sensitive species in response to chilling stress (Wang, 1982). Response to chilling stress includes; ethylene biosynthesis alteration, increased respiration rate, and solute leakage, cessation of protoplasmic streaming and uncoupling of oxidative phosphorylation (Henshkovitz *et al*., 2005). If chilling stress is prolonged, alterations and dysfunctions would result in the development of chilling injury symptoms such as; internal discoloration, tissue water-soaking and surface lesions (Saltveit and Morris, 1990). However, Van Rooyen and Bower (2007) found that green skin cultivar ‘Pinkerton’ could be stored at 2.0°C with minimal mesocarp discoloration but with some visible external injuries. Lütge *et al.* (2011) found that ‘Fuerte’ avocado fruit stored at 2.0°C had good internal quality with an evident external chilling injury. Moreover, ‘Hass’ avocado fruit stored at 1.0°C for 30 days had moderate chilling injury symptoms, with no internal damage but minor external damage (Bower and Papli, 2006). In contrast however, chilling injury increased the development of post-harvest rots for ‘Hass’ avocado fruit stored at 0 and 2.0°C (Hopkirk *et al.*, 1994). According to Levitt (1972), the chilling injury could be the result of cell membrane permeability change. Other studies showed effect of low storage temperature on membrane permeability, quantified as electrolyte leakage.

2.2.3 Electrolyte leakage

Electrolyte leakage is an important indicator of chilling susceptibility; of plant tissue and quantifies cell membrane integrity (Zhang *et al.,* 2011). It serves as a storage quality parameter, with low electrolyte leakage indicating lower membrane permeability (Woolf *et al.*, 2003). It is also indicative of intracellular ion leakage as well as cell membrane integrity (Tesfay, 2009). Moreover, Feng *et al.* (2005) found that prolonged exposure of 'Hass' avocado fruit to cold storage temperature 5.5°C for 17 days resulted in cell plasma membrane damage. Montoya *et al.* (1994) suggested that high electrolyte leakage might be related to biochemical browning mechanism, subsequently, an oxygenated environment, whereby, the polyphenolic oxidase, peroxidase and phenolics are combined. According to Van Rooyen (2002), increased electrolyte leakage for 'Hass' avocado fruit during cold storage resulted in high polyphenol oxidase activity, promoted cellular permeability, and was evident as mesocarp browning. In a study by Hershkovitz *et al*. (2009), increased electrolyte leakage for 'Arad' and 'Ettinger' avocado fruit stored at 5.0°C correlated with manifestation of chilling injury symptoms when held to ripen at 20°C.

2.2.4 Vascular browning

Vascular browning can be described as a physiological disorder caused by poor storage temperature management and notable by browning of vascular strands that run longitudinally through the fruit tissue (Arpaia *et al*., 2004). Mhlophe and Kruger (2012) found the incidence of vascular staining for 'Maluma' avocado fruit to decrease as the fruit matures. Moreover, Leclereq (1990) found that storage temperature of avocado fruit at 5.5°C for 30 days increased the potential for physiological disorders such as vascular browning. This was also proved by Hopkirk *et al*. (1994) where 'Hass' avocado stored at 6.0°C and ripened at 25°C had higher incidence of vascular browning when compared with fruit held to ripen at 15 and 20°C. According to Kahn (1975), disorders associated with browning reactions are results of oxidation of o-diphenols to o-quinones by the enzyme polyphenol oxidase (PPO).

2.2.5 Ripening physiology

Fruit ripening can be defined as the process associated with the change in colour, taste and texture; and therefore, making the fruit acceptable for consumption (Biale, 1975). In avocado fruit, ripening process involves many catabolic and anabolic changes and once began, the process is irreversible (Bower, 1985; Bower and Cutting, 1988). Fruit ripening as quantified by the loss of membrane integrity occurs through cell wall degradation (Platt-Aloia and Thomson, 1981). Furthermore, Platt-Aloia and Thomson (1981) found that during fruit ripening, the breakdown of cell wall correlated with enzyme activity increase. According to Awad and Young (1979), ripening process correlated with an increase in cellulose and polygalacturonase (PG) activities concomitantly decrease in pectin methylesterase (PME) activity. In addition, ethylene regulates fruit ripening by coordinating the expression of genes that are responsible for processes such as enhancement respiration rate, autocatalytic ethylene production, chlorophyll degradation, carotenoid synthesis, conversion of starch to sugars and increase activities of cell wall degrading enzymes (Gray *et al*., 1992).

2.2.6 Effect of ripening temperature on avocado fruit quality

Temperature is considered the most important factor affecting quality of agricultural commodities (Eaks, 1978). Ripening temperature affects the metabolic rate, mainly the ripening enzymes and ethylene production (Donkin, 1995). Avocado ripening temperature varies with growing and storage temperature. Therefore, fruit grown at a lower temperature should be ripened at temperature between 15-18°C and fruit grown at higher temperature ripened at temperature between 20-25°C (Hopkirk *et al*., 1994). Higher ripening temperatures (30-40°C) were found to increase fungal decay, vascular browning and resulted in miscellaneous ripening (Hopkirk *et al*., 1994). In 'Fuerte' avocado fruit, ripening temperature above 24°C was found to increase the incidence of anthracnose (Fitzell and Muirhead, 1983). Zauberman and Fuchs (1981) demonstrated that wounded and non-wounded 'Fuerte' avocado fruit stored at 5.0°C for 10 days ripened faster at 20°C when compared with 14°C. Furthermore, Hopkirk *et al*. (1994) suggested that ripening temperatures between 18-20°C could be suitable for ripening of 'Fuerte' and 'Hass' avocado fruit.

2.2.7 Post-harvest quality attributes

Fruit weight loss

The principal mechanism of moisture loss related to weight loss of fruit and vegetable is vapour phase diffusion driven by water vapour pressure gradient (Maftoonazad and Ramaswam, 2008). According to Javanmardi and Kubota (2006), the severity of fruit weight loss during storage is duration and temperature dependent. Therefore, the primary factors contributing to post-harvest fruit weight loss include transpiration and respiration (Pan and Bhowmick, 1992). Transpiration occurs through vapour pressure deficit, a function of air temperature, pressure and relative humidity (Javanmardi and Kubota, 2006; Nunes and Edmond, 2007). During post-harvest storage of mushrooms, low relative humidity (76% RH) had an effect on transpiration rate under various storage conditions (4, 10 and 16°C); and therefore, high weight loss (Mahajan *et al*., 2008).

According to Maguire *et al*. (2001), in apple fruit weight loss was driven by moisture loss through transpiration; and to a minor extent, carbon dioxide loss through gaseous exchange. In tomato fruit, weight loss of 3-6% resulted in drying, shriveling and dryness, therefore, market value loss (Nune and Edmond, 2007). Furthermore, Van Rooyen (2005) also found higher weight loss for 'Pinkerton' avocado stored at 5.5°C when compared with 2.0°C due to low relative humidity. This attributed to low relative humidity increased vapour pressure deficit between the fruit and the container. Woolf *et al.* (2002) suggested that vapour pressure deficit, a differential in water content between the fruit and the surrounding air can be used to explain why a high relative humidity (85-95%) is desired when storing avocado. Thus, under low relative humidity, fruit moisture is lost from fruit into the surrounding air, therefore, high fruit water loss. Therefore, minimising weight loss before storage and during storage is very important to sustaining membrane integrity and for optimal cell functioning (Wang, 1993).

Fruit firmness

Fruit texture comprises of a wide range of attributes including tissue, water content and cell wall composition (Valero and Serrano, 2010). Fruit firmness is the main factor responsible for restraining storage potential, shelf-life and marketability of many fruits (Liplap, 2013). The mechanisms involved in fruit firmness maintenance depend primarily on the species and cultivar (Liplap, 2013). According to Valero and Serrono (2010), changes in cell structure were associated with a change in middle lamella and cell wall components such as pectin, cellulose and hemicellulose. Therefore, during fruit ripening, firmness is induced by breaking down of load bearing bond inside and between polysaccharides, thus; loss of sugars (Liplap, 2013). Fruit firmness was hastened by enzymes such as pectinmethylesterase (PME), endo-polygalacturonase (PG) and exo-polygalacturonase (PG), α- and β-galactoidase (GAL), cellulose and α-L-rhamnosidase (Valero and Serrono, 2010). In tomato fruit, firmness during post-harvest was caused by degradation of pectin by PME and PG enzymes (Liplap, 2013). Moreover, Bower and Cutting (1988), found cellulose and PG enzymes were highly active during ripening of avocado fruit.

Respiration

In avocado fruit, respiration increases during ripening, reaching the climacteric peak, thereafter, decreasing to almost lowest post climacteric (Kadam and Salunkhe, 1995). Respiration rate of avocado fruit depends on several environmental factors such as; temperature, light, radiation stress, water stress, pathogen attack and chemical stress (Liplap, 2013). However, the temperature is the main factor regulating respiration rate of produce, and it doubles for every 10°C temperature increase (Bartz and Brecht, 2003; Wills *et al*., 2008). Waghmare *et al*. (2013) reported that temperature ranging between 10-30°C increased respiration rate of fresh cut produce by 4-5 folds. In a study by Eaks (1978), respiration rate and ethylene production of 'Hass' avocado fruit was increased by a ripening temperature between 20-40°C. Blakey and Whiley (1995) found 'Hass' and 'Fuerte' avocado fruit respiration rate increased, concomitantly, with ripening temperature. Furthermore, Liplap (2013) also found temperatures above 30°C to denature polygalacturonase (PG) enzyme, and reduced respiration rate for fruits and vegetables. Moreover, Valero and Serrano (2010) found the temperatures causing chilling injury to increase respiration rate of fruit and vegetables. Low temperature created by multiple pads evaporative cooler reduced respiration rate, ethylene production and delay metabolic rate of tomato fruit; and therefore, extended shelf-life (Getinet *et al*., 2011).

Colour as quality attribute of avocado fruit

Colour is the most important indicator of physiological maturity and quality for many fruits (Drake *et al*., 1982); and an important determinant of consumer product acceptance and marketability (Ahmed *et al*., 2010). According to Lancaster *et al.* (1997), fruit colour is influenced by the concentration and distribution of skin pigments such as anthocyanins, chlorophyll, and carotenoids and other environment factors (light, temperature, ethylene and cultural practice). In avocado fruit, colour can be determined using objective (lightness (L *), chroma (C *) and hue angle (h°) and subjective (eye colour) colour parameters (Cox *et al*., 2004; White *et al*., 2009). Objective colour parameters are measured using a chromameter. The lightness (L) coordinate is a measure of clarity or brightness (L * = 0 (black) to L * = 100 (white)). The a* scale varies from negative values for blue and to positive values for red, while b* scale varies from negative values for blue to positive values for yellow. Chroma and hue angle values were obtained based on a* and b* (McGuire, 1992).

In purple or black skinned cultivar as 'Hass', skin colour changes from green to purple or black during fruit ripening (Cox *et al*., 2004; Villa-Rodriguez *et al.*, 2011). However, in green skin cultivar 'Sharwil' avocado fruit, colour changed from green to bright yellow during ripening at 22°C (Chen *et al.,* 2009). Moreover, Ahmed *et al.* (2010) found that the colour of green skin cultivar 'Fuerte'; remained green when held to ripen at 20°C. Ahmad *et al.* (2001) found that banana fruit stored at 18°C and ripened at 20°C were less green and more yellow at advanced colour stage of ripening when compared with storage at 16°C and ripened at 20°C. Cox *et al*. (2004) found no significant difference in colour change of fruit ripened at a higher temperature (25 and 20°C), while fruit ripened at lower temperature showed a significant colour change. In addition, Ashton *et al*. (2006) found black skinned 'Hass' avocado fruit colour change to be associated with a decrease in chlorophyll content, concomitantly, an increase in cyanidin 3-*O*-glucoside concentration attributed by ripening temperatures (Kassim *et al*., 2013).

2.2.8 Pathological and physiological disorders

Stem-end rot

Stem-end rot (SER) is considered to be an economically important post-harvest disease for avocado in most production areas of South Africa (Darvas and Kotzé, 1981). It is caused by several fungi which infect the fruit through inflorescences. Pycinida produced by dead wood, leaves and fruit; and conidia are spread by rain or the wind to fruit or pedicel, thereafter, initiating an infection (Darvas and Kotzé, 1987). Therefore, an infection can be initiated during harvest through the cut surface of the fruit (Pegg *et al.,* 2002). As a mitigative strategy, harvesting should be done during dry period as wet condition favour the germination of spores and latent infection (Hartill and Everet, 2002). Stem end rot symptoms are initiated as dark-brown to black spots at the end of an avocado fruit and as the fruit ripen, as the rot progresses throughout into the flesh. According to Pegg *et al*. (2002), SER infections remain latent at harvest and symptoms manifest when ripening commences.

Johnson and Kotzé (1994) found that SER infected avocado fruit become shrivelled, watery and covered with fungal mycelium. Arpaia *et al*. (2015) found that storing of 'Hass' avocado fruit at either 1.0, 5.0 or 12°C up to 4 days showed less development of stem-end rot when compared with longer period of 14 days. In addition, Kruger and Lemmer (2012) found the incidence of SER to be significantly higher at 8°C for 'Maluma' and 'Ryan' when compared with 'Hass' avocado fruit.

Body rot

Body rot (BR) is caused fungi that penetrate the avocado fruit through the skin (White *et al*., 2001). Body rot symptoms are characterised by discrete areas, patches of brown and sunken flesh; which can be firm or soft and irregular as fruit begin to ripen (AGM, 2001; Woolf *et al*., 2002). Body rot infection is through fungal spores washed down from dead plant parts by rain. The first sign of infection manifest any time during growing season but remain quiescent at harvest until fruit ripening commences (Menge and Ploetz, 2003). Hopkirk *et al*. (1994) found the incidence of body rot for 'Hass' avocado fruit stored at either 0 or 2.0°C to be significantly higher when compared with 4.0 or 6.0°C. Furthermore, 'Hass' avocado fruit held to ripen at 30°C showed higher incidence of body rot when compared with fruit held at 20 and 25°C (Hopkirk *et al.,* 1994).

2.3 Addressing the identified gaps

In South Africa, the available commercial cultivars are incapable to increasing world competitiveness during the late season. The newly introduced 'Reed' avocado cultivar is a late season cultivar and performs well under South African growing conditions. Moreover, genetic evolution and pre-harvest aspects of 'Reed' avocado tree have been previously investigated (Whiley *et al*., 1990). However, post-harvest quality and responses of 'Reed' avocado fruit to post-harvest technologies are yet to be investigated and constitute the perceived gap in the research problem. Therefore, the effect of harvest time, post-harvest storage temperature and ripening temperature on the quality of late 'Reed' avocado cultivar was investigated in this study. Furthermore, the information generated from this study, will assist in closing the identified gap, could lead to the registration of 'Reed' cultivar; and enable the industry to access major export and new markets (China and the USA) during the late season.

CHAPTER 3
MATERIALS AND METHODS

3.1 Experimental sites

Avocado fruit were harvested from 10-years old ‘Reed’ trees at ZZ2-Bertie van Zyl farm (Olyfberg) in Limpopo province, South Africa (23°42’00”S, 29°54’00”E). The site is characterized by an annual rainfall of >1000 mm, with a maximum and minimum temperatures of 21.5 and 12°C, respectively. The soils are classified as clay soil (45% clay). Matured ‘Reed’ fruit were harvested in December (2015) and January (2016); and thereafter, transported at ambient temperature to Agriculture Research Council- Institute for Tropical and Subtropical Crop (ARC-ITSC) post-harvest laboratory in Nelspruit (25°27′04.8″S, 30°58′09.75″E) for storage and laboratory analysis.

3.2 Experimental design, treatment and procedures

The experiment was carried out as factorial, arranged in a completely randomised design (CRD) with three replicates. Treatment factors were: 2 × harvest time (mid- and late), 2 × post-harvest storage temperatures (2.0 and 5.5°C), 3 × ripening temperatures (16, 21 and 25°C). After each harvest seven fruits were graded into a uniform size and parked into commercial carton boxes and stored at 2.0 and 5.5°C for 28 days. After withdrawal from cold storage, fruit were ripened at three different ripening temperatures 16, 21 and 25°C until eating ripe was reached.

3.3 Data collection

Fruit assessments were carried out after removal from cold storage and every other day during ripening time. After fruit eating ripe was reached, fruit were assessed for post-harvest pathological infections and physiological disorder. Fruit were also assessed for physicochemical during ripening as follows:

3.3.1 Determination of moisture content

Moisture content at harvest was determined from six fruit for each harvest time. Individual fruit were weighed before cutting into halves with a fruit chopper. The seed and seed coat were removed and skin peeled using a potato peeler. The flesh of individual fruit was grated using a kitchen grater. A sample mass of 10 g of grated flesh from individual fruit was transferred into a weighing petri dish (Figure 3.1. A). The weighing petri dish plus content were oven dried (Labotec oven model: 279) at 30°C for 48 hours (Figure 3.1. B). The weighing petri dish was then removed and re-weighed on the weighing scale (Model: SBA 61, Scaltec instruments, Heiligenstadt-Germany) to determine the moisture content. Thereafter, moisture content was calculated using equation. 1.

$$\text{Moisture content (\%)} = [(M_0-M_1)/M_0]*100 \qquad 1$$

Where:

M_0 = Fresh sample mass

M_1 = Dried sample mass

.

Figure 3.1 Weighing scale measuring flesh sample mass **(A)** and oven drying fruit flash of ‘Reed’ avocado fruit **(B)**

3.3.2 Determination of weight loss

Fruits weight was measured from six fruits using a weighing scale (Model: SBA 61, Scaltec instruments, Heiligenstadt-Germany). Fruit weight loss was expressed as the difference in fruit initial mass before and after post-harvest storage, and calculated a percentage of the initial weight of each fruit, using equation. 2:

$$\text{Weight loss (\%)} = (W_0-W_1/W_0)\times 100 \qquad 2$$

Where:

W_0 = Weight of fruit before post-harvest storage

W_1 =Weight of fruit at a specific ripening day

3.3.3 Measuring of firmness

Fruit firmness was measured from 18 fruits after removal from cold storage using a non-destructive automated Sinclair IQ™ desktop firmness machine (Model: 51DFTB, International LTD, Jorrold, Bowthorpa, Nonwich, NR5, 9.D, England), by taking four measurements along the equatorial parts of fruit and the results were recorded in Sinclair units (SU). Thereafter, 18 fruits were used to measure days to ripening. The same 18 fruits were measured every other day of ripening period until full ripening is reached equivalent to 25 Sinclair units (SU).

Figure 3.2 Sinclair IQ™ automated desktop firmness machine used to measure fruit firmness of 'Reed' avocado fruit.

3.3.4 Determination of respiration rate

Respiration rate as determined by measuring CO_2 production was determined from 18 fruit per each treatment factor. CO_2 was measured using an infrared gas analyzer (250–Dual Gas Analyser, Japan) (Figure 3.3. A). Fruit were individually incubated in 1 L plastic jar and sealed (Figure 3.3.B) for 30 minutes. Thereafter, respiration rate was obtained by converting the headspace CO_2 concentration while considering the volume and mass of the fruit, free space in the jar and as well as the ambient CO_2 concentration and expressed as mmol CO_2 kg^{-1} h^{-1}.

Figure 3.3 Infrared gas analyzer measuring CO_2 evaluation **(A)** and individual ‘Reed’ avocado fruit Incubated in 1 L plastic jar **(B)**

3.3.5 Determination of colour

Fruit skin colour was measured and recoded after cold storage and every two days, with Chromameter (Minolta CR-400 Corp, Ramsey, NJ, USA) with 8 mm diameter light path aperture (Figure 3.4). Individually fruit were measured in three parts around the equatorial axis. Two mean colour parameters reading were automatically calculated and recorded, L* value (lightness or brightness) and chroma (C*) taking into account a* (redness or greenness) and b* (yellowness or blueness) by averaging three measurements of the fruit equatorial region. The value of hue angle (h^0) and chroma (C*) was calculated from a* and b* using the formula: 180 + [tan (a*/b*)] and $C^* = (a^{*\wedge 2} + b^{*\wedge 2})^{1/2}$ as previously described by McGuire (1992). The device was initially calibrated before use with a Minolta standard white tile.

Figure 3.4 Chromameter used to measure colour parameters Lightness (L *), a * and b * values)

3.3.6 Determination of tissue electrolyte leakage

Membrane permeability after cold storage was determined using electrolyte leakage. Six fruit were used for determining electrolyte leakage. Fruit mesocarp tissue were withdrawn from each fruit using a 10 mm cork borer, placed into test tube after being rinsed three times with 20 mL deionized water to remove cut residues and surface contamination. Thereafter, 20 mL of deionized water was added into test tube containing tissue samples. Electrical conductivity (EC_1) was measured after shaking the sample for 3 hours, with electrical conductivity EC meter (HI 9033, Hanna instruments, Johannesburg, RSA). The second electrical conductivity (EC_2) was measured after the samples were placed in a hot water bath controlled at 100°C for 1 hour and allowed to cool at room temperature. Electrolyte leakage was expressed in percentage using equation. 3:

$$\text{Total electrolyte leakage (\%)} = (EC_1/EC_2)*100 \qquad 3$$

Where:

EC_1 = initial electrolyte leakage reading

EC_2 = final electrolyte leakage reading

Figure 3.5 Electrical conductivity EC meter used to measure electrolyte leakage

3.3.7 Determination of physiological and pathological disorders on ripe 'Reed' avocado fruit

After fruit were fully ripe at 16, 21 and 25°C, disorders associated with pathogens and physiological factors were assessed. Ripe fruit were cut longitudinally in half with a blade knife and the following factors were assessed:

External chilling damage; evident by discrete patches on the skin of the fruit was visually assessed and the results were expressed using chilling injury % = [(number of fruit with chilling injury symptoms ÷ total number of fruit evaluated)*100].

Stem-end rots: manifest by rots entering through the fruit peduncle.

Vascular browning: evident by browning of the vascular bundles running longitudinally through the fruit tissues.

Body rots: as evident by rot entering through the fruit skin. For each fruit, physiological disorder and pathological disease were rated on a scale of 0-(absent) to 3-(severe) according to Hopkirk *et al*. (1994). Results for each disorder and disease were expressed as a percentage of fruit with symptoms or incidence (scale 1-3) over the total number of fruit evaluated.

3.4 Data analysis

Statistical analyses were carried out using a windows software GenStat® version 16th (VSN International, Hemel Hempstead, UK). Analysis of variance (ANOVA) was done followed by comparison of mean using Duncan Multiple Range Test at $P \leq 0.01$ or $P \leq 0.05$. Data for all physicochemical and colour variables were further subjected to correlation analysis to determine their relationship.

CHAPTER 4
RESULTS

4.1 Moisture content

Harvest time had no significant effect (P > 0.05) on the moisture content of ‘Reed’ avocado fruit at harvest (Appendix 1). However, moisture content showed a decreasing trend with harvest time of ‘Reed’ avocado fruit. Furthermore, mid-harvest time showed slightly higher moisture content (73.33%) when compared with late harvest (71.83%) (Figure 4.1).

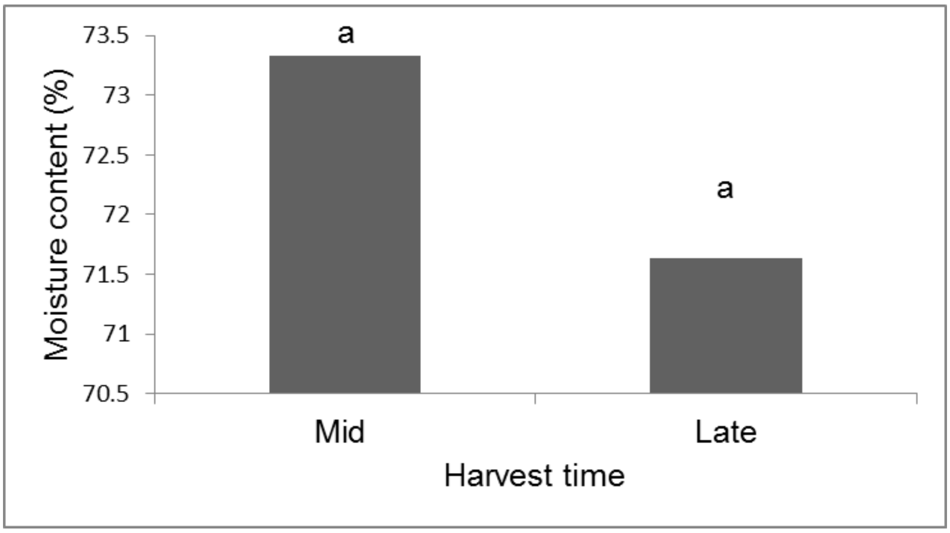

Figure 4.1 Moisture content percentage of ‘Reed’ avocado fruit at mid- and late harvest time

4.2 Weight loss

Harvest time, post-harvest storage, ripening temperature and ripening time had no significant effect (P > 0.05) on weight loss of ‘Reed’ avocado fruit (Appendix 2). In general, ripening at a higher temperature (25°C) resulted in higher fruit moisture loss when compared with lower ripening temperatures (16 and 21°C) throughout the ripening time, irrespective of storage temperature and harvest time. However, fruit weight loss increased with ripening time for both storage and ripening temperature during both harvest time. Furthermore, mid-harvest fruit stored at 2.0°C showed higher fruit weight loss of 8.79 and 5.89% after 4 and 8 days when held to ripen at 25 and 16°C, respectively (Figure 4.2). Whereas, late harvest fruit stored at 2.0°C showed lower weight loss of 8.54 and 5.3% after 4 and 8 days when held to ripen at 25 and 16°C, respectively (Figure 4.2). Moreover, mid-harvest fruit stored at 5.5°C showed higher moisture loss of 7.25 and 7.71% after 4 and 8 days, respectively (Figure 4.2). Whereas, late harvest fruit stored at 5.5°C showed lower moisture loss of 6.47 and 4.64% when ripened at 25 and 16°C, respectively.

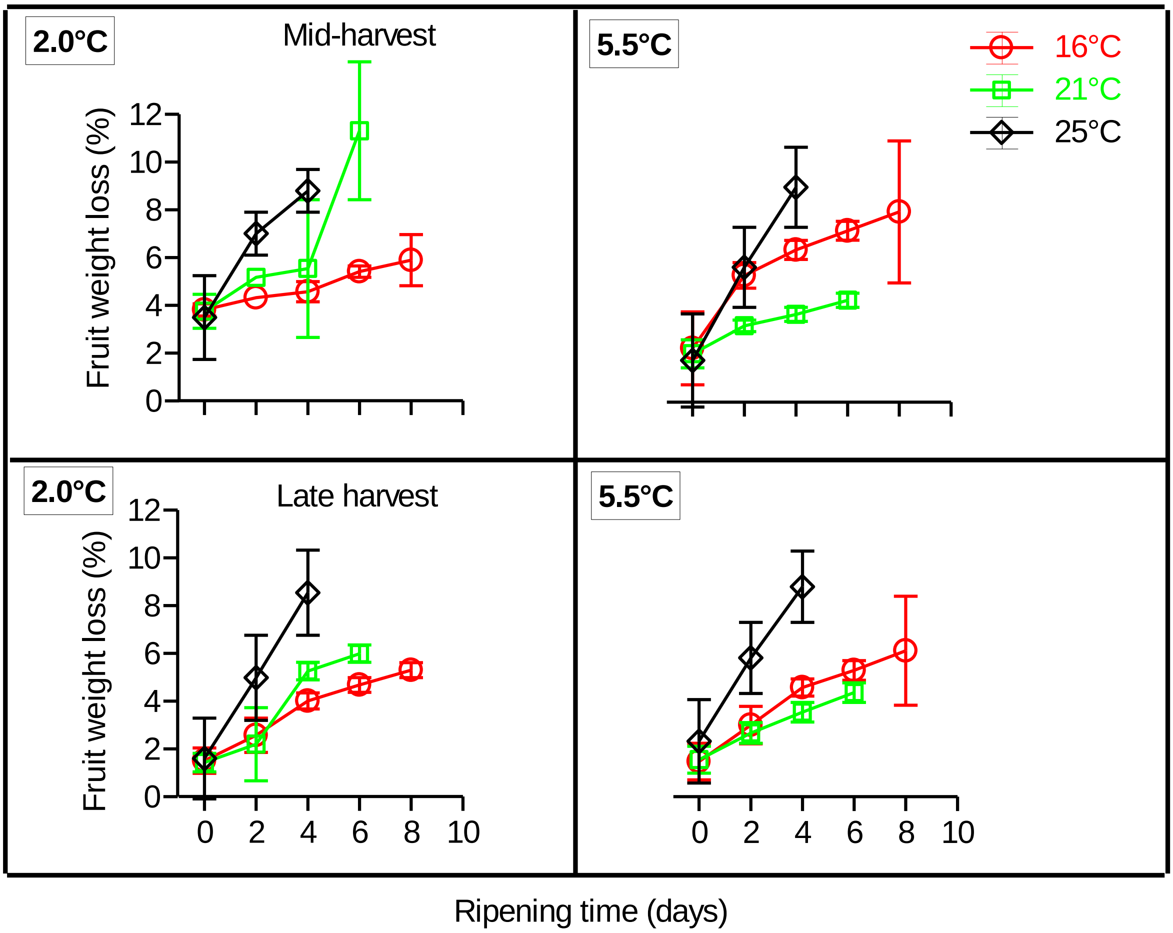

Figure 4.2 Effect of harvest time, post-harvest storage, ripening temperature and ripening time on the fruit weight loss of 'Reed' avocado fruit

4.3 Fruit firmness

Harvest time, post-harvest storage, ripening temperature and ripening time had a significant effect ($P < 0.05$) on the firmness of 'Reed' avocado fruit (Appendix 3). Ripening at higher temperatures (21 and 25°C) showed lower fruit firmness when compared with lower temperature (16°C) irrespective of storage temperature, ripening time, and harvest time. However, harvest time, storage and ripening temperature had no significant effect on fruit firmness during the onset of ripening time (day 0) (Figure 4.3). Ripening at different temperatures influences fruit firmness decreasing trend with time after withdrawal from cold storage all harvest time. However, fruit firmness decreased faster at higher temperatures (21 and 25°C) with fruit fully ripe at 4 and 6 days; and slower at lower ripening temperature (16 °C) with fruit fully ripe at day 8 after withdrawal from cold storage for both harvest times. Furthermore, mid-harvest fruit stored at 2.0°C showed a decrease on fruit firmness from 44.33 to 21.69 and 46.33 to 17.17 SU throughout the ripening time when held to ripen at 16 and 25°C, respectively (Figure 4.3). Whereas, late harvest fruit stored at 2.0°C showed a decrease on fruit firmness from 45.33 to 19 and 44 to 18.17 SU when held to ripen at 16 and 25°C throughout the ripening time, respectively (Figure 4.3). Meanwhile, mid-harvest fruit stored at 5.5°C showed a decrease on fruit firmness from 41.81 to 15.33 and 43.83 to 13 SU throughout the ripening time when held to ripen at 16 and 25°C, respectively (Figure 4.3). Whereas, late harvest fruit stored at 5.5°C decreasing fruit firmness from 46 to 18.26 and 41.67 to 13.33 SU throughout the ripening time when held to ripen at 16 and 25°C, respectively.

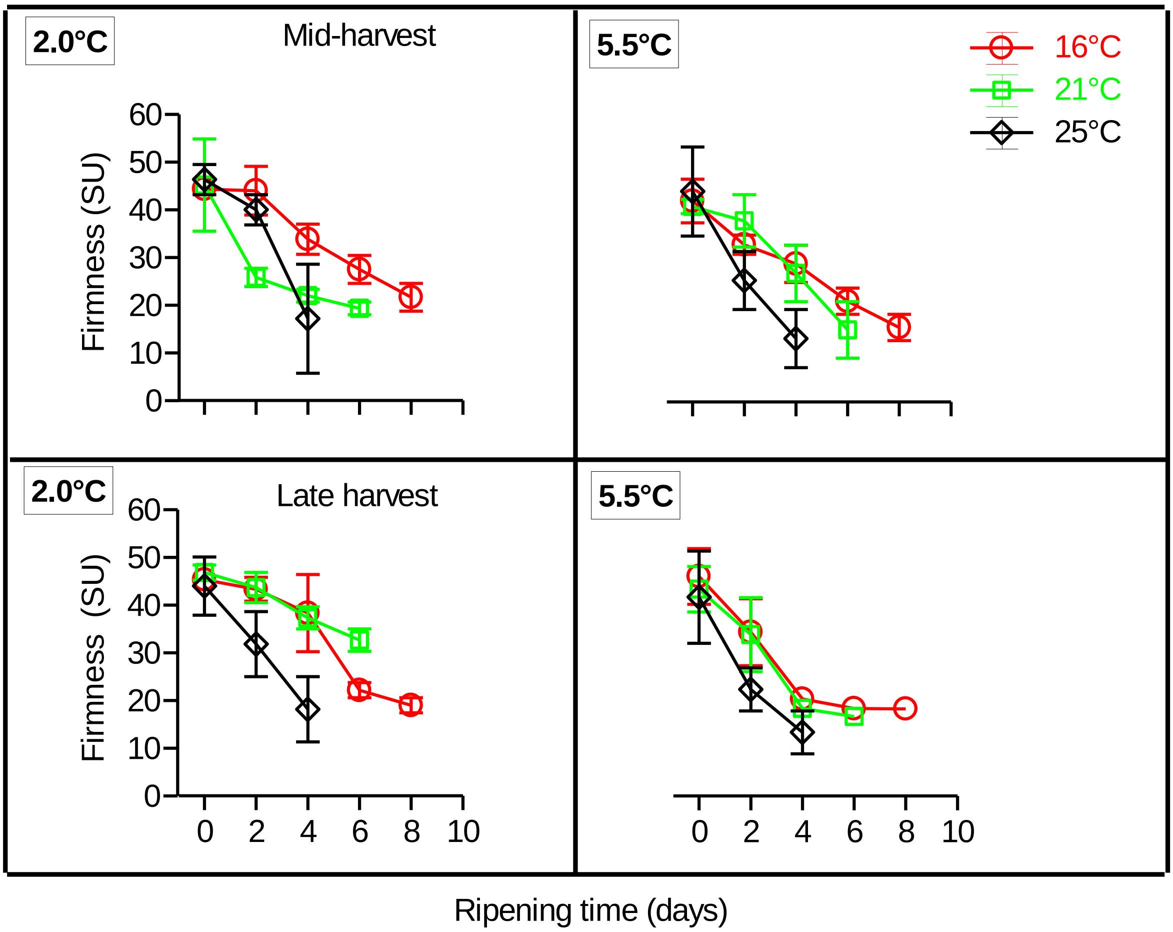

Figure 4.3 Effect of harvest time, post-harvest storage, ripening temperature and ripening time on the firmness of 'Reed' avocado fruit

4.4 Respiration rate

Harvest time, post-harvest storage, ripening temperature and ripening time had a significant effect ($P < 0.05$) on the respiration rate of 'Reed' avocado fruit (Appendix 4). During ripening, respiration rate increased reached a respiratory climacteric peak and decreased with ripening time for all storage, ripening temperature and harvest time. However, ripening at higher temperatures (21 and 25°C) showed higher respiration rate throughout the ripening time for all storage temperatures and harvest times. Contrary, ripening at lower temperatures (16°C) showed lower respiration rate throughout ripening time at all storage temperature and harvest time. Furthermore, mid-harvest fruit stored at 2.0°C reached the respiratory climacteric peak of 1.10 and 2.63 mmol CO_2 kg^{-1} h^{-1} on day 4 of ripening at 16 and 25°C, respectively. Whereas, late harvest fruit stored at 2.0°C reached the respiratory climacteric peak of 1.21 and

2.24 mmol CO_2 kg^{-1} h^{-1} on day 2 and 4 of ripening at 16 and 25°C, respectively (Figure 4.4). Moreover, mid-harvest fruit stored at 5.5°C reached the respiratory climacteric peak of 1.26 and 1.9 mmol CO_2 kg^{-1} h^{-1} on day 4 of ripening at 16 and 25 °C, respectively (Figure 4.4). Late harvest fruit stored at 5.5°C reached the respiratory climacteric peak of 1.45 and 1.63 mmol CO_2 kg^{-1} h^{-1} on day 4 of ripening at 16 and 25°C, respectively (Figure 4.4). Mid- and late harvest fruit stored at 2.0°C, thereafter, ripened at 21°C showed a similar respiratory pattern with a respiration climacteric peak of 1.79 and 1.81 mmol CO_2 kg^{-1} h^{-1} on day 2 of ripening, respectively (Figure 4.4). Whereas, mid- and late harvest fruit stored at 5.5°C, thereafter, ripened at 21°C reached the respiratory climacteric peak of 1.49 and 1.67 mmol CO_2 kg^{-1} h^{-1} on day 2 of ripening, respectively.

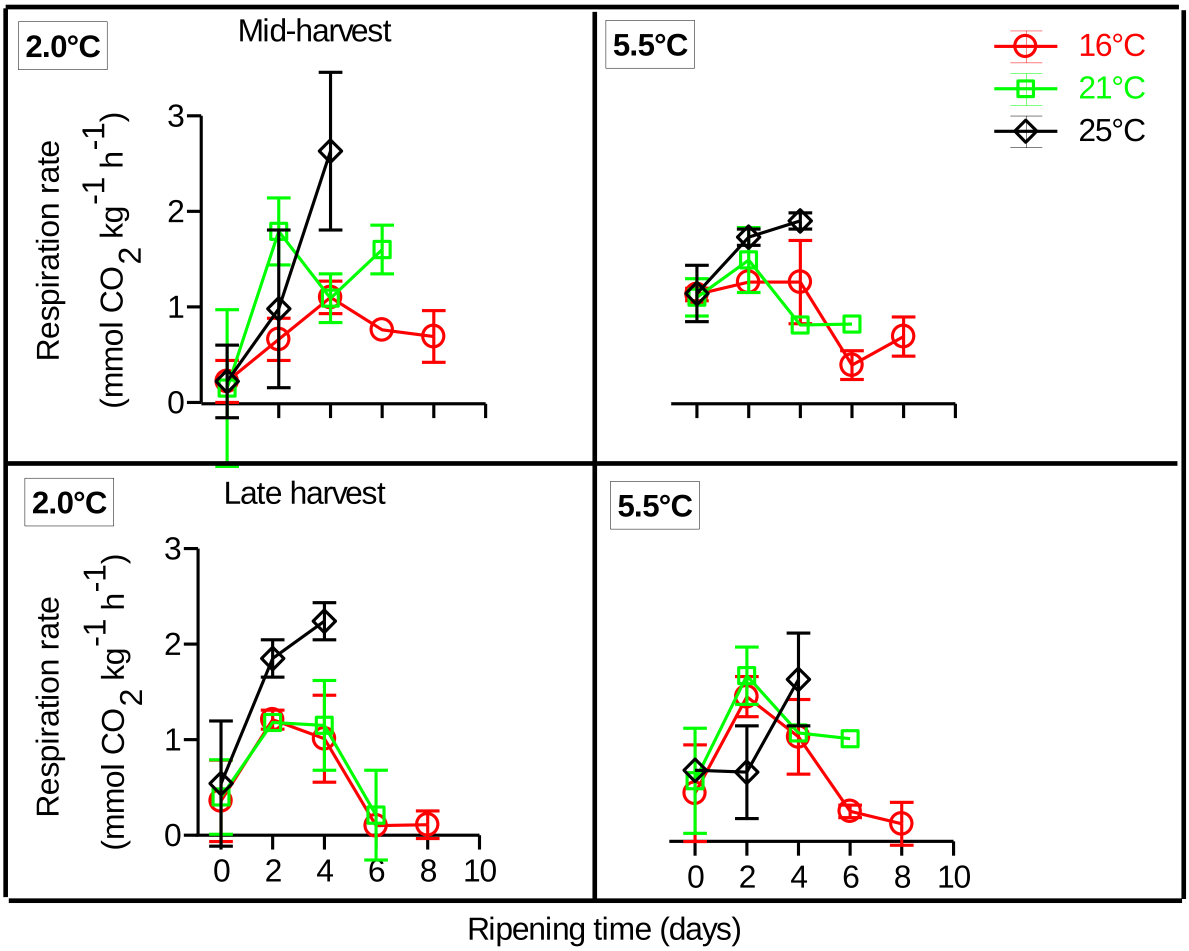

Figure 4.4 Effect of harvest time, post-harvest storage, ripening temperature and ripening time on the respiration rate of 'Reed' avocado fruit

4.5 Ripening percentage

Harvest time, post-harvest storage, ripening temperature and ripening time had no significant effect ($P > 0.05$) on the ripening percentage of 'Reed' avocado fruit (Appendix 5). The respond of 'Reed' avocado fruit to different ripening temperature were observed after 2, 4, 6 and 8 days after withdrawal from cold storage for both harvest time (Figure 4.5). However, ripening at higher temperatures (21 and 25°C) yielded higher ripening percentage when compared with lower temperature (16°C). Furthermore, mid- and late harvest fruit fully ripened after 4, 6 and 8 when held to ripen at 25, 21 and 16°C, respectively (Figure 4.5). Mid- and late harvest fruit stored at 2.0°C and ripened at 16°C showed extended days to ripening (8) with the lower ripening percentage of 55.56 and 72.22%, respectively (Figure 4.5). Whereas, mid- and late harvest fruit stored at 2.0°C and ripened at 25°C showed higher ripening percentage of 100 and 94.44% within 4 days to ripening, respectively (Figure 4.5). In addition, mid- and late harvest fruit stored at 5.5°C showed the higher ripening percentage of 100% after 4, 6 and 8 days to ripening at 25, 21 and 16°C for all storage temperatures and harvest times (Figure 4.5).

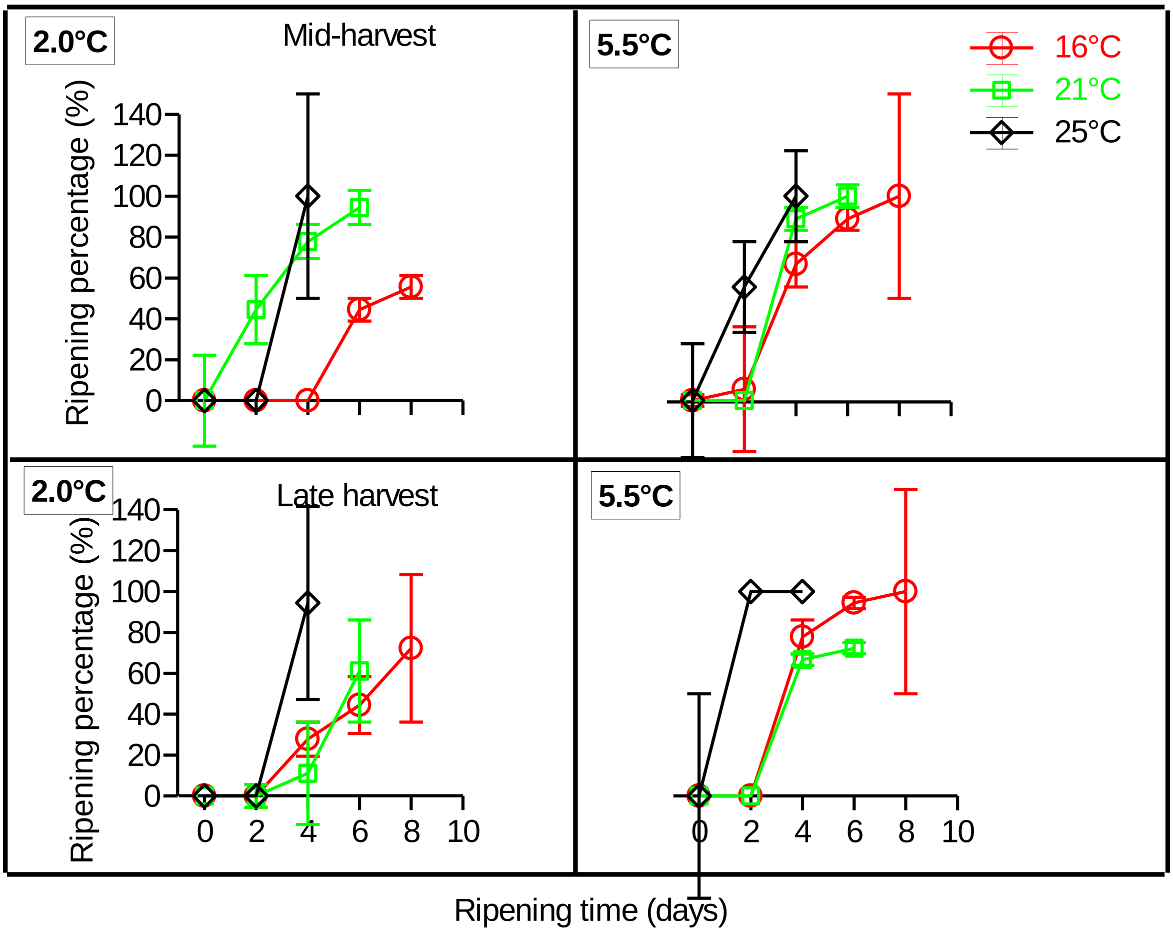

Figure 4.5 Effect of harvest time, post-harvest storage, ripening temperature and ripening time on the ripening percentage of 'Reed' avocado fruit

4.6 Colour parameters

Evaluated 'Reed' avocado fruit showed a change in objective Lightness (L *), Chroma (C *), and Hue angle ($h°$) and subjective (Eye colour) colour parameters during ripening.

Lightness (L *)

Harvest time, post-harvest storage, ripening temperature and ripening time had a significant effect ($P < 0.05$) on fruit lightness of 'Reed' avocado fruit (Appendix 6). Fruit lightness values increased with ripening time for fruit stored at 2.0°C at all ripening temperature and harvest times. Moreover, fruit lightness values for fruit stored at 5.5°C increased with ripening time on fruit held to ripen at 16 and 21°C, irrespective of harvest time. Fruit stored at 2.0°C and ripened at 16°C showed lower L values when compared with 21 and 25°C throughout ripening time and harvest time. Meanwhile, fruit stored at 5.5°C and ripened at 25 °C showed lower L values after day 4 of ripening time at all harvest time. Mid-harvest fruit stored at 2.0°C showed increased L values from 34.47 to 39.75 and 34.6 to 41.98 when held to ripen at 16 and 25°C, respectively (Figure 4.6). Furthermore, late harvest fruit stored at 2.0°C showed an increase in L values from 34.79 to 36.96 and 34.19 to 37.75 when held to ripen at 16 and 25°C, respectively (Figure 4.6). Mid-harvest fruit stored at 5.5°C showed increased L values from 32.67 to 37.31 and 32.04 to 34.99 when held to ripen at 16 and 25°C, respectively (Figure 4.6). Moreover, late harvest fruit stored at 5.5°C showed increased L values from 33.22 to 38.34 and 34.8 to 37.75 when held to ripen at 16 and 25°C, respectively (Figure 4.6).

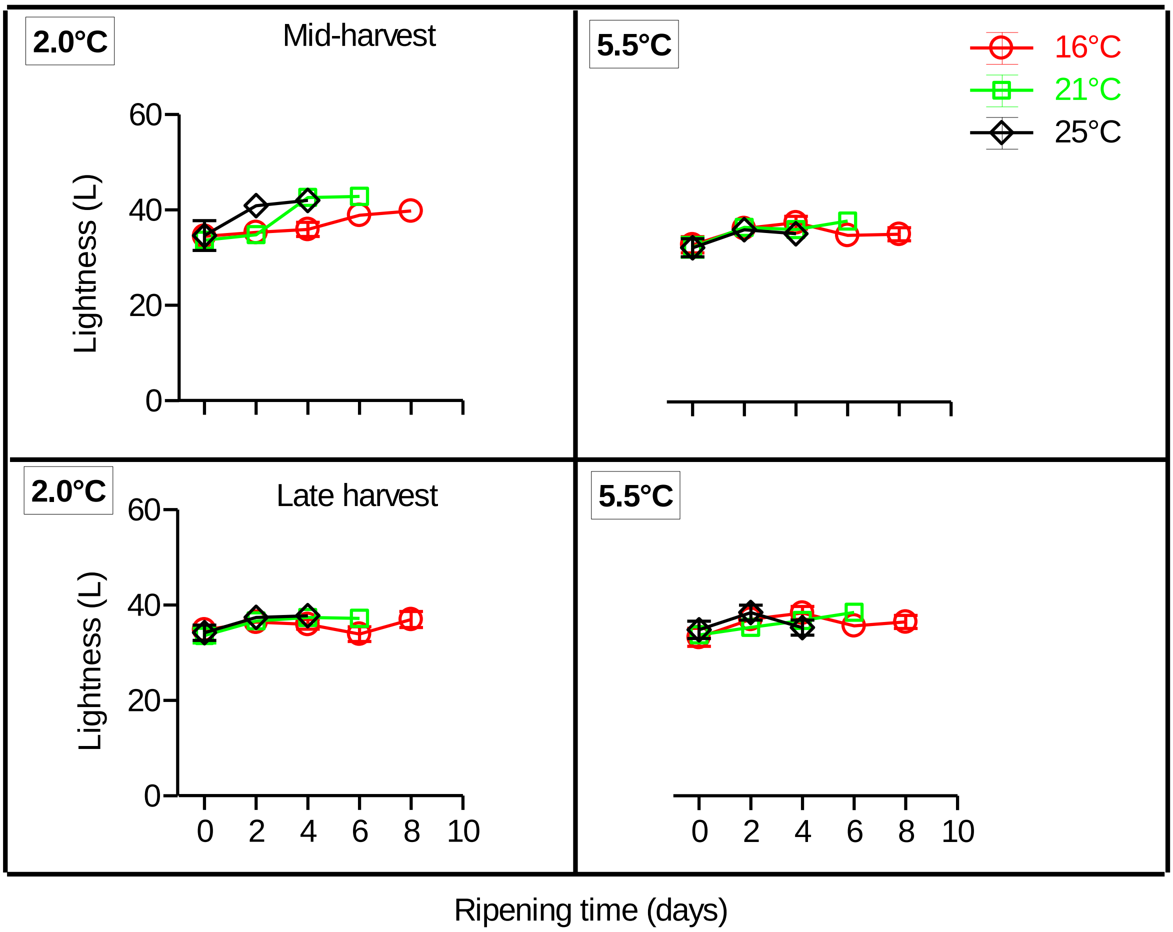

Figure 4.6 Effect of harvest time, post-harvest storage, ripening temperature and ripening time on fruit lightness (L *) of 'Reed' avocado fruit

Chroma (C *)

Harvest time, post-harvest storage, ripening temperature and ripening time had no significant effect (P > 0.05) on the skin chroma of 'Reed' avocado fruit (Appendix 7). However, chroma values slightly changed with ripening time, for all ripening temperature and harvest time. Interestingly, lower ripening temperature (16°C) showed higher C values when compared with fruit ripened at higher temperature (21 and 25°C) throughout days to ripening after withdrawal from higher cold storage 5.5°C for all harvest time. Moreover, mid- and late harvest fruit stored at 2.0 and 5.5°C, thereafter, ripened at 16 and 21°C showed similar trends with a higher magnitude increase on C values throughout the ripening time. Whereas, mid- and late harvest fruit stored at 2.0 and 5.5°C, thereafter, ripened at 25°C showed lower magnitude increase on C values at day 2, afterwards, decreased until fully ripe. Mid-harvest fruit stored at 2.0°C showed higher C values of 144 and 153 after 4 and 8 days to ripening at 25 and 16°C, respectively (Figure 4.7). Late harvest fruit stored at 2.0°C showed lower C values of 70 and 147 after 4 and 8 days to ripening at 25 and 16°C, respectively (Figure 4.7). Mid-harvest fruit stored at 5.5°C showed higher C values of 39 and 115 after 4 and 8 days to ripening at 25 and 16°C, respectively (Figure 4.7). Moreover, late harvest fruit stored at 5.5°C showed lower C values of 39 and 120 after 4 and 8 days to ripening at 25 and 16°C, respectively (Figure 4.7).

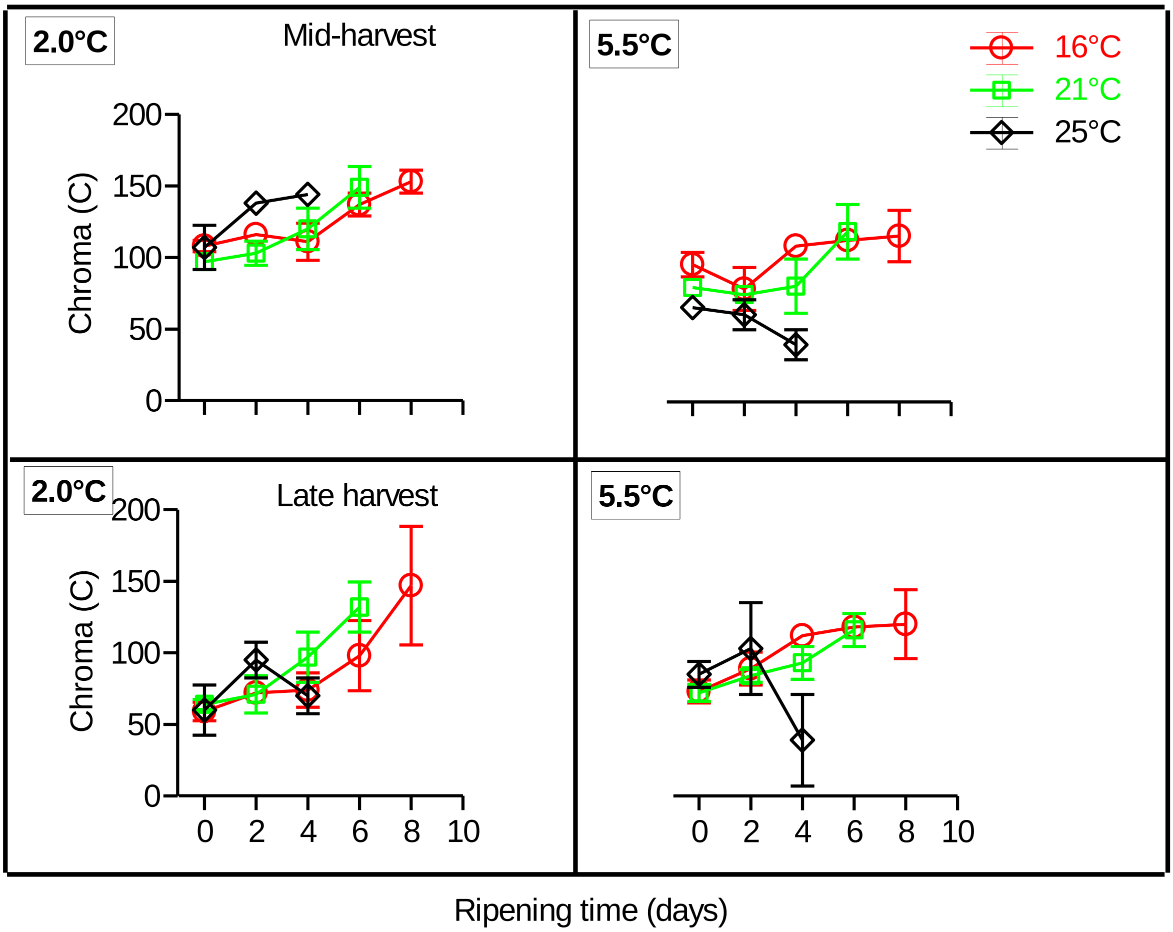

Figure 4.7 Effect of harvest time, post-harvest storage, ripening temperature and ripening time on the chroma (C *) of 'Reed' avocado fruit

Hue angle (*h*°)

Harvest time, post-harvest storage, ripening temperature and ripening time had a significant effect ($P < 0.05$) on the hue angle of 'Reed' avocado fruit (Appendix 8). Mid- and late harvest fruit showed change on skin hue angle throughout ripening time, irrespective of ripening temperature. In general, hue angle values showed a decreasing trend with ripening time at all storage, ripening temperature and harvest time. Mid- and late harvest fruit stored at 2.0°C and ripened at lower temperature (16°C) showed higher hue angle values when compared with higher temperature (21 and 25°C) throughout the ripening time. Mid-harvest fruit stored at 2.0°C showed a decrease in hue angle values from 140 to 99.9 and 138.9 to 108 throughout the ripening time at 16 and 25°C, respectively (Figure 4.8). Meanwhile, late harvest fruit stored at 2.0°C showed a decrease on hue angle from 149.3 to 94 and 149.3 to

134.5 throughout the ripening time at 16 and 25°C, respectively (Figure 4.8). Mid-harvest fruit stored at 5.5°C showed a decrease in hue angle values from 140.3 to 128.1 and 65 to 39 throughout the ripening time at 16 and 25°C, respectively (Figure 4.8). Whereas, late harvest fruit stored at 5.5°C showed decreasing hue angle values from 148.1 to 108 and 139.2 to 112.5 throughout the ripening time at 16 and 25°C, respectively (Figure 4.8).

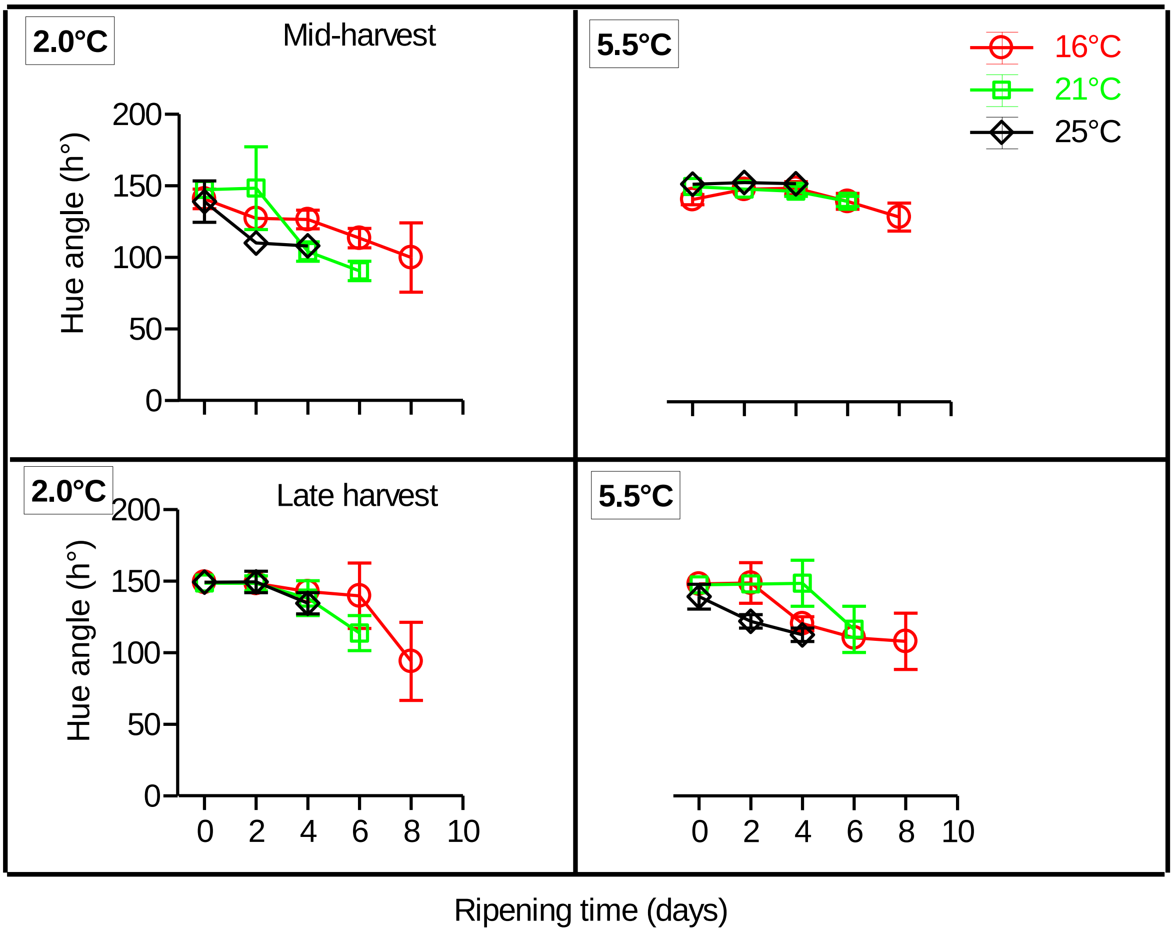

Figure 4.8 Effect of harvest time, post-harvest storage, ripening temperature and ripening time on the hue angle (h°) of 'Reed' avocado fruit

Eye colour

Harvest time, post-harvest storage, ripening temperature and ripening time had no significant effect (P > 0.05) on skin eye colour of 'Reed' avocado fruit (Appendix 9). In general, skin eye colour values increased with ripening time, irrespective of ripening temperature and harvest time. Mid-harvest fruit stored at 2.0°C showed an increase on eye colour values from 1.00 to 2.88 throughout ripening time, irrespective of ripening temperature (Figure 4.9). Moreover, late-harvest fruit stored at 2.0°C showed an increase on eye colour values from 1.00 to 2.50 throughout the ripening time at all ripening temperature (Figure 4.9). Furthermore, mid-harvest fruit stored at 5.5°C also showed increasing eye colour values from 1.00 to 1.67 throughout the ripening time at all ripening temperature (Figure 4.9). Moreover, late harvest fruit stored at 5.5°C showed increasing eye colour values from 1.00 to 2.17 throughout the ripening time at all ripening temperature (Figure 4.9). Overall, storage and ripening at lower temperatures resulted in higher skin eye colour values when compared with fruit stored and ripened at higher temperatures throughout all the ripening time and harvest time.

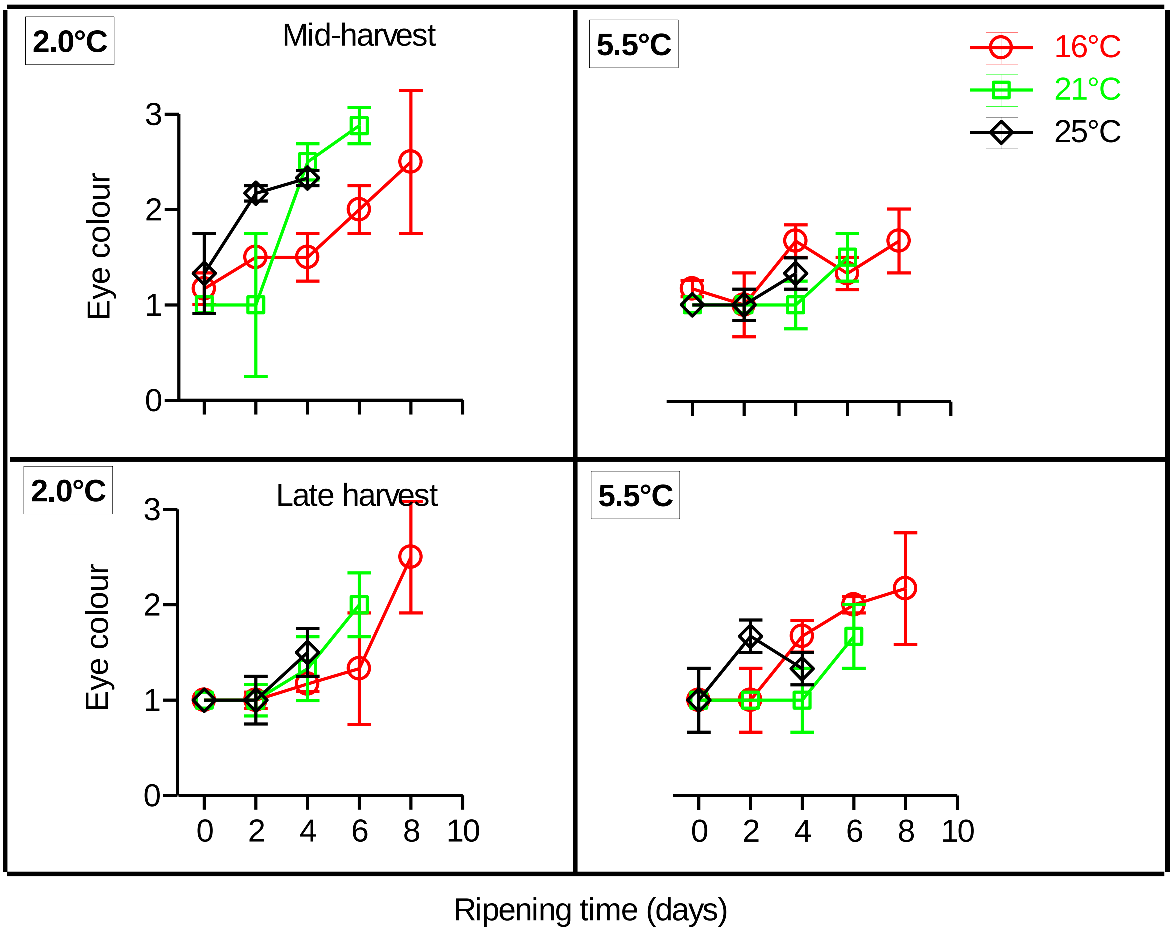

Figure 4.9 Effect of harvest time, post-harvest storage, ripening temperature and ripening time on eye colour of 'Reed' avocado fruit

4.7 Electrolyte leakage

Harvest time, post-harvest time and ripening temperature had no significant effect ($P > 0.05$) on electrolyte leakage of 'Reed' avocado fruit after withdrawal from cold storage (Appendix 10). However, electrolyte leakage of 'Reed' avocado fruit slightly varied but non-significantly after withdrawal from cold storage at both harvest time. Mid-harvest fruit stored at 2.0°C showed a slightly higher electrolyte leakage (20.18%) when compared with late harvest fruit (17.93%) (Figure 4.10). Whereas, mid-harvest fruit stored at 5.5°C showed higher electrolyte leakage percentage (18.62%) when compared with late harvest fruit (16.71%) (Figure 4.10).

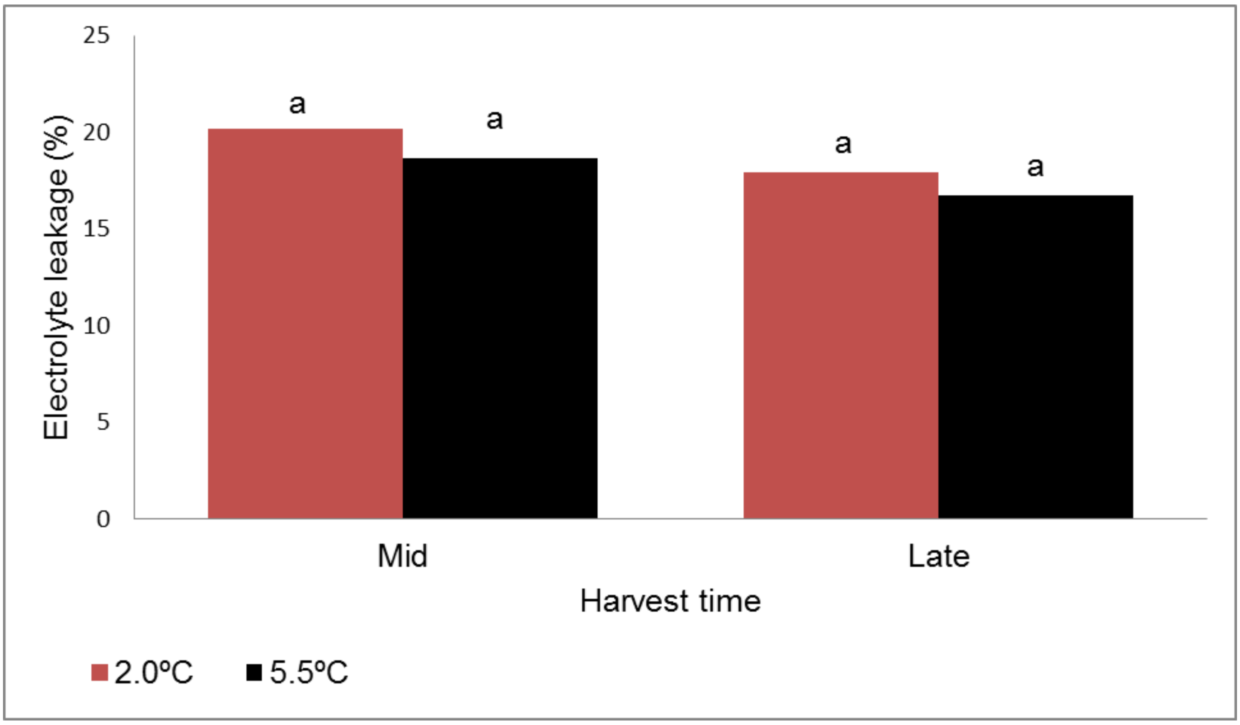

Figure 4.10 Effect of harvest time and post-harvest storage on electrolyte leakage of 'Reed' avocado fruit

4.8 Chilling injury

Harvest time, post-harvest storage and ripening temperature had a significant effect ($P < 0.05$) on external chilling damage of 'Reed' avocado fruit after withdrawal from cold storage (Appendix 11). However, mid-harvest fruit stored at 2.0°C and ripened at 21°C showed higher chilling damage (83.33%) when compared with fruit ripened at 16 (16.67%) and 25°C (0%) (Figure 4.11). Moreover, mid-harvest fruit stored at 5.5°C and ripened at 16°C showed higher chilling damage (77.78 %) when compared with fruit ripened at 21 and 25°C (44.44 %) (Figure 4.11). Late harvest fruit stored at 2.0°C and ripened at 25°C showed higher chilling damage (50%) when compared with fruit ripened at 16 and 21°C (0%) (Figure 4.11). Furthermore, late-harvest fruit stored at 5.5°C and ripened at 25°C showed higher chilling damage (77.78%) when compared with fruit ripened at 16 (50%) and 21°C (33.33%) (Figure 4.11).

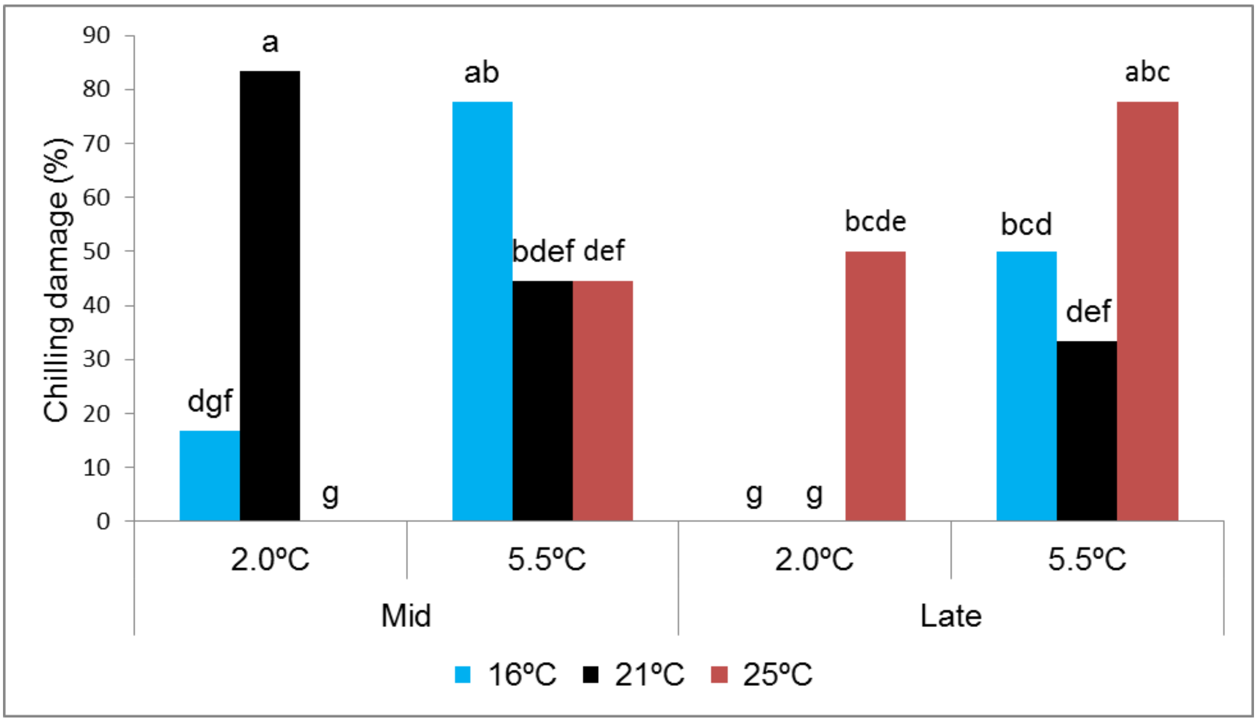

Figure 4.11 Effect of harvest time, post-harvest storage and ripening temperature on chilling injury of 'Reed' avocado fruit

4.9 Vascular browning

Harvest time, post-harvest storage and ripening temperature had no significant effect ($P > 0.05$) on the incidence of vascular browning of 'Reed' avocado fruit after withdrawal from cold storage (Appendix 13). However, late harvest fruit showed higher vascular browning incidence at all ripening temperature when compared with mid-harvest fruit. Whereas, mid-harvest fruit stored at 2.0°C showed lower vascular browning incidence of 66.67 and 0% when held to ripen at 16 and 25°C, respectively (Figure 4.12). Contrarily, late harvest fruit stored at 2.0°C showed higher vascular browning incidence of 100 and 72.22% when held to ripen at 16, 21 and 25°C, respectively (Figure 4.12). Mid-harvest fruit stored at 5.5°C showed lower vascular browning incidence of 33.33 and 72.22% when ripened at 16 and 21°C, respectively

(Figure 4.12). Late harvest fruit stored at 5.5°C showed higher vascular browning incidence of 83.33 and 88.89% when ripened at 16 and 21°C, respectively.

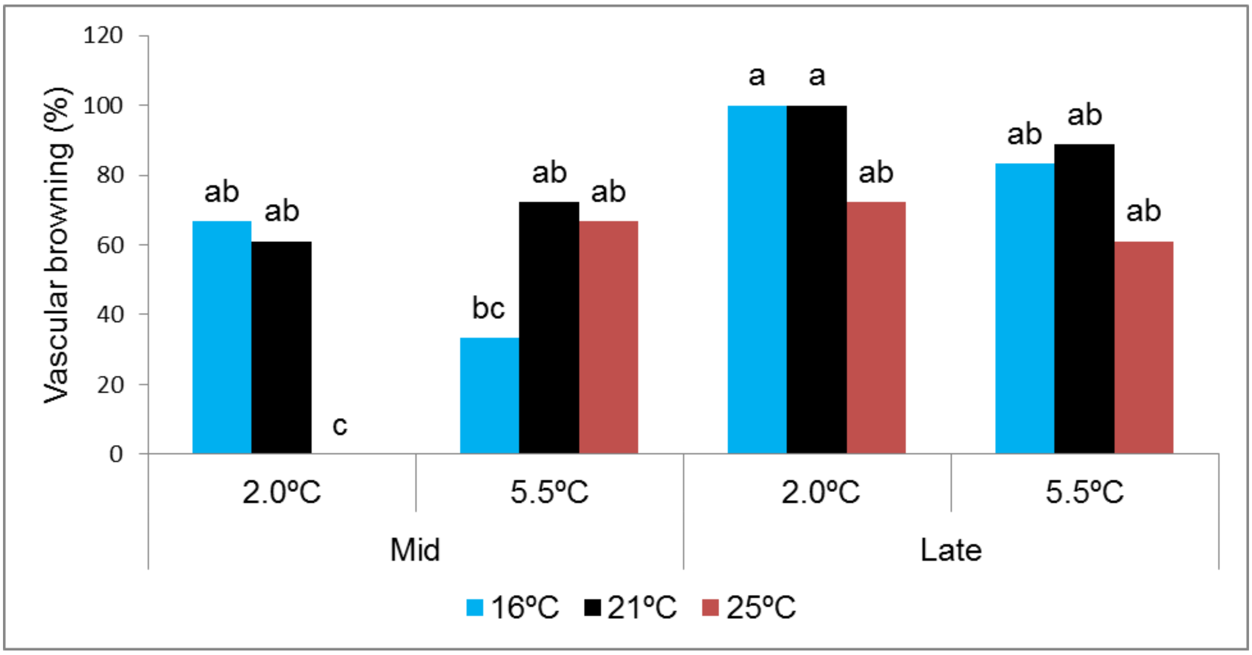

Figure 4.12 Effect of harvest time, post-harvest storage and ripening temperature on incidence of vascular browning on 'Reed' avocado fruit

4.10 Stem-end rot

Harvest time, post-harvest storage and ripening temperature had no significant effect ($P > 0.05$) on stem-end rot incidence of 'Reed' avocado fruit (Appendix 12). However, mid-harvest fruit showed higher stem-end rot incidence when compared with late harvest fruit at all ripening temperature after withdrawal from cold storage (Figure 4.13). Furthermore, mid-harvest fruit stored and ripened at higher temperatures showed higher incidence of stem-end rot when compared with late harvest fruit. Mid-harvest fruit stored at 2.0°C showed higher stem-end rot incidence of 44.44, 50.00 and 11.11% when ripened at 16, 21 and 25°C, respectively (Figure 4.13). Whereas, late harvest fruit stored at 2.0°C showed no incidence of stem-end rot at all ripening temperature. Mid-harvest fruit stored at 5.5°C showed higher stem-end rot incident of 50.00, 33.33 and 66.67% when ripened at 16, 21 and 25°C, respectively (Figure 4.13). Meanwhile, late harvest fruit stored at 5.5°C showed lower stem-end rot incidence of 38.89, 27.78 and 11.11% when ripened at 16, 21 and 25°C, respectively.

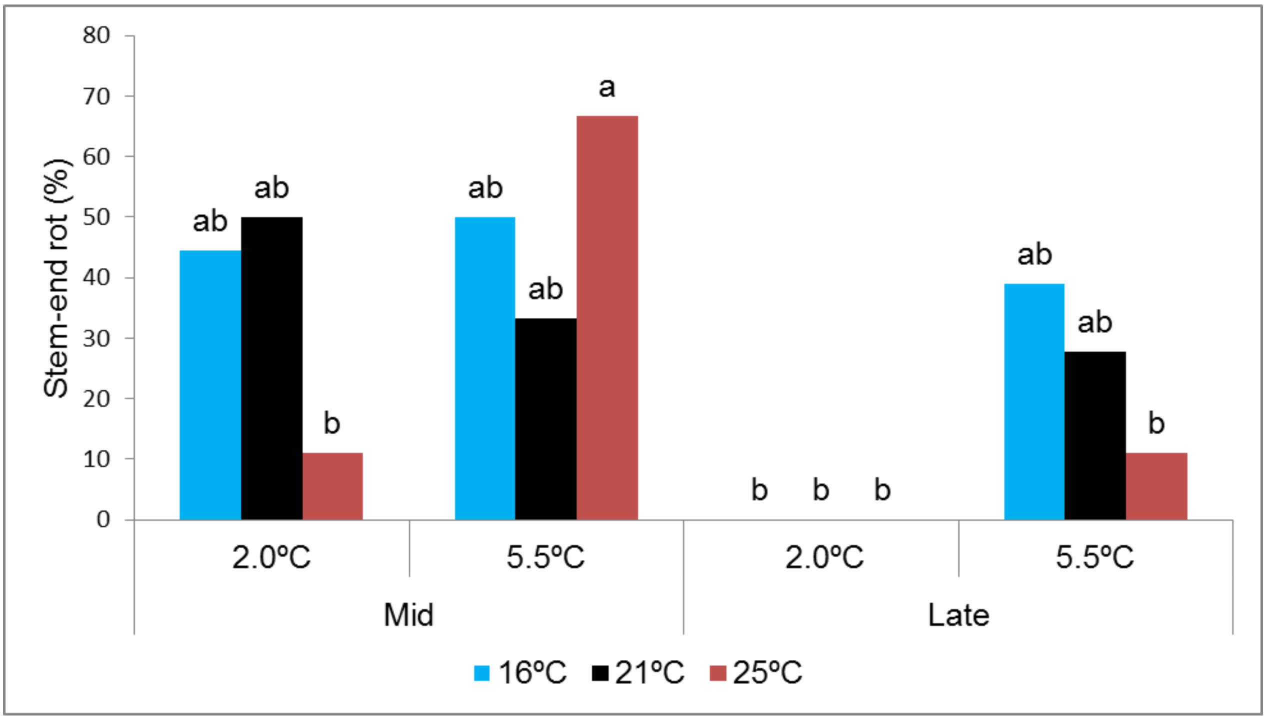

Figure 4.13 Effect of harvest time, post-harvest storage and ripening temperature on incidence of stem-end rot on 'Reed' avocado fruit

4.11 Body rot

Harvest time, post-harvest storage and ripening temperature had no significant effect ($P > 0.05$) on incidence of body rot on 'Reed' avocado fruit after withdrawal from cold storage (Appendix 14). Interestingly, fruit stored and ripened at higher temperature had higher incidence of body rot when compared with lower temperature at both harvest time. However, mid-harvest fruit stored at 2.0°C ripened at 16 and 25°C showed lower body rot incidence of 0 and 38.89 %, respectively (Figure 4.14). While, late harvest fruit stored at 2.0°C and ripened at 16 and 25°C showed higher body rot incidence of 22.22 and 66.67%, respectively (Figure 4.14). Whereas, mid-harvest fruit stored at 5.5°C and ripened at higher temperatures (21 and 25°C) showed no incidence of body rot. Moreover, late harvest fruit stored at 5.5°C showed higher body rot incidence of 11.11 and 72.22% when ripened at 21 and 25°C, respectively.

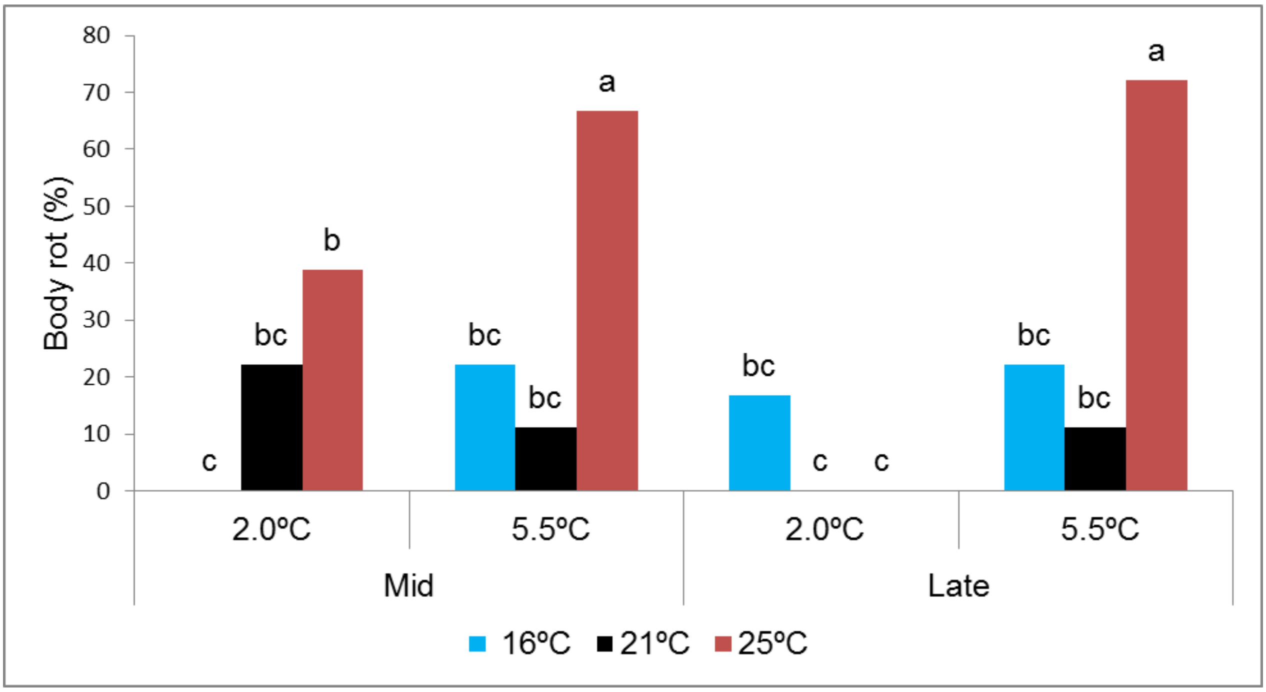

Figure 4.14 Effect of harvest time, post-harvest storage and ripening temperature on incident of body rot on 'Reed' avocado fruit

4.12 Correlation between parameters

In 'Reed' avocado, mid- and late harvest fruit showed negative and weak correlation of R^2 = -0.182 and -0.119 between chilling injury and electrolyte leakage after withdrawal from cold storage (2.0°C), respectively (Figure 4.15). However, mid-harvest fruit showed a positive and weak correlation of R^2 = 0.242 between chilling injury and electrolyte leakage after withdrawal from cold storage (5.5°C) (Figure 4.15). Furthermore, mid-harvest fruit held to ripen at 16, 21 and 25°C showed negative and weak correlation of R^2 = -0.355, -0.450 and -0.566 between fruit weight loss and firmness after withdrawal from lower cold storage (2.0°C), respectively (Table 4.1). Moreover, mid-harvest fruit showed negative and weak correlation of R^2 = -0.450, -0.718 and -0.926 between fruit weight loss and firmness when ripened at 16, 21 and 25°C after withdrawal from higher cold storage (5.5°C), respectively (Table 4.1). Late harvest fruit showed strong negative correlation of R^2 = -0.790 and -0.994 when ripened at 16 and 25°C after lower cold storage at 2.0°C, respectively (Table 4.1). In addition, similar trends on correlation of R^2 = -0.907, -0.916 and -0.906 was observed on fruit ripened at 16, 21 and 25°C during late harvest fruit after higher cold storage (5.5°C), respectively (Table 4.1).

Mid- and late harvest fruit, showed a positive and strong correlation of R^2 = 0.668 and 0.871 between fruit weight loss and respiration rate during ripening at 25°C after withdrawal from lower cold storage (2.0°C), respectively (Table 4.1). Furthermore, the correlation between fruit weight loss and respiration rate was positive and strong (R^2 = 0.612) for fruit ripened at 25°C, after withdrawal from cold storage at 5.5°C during late harvest time (Table 4.1).

There was a positive and weak correlation (R^2 = 0.377) between fruit lightness and chroma for fruit ripened at 16°C, but fruit ripened at 25°C (R^2 = 0.862) showed a positive and strong correlation after withdrawn from cold storage (2.0°C) during mid-harvest (Table 4.1). Late harvest fruit showed strong correlation (R^2 = 0.838) between fruit lightness and chroma after withdrawal from lower cold storage (2.0°C) and ripened at 21°C (Table 4.1). Moreover, the correlation between fruit lightness and chroma was positive and very weak for fruit ripened at 25°C (R^2 = 0.095) during late harvest, but was strong for fruit ripened at 21°C (R^2 = 0.963) after higher cold storage (5.5°C) (Table 4.1). Late harvest fruit showed negative and very weak correlation (R^2= -0.172) between lightness and hue angle after withdrawal from lower cold storage (2.0°C) and ripened at 21°C (Table 4.1). Mid-and late harvest fruit showed negative and very weak correlation (R^2 = -0.004 and -0.002) between fruit lightness and hue angle after withdrawal from higher cold storage (5.5°C) and ripened at 21 and 16°C, respectively.

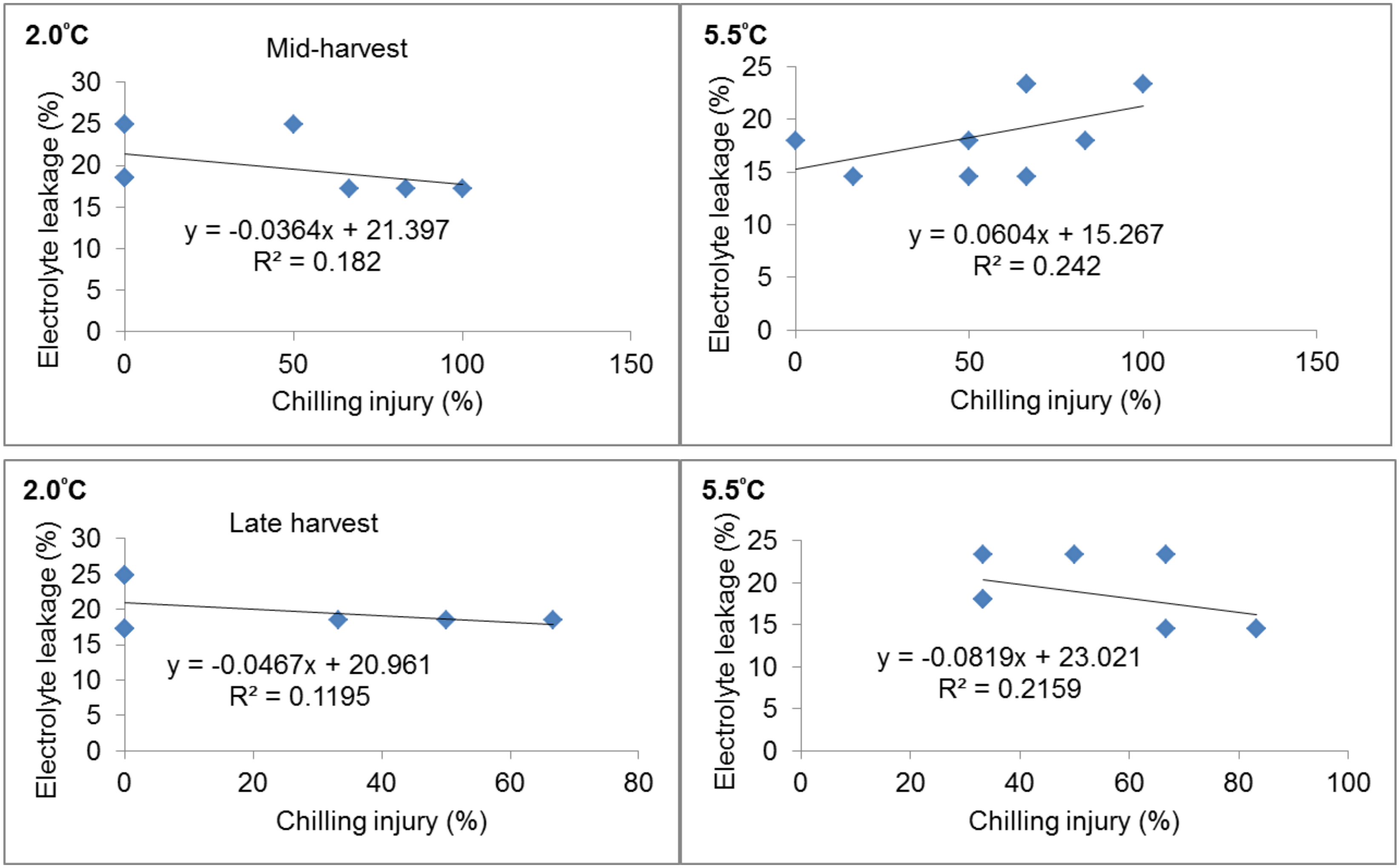

Figure 4.15 Correlation between chilling injury and electrolyte leakage after withdrawal from lower (2.0ºC) and higher (5.5ºC) cold storage temperatures during mid- and late harvest time

Table 4.1 Correlation coefficients (R^2) between 'Reed' avocado quality parameters after removal from lower (2.0 ºC) and higher (5.5 ºC) cold storage temperatures to ripening at 16, 21 and 25 ºC during both mid- and late harvest time

			2.0ºC				**5.5ºC**			
Harvest Time	Ripening temperature (ºC)	Parameters	Firmness (SU)	Respiration rate (mmol CO_2 kg^{-1} h^{-1})	chroma (C)	Hue angle (h°)	Firmness (SU)	Respiration rate (mmol CO_2 kg^{-1} h^{-1})	chroma (C)	Hue angle (h°)
Mid	16	Weight loss	-0.355	0.014			-0.450	-0.107		
	21		-0.450	0.235			-0.718	-0.163		
	25		-0.566	0.668			-0.907	0.348		
Late	16		-0.790	-0.159			-0.907	-0.154		
	21		-0.167	0.021			-0.916	0.167		
	25		-0.994	0.871			-0.906	0.612		
Mid	16	Lightness (L)			0.377	-0.261			0.574	-0.217
	21				0.589	-0.992			0.302	-0.004
	25				0.862	-0.926			0.059	-0.049
Late	16				0.306	-0.300			0.095	-0.002
	21				0.838	-0.172			0.963	-0.620
	25				0.527	0.418			0.387	0.024

CHAPTER 5
DISCUSSIONS

5.1 Moisture content

At harvest, an ideal recommended moisture content for avocado fruit range between 80-69% for the South Africa Avocado industry (Mans *et al*., 1995; Kassim *et al*., 2013). In this study, the moisture content of ‘Reed’ avocado fruit at harvest was slightly higher at a mid-harvest time when compared with late harvest time (Figure 4.1). Our findings agreed with Kruger *et al*. (1995), who found that moisture content for ‘Hass’, ‘Fuerte’, ‘Edranol, ‘Pinkerton’ ‘Ryan’ and ‘Rinton’ avocado fruit declined as the harvest season progresses, therefore, fruit increase in physiological maturity. Toerien (1986) early season fruit were found to be high in moisture content; and therefore, highly susceptible to low storage temperatures when compared with late season fruit.

Moisture content is related to maturity and was found to have an effect on chilling susceptibility of ‘Fuerte’ avocado during storage (Lütge, 2011). This could explain, higher occurrence of chilling damage (83.33%) observed on mid-harvest fruit stored at 2.0°C and ripened at 21°C when compared with late harvest fruit (0%) (Figure 4.11). Adato and Gazit (1974) found time to ripening to be also influenced by the moisture content of the fruit with fewer days to ripening as maturity increase. In this study, late harvest fruit stored at 2.0°C and ripened at 16°C showed high ripening percentage (72.22 %) when compared with mid-harvest (55.56 %) after 8 days to ripening (Figure 4.1). Zauberman *et al*. (1986) found ‘Fuerte’ avocado fruit harvested late season soften at an accelerated rate when compared with earlier harvest fruit. Furthermore, Kremer-Köhne (1998) found that early harvested ‘Fuerte’ avocado fruit becomes highly susceptible to post-harvest diseases when compared with a late harvest. This could be an explanation for higher occurrence of stem-end rot obtained on mid-harvest ‘Reed’ avocado fruit when compared with late harvest after withdrawal from cold storage.

5.2 Fruit weight loss

Storage temperature and days to ripening had a significant effect on 'Reed' avocado fruit weight loss after withdrawal from cold storage during both harvest times. At higher temperatures (21 and 25°C), fruit weight loss was higher when compared with lower temperature (16°C). These findings were similar to Ahmad *et al*. (2001), who found higher weight loss for 'Cavendish' banana fruit kept at higher temperature when compared with those at lower temperature. Furthermore, weight of 'Reed' avocado fruit began to decline when held at different ripening temperatures after withdrawal from cold storage. This agrees with the findings of Herdenburg *et al*. (1990) who reported that fruit weight loss of fruit and vegetable increased rapidly after withdrawal from cold storage temperature to ripening temperature.

According to Maguire *et al*. (2001), fruit weight loss mainly consists of moisture loss through transpiration and to a minor extent, carbon dioxide loss through gas exchange. However, fruit weight loss at higher temperature could be associated with the process of respiration which involves the degradation of reserved sugars for energy production (Pan and Bhowmilk, 1992). Therefore, late harvest fruit stored at 2.0 and 5.5°C and ripened at 25°C showed a positive and strong correlation of R^2 = 0.871 and 0.963 between weight loss and respiration rate, respectively (Table 4.1). Mutari and Rees (2011) suggested that tomato fruit weight loss stored at 12 and 20°C was related to metabolic activities, and metabolic rate was accelerated by increased storage temperature. In addition, Van Rooyen (2005) also found avocado fruit stored at 2.0°C to have lost higher weight when compared with fruit stored at 5.5°C. In contrast, this study indicated that fruit stored at 5.5°C lost higher fruit weight compared with fruit stored at 2.0°C during ripening at different ripening temperatures (Figure 4.2).

5.3 Fruit firmness

In this study, late harvest fruit stored at 5.5°C became softer at an accelerated rate when held to ripen 25°C, when compared with mid-harvest. Late harvest 'Fuerte' avocado fruit became softer at accelerated rate when compared with earlier harvest fruit (Zauberman *et al*., 1986). In many fruits, degradation of insulated protopectin to a more soluble pectin acid and pectin contribute to firmness decrease (Pranamornkith, 2009). Fruit softness reduction is thought to be related to inhibition of cell wall degradation (Tucker and Grierson, 1982). Fruit softness in the current study was mainly depended on storage temperature when compared with harvest time. Fruit held at 25°C became softer at an accelerated rate followed by at 21°C then lastly at 16°C, irrespective of harvest time. These findings were in agreement with Swarts (1980), who found firmness of ‘Fuerte’ avocado fruit to have decreased when held to ripen at 17°C. Furthermore, Ahmad *et al*. (2001) found that banana fruit kept at higher temperature (20°C) were softer when compared with those at lower temperature (14 and 16°C). According to Fuchs *et al*. (1995), biological process associated with fruit quality and ripening are affected by storage temperature.

Zauberman *et al*. (1977) found the metabolic activities of ‘Hass’, ‘Fuerte’ and ‘Naval’ can be reduced under storage at 6 and 8°C; and therefore, delayed ripening and reduced softening until transferred to higher temperature. This confirmed the observation in this study and explained why fruit did not ripen while still under cold storage until after withdrawn and held to ripen at higher temperature. Lütge (2011) found the storage temperature at 5.5°C reduced firmness of ‘Fuerte’ avocado fruit by minimising enzyme activities responsible for cell wall degradation. This could be the justification for the rapid decrease in firmness observed for fruit stored at 5.5°C when compared with 2.0°C during both harvest time. Furthermore, Bower and Cutting (1988) reported that, cellulase and polygalacturonase were highly active; and therefore, responsible for cell wall degradation consequently, softening of avocado fruit. The Q_{10} principle states that for a 10°C increase in temperature enzyme activity doubles (Wills *et al*., 2008). Donkin (1995) that found ripening temperature to have affected the metabolism rate, particularly, the ripening enzyme of ‘Fuerte’ avocado fruit stored at 5.5°C for 28 days and ripened at 18-22°C. Therefore, in this study, storage at lower temperature benefited the fruit by slowing down the metabolic activities and preserved membrane integrity until transferred to higher temperature.

5.4 Respiratory rate

The respiratory pattern of the evaluated ‘Reed’ avocado fruit followed a climacteric respiratory pattern at each ripening temperature (Figure 4.4) characterised by increased carbon dioxide, reaching a maximum climacteric respiratory rate after 2 and 4 days; and thereafter, decreased until the end of shelf-life, irrespective of harvest season. According to Kadam and Salunkhe (1995), avocado fruit respiration is characterised by three stages; pre-climacteric with minimum respiration, climacteric maximum with the highest respiration and a post-climacteric stage synonymous with a decline in respiration. In this study, it was recorded that after withdrawal from cold storage, fruit held to ripen at higher temperatures (21 and 25°C) had higher respiration rate when compared with lower temperature (16°C) during both harvest times. These findings were in agreement with Blanke and Whiley (1995), who found the respiration rate of 'Hass' and 'Fuerte' avocado fruit to have concomitantly with temperature.

Mutari and Rees (2011) demonstrated the effect of temperature on respiration process by increasing the demand for energy to drive metabolic rate, therefore, the process increased with increasing temperature. Whereas, low storage temperature for tomato reduced respiration rate of and ethylene production, therefore, retarded metabolic rate and an extended shelf-life (Getinet *et al*., 2011). According to Eaks (1978), ripening rate, ethylene production of 'Hass' avocado fruit was affected by ripening temperatures at 20, 25, 30, 35 and 40°C. Getinet *et al*. (2011) found the higher respiratory rate at a higher temperature to be due to an increase in chemical reaction characterised by conversion of sugar and oxygen (O_2) to form carbon dioxide (CO_2) and water (H_2O). Maftoonazad and Ranaswamy (2008) suggested that increase respiratory rate of produce hastens senescence and contribute to poor fruit quality. This could explain the positive and strong correlation (R^2 = 0.668 and 0.871) obtained between weight loss and respiration rate for mid- and late harvest fruit stored at 2.0°C and ripened at 25°C, respectively (Table 4.1). Results from this study, demonstrated that higher ripening rate is associated with fruit softening and accelerated ripening rate, irrespective of harvest time and storage temperature.

5.5 Ripening percentage

The evaluated mid- and late harvest 'Reed' avocado fruit were fully ripen after 4, 6 and 8 days to ripening when held at 25, 21 and 16°C, respectively (Figure 4.5). These findings were similar to Mathaba *et al*. (2015), who reported that 'Hass' avocado fruit ripened after 4, 6 and 8 when held to ripen at 25, 21 and 16°C, respectively. According to Adato and Gatiz (1974), post-harvest ripening of avocado fruit was thought to be influenced by physiological maturity, as earlier harvest fruit took longer to ripen when compared with late harvest fruit. Blakey *et al*. (2009) found the ripening of ‘Hass’ avocado fruit to be more pronounced with increasing maturity. In addition, Adato and Gatiz (1974) found that fruit ripening after harvest depended on physiological maturity, temperature and exposure to ethylene.

Storage at 5°C for 2 weeks was able to reduce ethylene production when ripened at 20°C, while early climacteric was observed at storage up to a week (Eaks, 1983). In this study, late harvest fruit stored at 5.5°C and ripened at 25°C shower higher ripening percentage after 2 days to ripening when compared 2.0°C (Figure 4.5). Eaks (1978) found ethylene production of ‘Hass’ avocado to have increased with an increase in ripening temperature (20 to 25°C). Higher temperatures tend to disrupt physiological processes such as; cell wall degrading enzymes and ethylene production by thermally changing the enzymes as well as the essential cellular and sub-cellular structures (Ting, 1982). In this study, ripening at higher temperatures (21 and 25°C) showed higher ripening percentage when compared with lower temperature (16°C) for both harvest times (Figure 4.5).

5.6 Colour parameters

In this study, throughout ripening, the three colour parameters lightness, chroma and hue angle changed unevenly due to harvest time, cold storage, ripening temperature and days to ripening. Furthermore, lightness slightly increased, while chroma and hue slightly decreased. Therefore, overall results showed a visual change in ‘Reed’ avocado fruit, with eye colour changing from green to bright yellow, irrespective of harvest time, storage, ripening temperature and ripening time. These findings were in agreement with Chen *et al*. (2009), who found ‘Sharwil’ avocado fruit skin change to bright yellow when ripe. The skin colour of green mature ‘Sharwil’ avocado fruit remained fairly stable as the harvest season progressed when ripened at 22°C (Chen *et al*., 2009). In this study, mid- and late harvest fruit stored at 5.5°C showed a positive and strong correlated of R^2 = 0.574 and 0.963 between lightness and chroma when ripened at 16 and 21°C. This could imply that ‘Reed’ avocado fruit colour change was attributed to ripening temperature.

According to Cox *et al*. (2004), decrease of chroma, hue and lightness for ‘Hass’ avocado fruit was due to chlorophyll degradation and synthesis of cyanidin 3-*O*-glucoside. In this study, it was assumed that colour change of ‘Reed’ avocado fruit could be associated with carotenoids synthesis which was influenced by ripening temperatures. Consequently, skin colour of 'Reed' avocado fruit was stable during storage but changed during ripening under different ripening temperatures, irrespective of harvest time.

5.7 Chilling injury and electrolyte leakage

Mid-harvest fruit stored at 2.0 and 5.5°C showed higher chilling damage of 83.33 and 77.78% when compared with late harvest fruit (0 and 50%) ripened at 21 and 16°C, respectively. These findings were in agreement with Lütge *et al*. (2010), who found significantly higher chilling injury on 'Fuerte' avocado fruit stored at 2.0°C when compared with fruit stored at 5.5°C. Kok *et al*. (2010) also found higher chilling damage on 'Hass' avocado fruit at stored at 1.0°C when compared with 5.5 °C. According to Bower and Magwaza (2004), reduction in chilling susceptibility for late harvest avocado fruit ('Pinkerton') could be attributed to lower moisture content at harvest. This could be an explanation for the higher occurrence of chilling injury and electrolyte leakage on mid-harvest stored at 2.0°C when compared with late harvest.

According to Lutz and Hardenburg (1968), the optimum storage temperature for avocado fruit ranges between 4.4 to 12.8°C. Therefore, Lütge (2011) assumed that chilling damage on 'Fuerte' avocado fruit stored at 2.0°C was directly related to stress induced during cold storage. Previously, Wang (2010) indicated that tropical and subtropical crops have a critical threshold temperature ranging from 5.0 to 10°C. Storage temperature below 6°C resulted in chilling injury for many avocado cultivars (Woolf, 1997). Prolonged exposure of chilling-sensitive species to temperatures below critical threshold leads to loss of membrane integrity and leakage of solutes (Wang, 2010). This could explain the positive but weak correlation of R^2 = 0.242 between chilling injury and electrolyte leakage for mid-harvest fruit after withdrawal from high storage temperature at 5.5°C.

In a study conducted by Fuchs *et al*. (1995) it was reported that low storage temperature at 2.0°C enhanced ACC-oxidase activity of 'Fuerte' and 'Reed' avocado fruit after 3 and 6 weeks when compared with 5.0°C when held to ripen at 20°C. According to Lelievre *et al*. (1995), enhanced ACC-oxidase activity of 'Granny smith' apples was related to chilling injury development. Moreover, Eaks (1983) reported that cold storage at 0 and 5.0°C for 4 - 6 weeks prevented normal ethylene production and ripening for 'Hass' avocado fruit held to ripen at 20°C. In contrast, this study revealed that, storage at 2.0 and 5.5°C for 28 days did not prevent normal ripening at different temperature after withdrawal from cold storage during both harvest time.

5.8 Vascular browning

According to Kremer-Köhne and Mokgalabone (2003), the incidence and severity of vascular browning for 'Harvest', 'Gem', 'Jewel', 'Sir Prize', 'Nobel' and '8-22-5' avocado fruit increased with harvest season. In this study, similar results were obtained with late harvest fruit showing higher incidence of vascular browning at all ripening temperatures when compared with mid-harvest fruit. In contrast, Swarts (1984) stated that the incidence of mesocarp browning was severe in the early season for avocado fruit.

Post-harvest disorders of 'Hass' avocado fruit increased with extended storage at 6°C for 3 weeks (Hopkirk *et al*., 1994). Exposure of 'Hass' avocado fruit to storage temperature between 3.0-5.0°C for 2 weeks and resulted in internal flesh browning, failure to ripen and increased susceptibility to pathogen attack (Yahia, 2011). Furthermore, 'Hass' avocado fruit stored at 5.5°C had significantly high incidence of vascular browning when compared with fruit stored at 1.0°C (Kok *et al*., 2010). In this study, 'Reed' avocado fruit harvest late season stored at 2.0°C showed higher incidence of vascular browning at all ripening temperature when compared with 5.5°C. Hopkirk *et al*. (1994) found that susceptibility of 'Hass' avocado fruit to pathological disease and physiological disorder intensified with temperature increase. Therefore, high ripening temperatures from 30-40°C increased the risk of fungal decay, vascular browning for 'Hass' and 'Fuerte' avocado fruit (Eask, 1973). in the current study, mid-harvest fruit stored at 5.5°C showed high incidence of vascular browning when compared with lower temperature (16°C) during ripened at higher temperatures (21 and 25°C).

5.9 Stem-end rot and body rot

Results obtained showed higher occurrences of stem-end rot during mid-harvest when compared with late harvest time. However, Kruger *et al*. (2004) that susceptibility of 'Hass', 'Fuerte', 'Edranol', 'Ryan' and 'Pinkenton' avocado fruit to pathological disorder increased with physiological maturity advancement. Our findings were in agreement with Pak *et al*. (2003) who found fruit harvested at early maturity to be poor in quality due to shrivelling, rubbery texture and when ripe, stingy vascular tissues, insipid flavour and high in pathological rots.

According to Arpaira *et al*. (2015), the incidence of stem-end rot, body rot and vascular staining for ‘Hass’ avocado fruit were influenced by duration of cold storage. In our study, late harvest fruit stored at 2.0°C showed no symptoms of stem-end rot and body rot after 8, 6 and 4 days to ripening when held to ripen at 25, 21 and 16°C. In this study, mid-harvest fruit stored at 5.5°C showed higher incidence of stem-end rot and body rot when ripened at 25°C for 4 days when compared with 16 (8) and 21°C (6 days). Similar results were also reported by Arpaia *et al.* (2003), when comparing ripening temperature of 20 and 25°C, whereby, ripening at 25°C resulted in higher incidence of stem-end rot and body rot when compared with 20°C.

CHAPTER 6
SUMMARY, RECOMMENDED FUTURE RESEARCH AND CONCLUSION

6.1 Summary

In this study, the effect of harvest time, post-harvest storage, ripening temperature on quality of ‘Reed’ avocado fruit during ripening was investigated. During ripening, weight loss, firmness, respiration rate, ripening percentage of ‘Reed’ avocado fruit were affected by harvest time, post-harvest storage and ripening temperatures. However, storage and ripening temperatures were the two main factors affecting weight loss, firmness, respiration rate and ripening percentage throughout days to ripening irrespective of harvest time. In addition, colour change of ‘Reed’ avocado fruit from green to bright yellow was noticeable during ripening, irrespective of storage, ripening temperature and harvest time. Moreover, higher storage temperature of 5.5°C resulted in chilling damage and, this was positively correlated with electrolyte leakage. High storage and ripening temperature were conducive for the establishment of post-harvest pathological and physiological disorders during both harvest times.

6.2 Recommendation and future research

In South Africa, ‘Reed’ avocado fruit is a newly introduced cultivar. Therefore, studies to identify pre-harvest practices that promote higher post-harvest fruit quality of ‘Reed’ avocado fruit under South African production environment are recommended. This includes production areas, pruning, irrigation, fertiliser application, girdling and different rootstocks. The use of post-harvest operations such as waxing, 1-MCP and other storage techniques could be investigated in conjunction with harvest time, storage and ripening temperatures to further assess quality of ‘Reed’ avocado fruit. In addition, future studies could focus on the effect of harvest time, post-storage and ripening temperature on sugar and bioactive compounds of ‘Reed’ avocado fruit.

6.3 Conclusion

The present study showed that harvest time, post-harvest storage and ripening temperatures had profound influence on quality of ‘Reed’ avocado fruit. It could be concluded that in South Africa ‘Reed’ avocado fruit could be harvest during mid- and late season and stored at recommended low temperature (2.0°C); and thereafter, ripened at either 16 or 21°C. This combination treatment appeared to be best treatment for ‘Reed’ avocado fruit as quality parameters such as weight loss, firmness, respiration and ripening are maintained when compared with ripening at higher temperature (25°C). This treatment combination also provided good external and internal quality as it reduced establishment of post-harvest disease and disorders when compared with ripening temperature at 25°C. Results from this study could provide post-harvest information required for registrations of ‘Reed’ avocado fruit for export market.

REFERENCES

ADATO, I. and S. GAZIT. 1974. Water-deficit stress, ethylene production and ripening in avocado fruits. *Plant Physiology* 53: 45-46.

AGM. 2001. *New Zealand Avocado Growers Association, Avocado Growers* Manual, Tauranga.

AHMAD, S., THOMPSON, A.K, AHMED, I.H. and A.A. ASGHAR. 2001. Effect of temperature on the ripening behaviour and quality of banana fruit. *International Journal of Agriculture and Biology* 3: 1560-8530.

AHMED, D.M., AML, R., YOUSEF, M. and H.S.A. HASSAN. 2010. Relationship between electrical conductivity, softening and color of ‘Fuerte’ avocado fruits during ripening. *Agriculture and Biology Journal of North America* 1: 878-885.

ARPAIA M. L. 2003. ‘Hass’ maturity project, new project, year 1 of 1. Department of Botany and Plant Sciences, University of California Riverside.

ARPAIA, M.L., COLLIN, S., SIEVERT, J. and D.OBENLAND. 2015. Influence of cold storage prior to and after ripening on quality factors and sensory attributes of ‘Hass’ avocado. *Postharvest Biology and Technology* 110: 149-157.

ARPAIA, M.L., VAN ROOYEN, Z., BOWER, J.P., HOFMAN, P.J. and A.B., WOOLF. 2004. Grower practices will influence postharvest fruit quality, II International Avocado Conference Quillota, Chile.

ASHTON, O.B.O., WONG, M, MCGHIE, T.K., VATHER, R., WANG, Y., REQUEJO-JACKMAN, C., RAMANKUTTY, P. and A.B. WOOLF. 2006. Pigments in avocado tissue and oil. *Agricultural Food Chemistry* 54: 10151-10158.

AWAD, M. and R. E. YOUNG. 1979. Post-harvest variation in cellulose, polygalacturonase and pectinmethylesterase in avocado (*Persea americana* Mill, cv. ‘Fuerte’) fruits in relation to respiration and ethylene production. *Plant Physiology*. 64: 306-308.

BARTZ, J.A. and J.K. BRECHT. 2003. Postharvest physiology and pathology of vegetables (2nd ed). Marcel Dekker, Inc., New York.

BIALE, J.B. 1975. Synthetic and degradative processes in fruit ripening. *In*: N.F. Haard and D.K. Salunkhe (eds.), Symposium: Postharvest biology and handling of fruits and vegetables. AVI Publ. Co., Westport, CT, pp. 5-18.

BLAKEY, R.J. 2011. Management of avocado postharvest physiology. PhD. thesis, School of Agricultural Sciences and Agribusiness. University of KwaZulu-Natal, Pietermaritzburg.

BLAKEY, R.J. and J.P. BOWER. 2009. The importance of maintaining the cold chain for avocado ripening quality. *South African Avocado Growers' Association Yearbook* 32: 48-52.

BLAKEY, R.J., BOWER, J.P. and I. BERTLING. 2009. Influence of water and ABA supply on the ripening pattern of avocado (*Persea americana* Mill.) fruit and the prediction of water content using near infrared spectroscopy. *Postharvest Biology and Technology* 53: 72-76.

BLAKEY, R.J., BOWER, J.P. and I. BERTLING. 2009. Protein and sugar trends during the avocado season. *South African Avocado Growers' Association Yearbook* 32: 18-21.

BLANKE, M. and A.W. WHILEY. 1995. Bioenergetics, respiration cost and water relations of developing avocado fruit. *Plant Physiology* 145: 87-92.

BOWER, J. P. and J. G. CUTTING. 1988. Avocado fruit development and ripening physiology. In: Horticultural Reviews. 10: 229-271. J. Janick (Ed.) Timber Press, Portland, OR. Posted with permission of J. Janick and the International Society for Horticultural Science.

BOWER, J.P. 1985. Some aspects of Water Relations on avocado (*Persea americana* Mill.) tree and Fruit Physiology. PhD thesis, School of Agricultural Sciences and Agribusiness. University of KwaZulu-Natal, Pietermaritzburg.

BOWER, J.P. and G. PAPLI. 2006. Effect of fruit coatings and packaging on chilling injury of 'Hass' avocados. *South African Avocado Growers' Association Yearbook* 29: 69-72.

BOWER, J.P. and L.S. MAGWAZA. 2004. Effect of coatings and packaging on external and internal quality with emphasis on “cold injury”. *South African Avocado Growers' Association Yearbook* 27: 35-39.

CANTÍN, C.M., CRISOSTO, CH., OGUNDIWIN, E.A., GRADZIEL, T., TORRENTS, J. and M.A. MORENO. 2010. Chilling injury susceptibility in an intra-specific peach [*Prunus persica* (L.) Batsch] progeny. *Postharvest Biology and Technology* 58: 79-87.

CHEN, N.J., WALL, M.M., PAULL, R.E. and P.A. FOLLETT. 2009. Variation in ‘Sharwil’ avocado maturity during the harvest season and resistance to fruit fly infestation. *Horticultural Science* 44: 1655-1661.

CLARK, C.J., McGLONE, V.A., REQUEJO, C., WHITE, A. and A.B. WOOLF. 2003. Dry matter determination in ‘Hass’ avocado by NIR spectroscopy. *Postharvest Biology and Technology* 29: 300-307.

COX, K.A., MCGHIE, T.K., WHITE, A. and A.B. WOOLF. 2004. Skin colour and pigment changes during ripening of ‘Hass’ avocado fruit. *Postharvest Biology and Technology* 31: 287-294.

DARVAS J. M. and J. M. KOTZE. 1981. Post-harvest diseases of avocado. *South African Avcoado Growers’ Association Yearbook* 4: 63-66

DARVAS J. M. and J. M. KOTZE. 1987. Avocado fruit diseases and their control in South Africa. *South African Avcoado Growers’ Association Yearbook* 10: 117-119.

DARVAS, J.M. and KOTZÉ, J.M. 1987. Avocado fruit diseases and their control in South Africa. *South African Avocado Growers' Association Yearbook* 10: 117-119.

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES (DAFF). 2010. Annual report of the department of forestry and fisheries for the period 1 April 2010 to 31 March 2011.

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES (DAFF). 2014. A profile of South African avocado market value chain, national department of agriculture. Pretoria, South Africa.

DIXON, J., PAK, H.A., MANDEMAKER, A.J., SMITH, D.B., ELMSLY, T.A. and J.G.M. CUTTING. 2003. Fruit age managment: the key to successful long distance export of New Zealand avocados, NZ Avocado Growers' Association Annual Research Report 4, pp. 47-53.

DIXON, J., SMITH, D.B. and T.A. ELMSLY. 2004. Fruit age, storage temperature and maturity effects on 'Hass' avocado fruit quality and ripening. *New Zealand Avocado Growers' Association Annual Research Report* 47-53.

DONKIN, D.J. 1995. Some aspects of Cold Storage of 'Fuerte' avocados (*Persea americana* Mill.) grown in the Natal Midlands. Msc thesis, School of Agricultural Sciences and Agribusiness. University of Kwazulu-Natal, Pietermaritzburg.

DONKIN, D.J. 2007. An overview of the South African Avocado Industry*. South African Avocado Growers' Association,* August 2007. www.subtrop.co.za, accessed: 25/04/2015.

DRAKE, S.R., PROEBSTING, E.L.J.R. and S.E. SPAYD. 1982. Maturity index for the colour grade of canned dark sweet cherries. *Journal of the American Society of Horticultural Science* 107: 180.

EAKS, I.L. 1973. Effects of clip vs. snap harvest of avocados on ripening and weight loss. *Journal of American Society of Horticultural Science* 98:106-108.

EAKS, I.L. 1978. Ripening, Respiration, and Ethylene Production of 'Hass' Avocado Fruits at 20 to 40ºC. *Journal of American Society of Horticultural Science* 103: 576-578.

EAKS, I.L. 1983. Effects of chilling on respiration and ethylene production of 'Hass' avocado fruit at 20ºC. *Horticultural Science* 19: 235-237.

EAKS, I.L.1976. Ripening, chilling injury and respiratory response of ‘Hass’ and ‘Fuerte’ avocado fruits at 20°C following chilling. *Journal of American Society of Horticultural Science* 10: 538-540.

EKSTEEN, G.J. 2001. Handling procedures for export avocados. *In*: de Villiers, E.A., The Cultivation of avocado. Institute for Tropical and Subtropical Crops, Nelspruit, South Africa.

FARMER’S WEEKLY. 2011. Westfalia developed new avocado varieties. Issue date 4February 2011. Online available from http://www.farmersweekly.co.za/article. Access on 04 June 2015.

FAUBION, D.F., MITCHELL, F.G. and G. MAYER. 1992. Response on ‘Hass’ avocado to Post-harvest Storage in Controlled Atmosphere Conditions. *Proceedings of Second World Avocado Congress.* Pp.467-472.

FENG, G., YANG H. and Y. LI. 2005. Kinetics of relative electrical conductivity and correlation with gas composition in modified atmosphere packaged bay berries (*Myrica rubra* Siebold and Zuccarini). *Swiss Society of Food Science and Technology* 38: 249-254.

FITZELL, R.D. and I.F. MUIRHEAD. 1983. Reducing postharvest disease in 'Fuerte' avocados by temperature management. *Australian Journal of Experimental Agriculture and Animal Husbandry* 23: 331-336.

FLORISSEN, P., EKMAN, J.S., BLUMENTHAL, C., MCGLASSON, W.B., CONROY, J. and HOLFORD, P.L. 1996. The effects of short heat treatments on the induction of chilling injury avocado fruit (*Persea americana* Mill.). *Postharvest Biology and Technology* 8: 129-134.

FUCHS, Y., ZAUBERMAN G. and E.I. LEDERMAN. 1995. Effect of postharvest treatments and storage conditions on avocado fruit ripening and quality. *Proceedings of The World Avocado Congress III.* Pp. 323-330.

GAMBLE, J., HARKER, F.R., JAEGER, S.R., WHITE, A., BAVA, C., BERESFORD, M.,STUBBINGS, B., WOHLERS, M., HOFMAN, P.J., MARQUES, R. and WOOLF, A. 2010. The impact of dry matter, ripeness and internal defects on consumer perceptions of avocado quality and intentions to purchase. *Postharvest Biology and Technology* 57: 35-43.

GETINET, H., WORKNEH, T.S. and K. WOLDETSADIK. 2011. Effect of maturity stages, variety and storage environment on sugar content of tomato stored in multiple pads evaporative cooler. *African Journal of Biotechnology* 10: 18481-18492.

GRAY, J., S. PICTON, J. SHABBEER, SCHUCH, W. and D. GRIERSON. 1992. Molecular biology of fruit ripening and its manipulation with ethylene gene. *Plant Molecule Biology* 19:69-87.

HARTILL, W.F.T.1991. Post-harvest diseases of avocado fruit in New Zealand*. New Zealand Journal of Crop and Horticultural Science* 19: 297-304.

HATFIELD, R. and D.J. NEVINS. 1986. Characterisation of the hydrolytic activity of avocado cellulase. *Plant and Cell Physiology* 27: 541-552.

HERDENBURG, R., WATADA, A.E. and Y. WANG. 1990. Commercial storage of fruit, vegetables, florist and nursery stocks. Agriculture Handbook 66. Davis, CA: USDA. Pp.19-20.

HERSHKOVITZ, V., FRIEDMAN, H., GOLDSCHMIDT, E.E. and E. PESIS. 2009. The role of the embryo and ethylene in avocado fruit mesocarp discoloration. *Experimental Botany* 60: 791- 799.

HOFMAN, P.J., BOWER, J., and A. WOOLF. 2013. Harvesting, Packing, Postharvest technology, Transport and Processing, *In*: BRUCE, S., WOLSTENHOLME, B.N., WHILEY, A.W. (eds.), The Avocado: Botany, Production and Uses, 2nd ed. CAB International, Nosworthy Way, Wallingford, Oxfordshire Ox10 8DE, UK. Pp. 489-540.

HOFMAN, P.J., FUCHS, Y. and D.L. MILNE. 2002. Harvesting, packing, postharvest technology, transport and processing. *In*: WHILEY, A.W., SCHAFFER, B.A. and WOLSTENHOLME, B.N. (eds.), 2002. The Avocado: Botany, Production and uses. CABI Publishing, Wallingford, Oxon, UK. pp. 363-391.

HOPKIRK, G., WHITE, A., BEEVER, D.J. and S.K. FORBES. 1994. Influence of postharvest temperatures and the rate of fruit ripening on internal postharvest rots and disorders of New Zealand 'Hass' avocado fruit. *New Zealand Journal of Crop and Horticultural Science* 22: 305-311.

JAVANMARDI, J. and C. KUBOTA. 2006. Variation of lycopene, antioxidant activity, total soluble solids and weight loss of tomato during postharvest storage. *Postharvest Biology and Technology* 41: 151-155.

JOHNSON, G.I. and J.M. KOTZE. 1994. Avocado stem end rot. *In*: PLOETZ, R.C., ZENTMYER, G.A., NISHIJIMA, W.T, ROHRBACH, K.G. and OHR, H.D. (eds.) Compendium of Tropical Fruit Diseases. St Paul, Minnesota.

KADAM S.S. and D.K. SALUNKHE 1995. Avocado. *In:* SALUNKHE D.K. and KADAM S.S. (eds.). Fruit Science and Technology. New York: Marcel Dekker, Inc.

KADER, A.A. 1992. Postharvest biology and technology. Publication 3311. An overview. In Postharvest Technology of Horticultural Crops, AA Kader Edition. University of California, California

KAHN. V.1975. Polyphenol oxidase activity and browning by three avocado varieties. *Science and Food Agriculture* 26: 1319-1324.

KASSIM, A. WORKNEH T. S. and C. N. BEZUIDENHOUT. 2013. A review on postharvest handling of avocado fruit. *African Journal of Agricultural Research* 8: 2385-2402.

KLEIN, J.D. and S. LURIE. 1991. Postharvest heat treatment and fruit quality. *Postharvest News and Info* 2: 15-19.

KOK R.D. 2011. Enhancement of ‘Hass’ avocado shelf life using ultra- low temperature shipping or 1-mcp treatment and cold chain management. Msc thesis, School of Agricultural Sciences and Agribusiness. University of KwaZulu-Natal, Pietermaritzburg.

KOK, R.D., BOWER, J.P. and I. BERTLING. 2010. Low temperature shipping and cold chain management of ‘Hass’ avocados: An opportunity to reduce shipping costs. *South African Avocado Growers Association Yearbook* 33: 33-37.

KOSIYACHINDA, S. and R.E. YOUNG. 1976. Chilling sensitivity of avocado fruit at different stages of the respiratory climacteric. *Journal of American Society of Horticultural Science* 101: 665-667.

KREMER-KÖHNE, S. 1998. Postharvest management of South African Avocado fruit, Merensky Technological Services, Westfalia Estate, P.O. Box 14, Duivelskloof, 0835, South Africa.

KREMER-KÖHNE, S. and M. L. MOKGALABON. 2003. Evaluation of new 'Hass'-like avocado cultivars in South Africa. *South African Avocado Growers' Association Yearbook* 26: 41-43.

KRUGER, F. J., SNIJDER, B. and J. M. MATHUMBU. 2004. Establishing appropriate maturity and fruit mineral content norms for the main avocado export cultivars. *South African Avocado Growers' Association Yearbook* 27: 5-10.

KRUGER, F.J. and D. LEMMER. 2012. Respiration and softening rates of 'Maluma' and 'Ryan' avocados and the effect that cold chain breaks have on the ripening and quality of these cultivars. *South African Avocado Growers' Association Yearbook* 35.

KRUGER, F.J. and N.J.F. CLAASSENS. 2001. Packhouse Procedures. *In*: de Villiers, E.A., The Cultivation of Avocado. Institute for Tropical and Subtropical Crops, Nelspruit, South Africa. pp. 319-330.

KRUGER, F.J., STASSEN, P.J.C. and B. SNIJDER. 1995. A preliminary study on variation in the maturity parameters of avocados from the Kiepersol/Hazyview area. *South African Avocado Growers Association Yearbook* 18: 67-73.

LANCASTER, J.E., LISTER, C.E., REAY, P.F. and C.M., TRIGGS. 1997. Influence of pigment composition on skin colour in a wide range of fruit and vegetables. *Journal of American Society of Horticultural Science* 122: 594-598.

LECLEREQ, H. 1990. Observations on overseas markets during the 1989 avocado season. *South African Avocado Growers' Association Yearbook* 13: 11-13.

LEE, S.K. and A.A. KADER. 2000. Pre-harvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology* 20: 207-220.

LEE, S.K., YOUNG, R.E., SCHIFFMAN, P.M. and C.W. COGGINS. 1983. Maturity studies of avocado fruit based on picking dates and dry weight. *Journal of American society of Horticultural Science* 108: 390-394.

LELIEVRE, J.M., LATCHE, A., JONES., B. and M. BOUZAYEN. 1997. Ethylene and fruit ripening. *Physiology of Plant*. 101: 727-739.

LELIEVRE, J.M., TICHIT, L., FILLION, L., LARRIGAUDIERE, M., VENDRELL, M. and J.C. PECH. 1995. Cold-induced accumulation of 1-aminocyclopropane-l-carboxylate oxidase protein in Granny Smith apples. *Postharvest Biology and Technology* 5: 11-17.

LEVITT, J. 1972. Response of Plants to Environmental Stress. Academic Press, New York, NY, USA. pp. 497

LIPLAP. P. 2013. Respiration rate in transient period, its implication on the effect of hyperbaric pressure treatment; the treatment advantage in shelf life extension of various commodities. PhD thesis, Department of Bio-resource Engineering McGill University, Montreal Quebec, Canada.

LÜTGE, A. 2011. Ultra-Low Temperature Shipping and Cold Chain Management of 'Fuerte' Avocado (*Persea americana* Mill.). Msc thesis, Grown in the KwaZulu-Natal Midlands, Horticultural Science, School of Agricultural Sciences and Agribusiness. University of KwaZulu-Natal, Pietermaritzburg.

LÜTGE, A., BOWER, J.P. and I. BERTLING. 2010. Low Temperature Shipping and Cold chain management of ‘Fuerte’ Avocados: An opportunity to reduce shipping costs. *South African Avocado Growers' Association Yearbook* 33: 39-43

LUTZ J.M. and R.E. HARDENBURG. 1968. The commercial storage of fruits, vegetables and florist and nursery stocks. United States Department of Agriculture, Agriculture Handbook 66.

LYONS, J.M. 1973. Chilling injury in plants. *Annual Review of Plant Physiology* 24: 445-466.

LYONS, J.M. and R.W. BREIDENBACH. 1987. Chilling Injury. *In*: WEICHMANN, J. (ed). Post-harvest Physiology of Vegetables. Marcel Dekker Inc., New York. pp. 305-326.

MAFTOONAZAD, N. and H.S. RAMASWAMY.2008. Effect of pectin-based coating on the kinetics of quality change associated with stored avocados. *Food Process and Preservation* 32: 621-643.

MAGUIRE, K.M., BANKS, N.H. and L.U. OPARA. 2001. Factors affecting weight loss of apples. *Horticulture Review* 25: 197-234.

MAGWAZA, L.S. and S.Z. TESFAY. 2015. A review of destructive and non-destructive method for determining avocado fruit maturity. *Food and Bioprocess Technology* 8: 1995-2011.

MAHAJAN, P.V., OLIVEIRA, F.A.R., and I. MACEDO. 2008. Effect of temperature and humidity on the transpiration rate of the whole mushrooms. *Food England* 84: 281-288.

MANS, C.C, DONKIN, D.J. and M. BOSHOFF. 1995. Maturity and storage temperature regimes for KwaZulu-Natal avocados. *South African Avocado Growers' Association Yearbook* 18: 102-105.

MATHABA, N., MAFEO, T.P. and F.J. KRUGER. 2015. The skin colouring problem of 'Hass' avocado fruit during ripening. *South African Avocado Growers Association Yearbook* 38: 51-58

MCGUIRE, R.G. 1992. Reporting of objective colour measurements. *Horticultural Science* 27: 1254-1260.

MENGE, J.A. and R.C. PLOETZ. 2003. Diseases of Avocado. *In*: PLOETZ, R.C. (ed.). Diseases of tropical fruit crops. CABI Publishing, Wallingford, Oxon, UK. pp. 35-46.

MHLOPHE S.D. and F.J. KRUGER. 2012. Effects of harvest maturity, storage temperature, controlled atmosphere and Smart Fresh on the post-harvest vascular staining disorder of 'Maluma' avocado fruit. *South African Avocado Growers' Association Yearbook* 35: 8-12.

MIZRACH A, FLITSANOV U, AKERMAN M. and G. ZAUBERMAN. 2000. Monitoring avocado softening in low-temperature storage using ultrasonic measurements. Computer Electron Agriculture. 26: 199-207.

MONTOYA, M.M., DE LA PLAZA J.L. and V. L. LÓPEZ-RODRIGUEZ RODRIGUEZ. 1994. Electrical Conductivity of Avocado Fruits During Cold Storage and Ripening*. Lebensmittel Wiss Technology* 27: 29–33.

MUTARI, A. and D. REES. 2011. The effects of postharvest handling and storage temperature on the quality and shelf of tomato. *African Journal of Food Science* 5: 446-452.

NEWETT, S., WHILEY, A., DIROU, J. and G. IRELAND. 2002. Growing the crop. *In*: VOCK, N. (ed.) Avocado information kit. Queensland Department of Primary Industries.

NUNES, M.C.N. and J.P. EDMOND. 2007. Relationship between weight loss and visual quality of fruits and vegetables. *Proceedings of the Florida State Horticultural Society* 120: 235-245.

NUNES, M.C.N., EDMOND, J.P., RAUTH, M., DEA, S. and K. V. CHAU. 2009. Environmental conditions encountered during typical consumer retail display affect fruit and vegetable quality and waste. *Postharvest Biology and Technology* 51: 232-241.

OLAREWAJU, O.O. 2014. Evaluation of maturity parameters of 'Fuerte' and 'Hass' avocado fruit. Msc thesis, School of Agricultural Sciences and Agribusiness. University of KwaZulu-Natal, Pietermaritzburg.

PAK, H.A., DIXON, J., SMITH, D.B., ELMSLY, T.A. and J.G.M. CUTTING. 2003. Impact of rainfall prior to harvest on ripe fruit quality of 'Hass' avocados in New Zealand. Proceedings V World Avocado Congress (Actas V Congreso Mundial del Aguacate) Pp. 22-31.

PAN, J.C. and S.R. BHOWMIK. 1992. Shelf life of mature green tomatoes stored in controlled atmosphere and high humidity. *Food Science* 57: 948–953.

PARKIN, K. L. and S. J. KUO. 1989. Chilling-induced lipid degradation in cucumber (*Cucumis sativa* L. cv Hybrid C) fruit. *Plant Physiology* 90: 1049.

PAULL, R.E. 1990. Chilling injury of crops of tropical and subtropical origin. *In*: WANG, C.Y. (ed.), Chilling Injury of Horticultural Crops. CRC Press, Boca Raton, FL, USA. Pp.17-36.

PEARSON, D. 1975. Seasonal English market variation in the composition of South Africa and Israeli avocados. *Science and Food Agriculture* 26: 207-213.

PEGG, K.G., COATES, L.M., KORSTEN, L. and R.M. HARDING. 2002. *In*: WHILEY, A.W., SCHAFFER, B. and WOLSTENHOLME, B.N. (eds.). The Avocado: Botany, Production and Uses. CABI Publishing, Wallingford, Oxon, UK. Pp. 299-331.

PLATT, R.G. 1976. Avocado varieties recently registered with the California Avocado Society. *California Avocado Society Yearbook* 59: 41-51.

PLATT-ALOIA, K.A. and W.W. THOMSON. 1981. Ultrastructure of the mesocarp of mature avocado fruit and changes associated with ripening. *Annals of Botany* 48: 451-465.

PRANAMORNKITH, T. 2009. Effect of post-harvest treatment on storage quality of lime (*Citrus latifolia* Tamaka) fruit. A thesis presented in partial fulfilment of the requirements for the degree of doctor of philosophy in food technology at Massey University of New Zealand.

SALTVEIT, M.E. and L.L. MORRIS. 1990. Overview of chilling injury of horticultural crops. In: Wang, C.Y. (ed). Chilling injury of horticultural crops. CRC Press. Pp. 3-16.

SOUTH AFRICAN AVOCADO GROWERS' ASSOCIATION AVOCADO (SAAGA). 2005 . SAAGA Tree Census.

SWARTS, D. H. 1980. ''A method of determining the ripeness of avocado.'' *Citrus and Subtropical Fruit Research Institute*, No., 90:15 –18. (c.f. Hort. Abst., 1981, 1:6544).

SWARTS, D. H. 1984. Postharvest problems of avocados -let's talk the same language. *South African Avocado Growers Association Yearbook* 7:15-19.

SWARTS, D.H. 1978. The on-nonsense determination of oil content for avocados. Citrus and Subtropical Fruit Research Institute Information Bulletin. 41: 4

TESFAY, S.Z. 2009. Special carbohydrates of avocado – their function as 'sources of energy' and 'anti-oxidants'. PhD thesis, School of Agricultural Sciences and Agribusiness. University of KwaZulu-Natal, Pietermaritzburg.

THOMPSON, A. K. 2003. Pre-harvest factors on post-harvest life. *In*: Fruit and vegetable harvesting, handling and storage. Blackwell. Oxford OX4 2DQ, UK. Chap. 1. pp 1-8.

TING, I.P. 1982.The energy budget of plants. *In*: TING, I.P.(ed.) Plant physiology. Reading: Addison-Wesley Publishing Company. Pp.170-188.

TOERIEN, J.C. 1986. Temperature control of avocados for sea export. *South African Avocado Growers Association Yearbook* 9: 31-32

TUCKER, G. and D. GRIERSON. 1982. Synthesis of polygalacturonase during fruit ripening. *Plant Science* 43: 201-20

VALERO, D. and M. SERRANO. 2010. Post-harvest Biology and Technology for Preserving Fruit Quality. CRC Press, Boca Raton, FL, USA.

VAN ROOYEN, Z. and J.P. BOWER. 2002. Tackling the 'Pinkerton' problem. *South African Avocado Growers' Association Yearbook* 25: 64-71.

VAN ROOYEN, Z. 2005. Factors affecting mesocarp discolouration severity in 'Pinkerton avocados. Horticultural Science, School of Agricultural Sciences and Agribusiness. University of KwaZulu-Natal, Pietermaritzburg, PhD.

VAN ROOYEN, Z. 2009. Semi-commercial trials to determine the risk of shipping 'Hass' at 1ºC for 30 days. *South African Avocado Growers' Association Yearbook* 32: 36-41.

VAN ROOYEN, Z. and J.P. BOWER. 2007. Post-harvest treatments used to reduce chilling injury in 'Pinkerton' avocados. *Proceedings VI World Avocado Congress*, Chile. 12-15 Nov 2007.

VILLA-RODRIGUEZ, J.A., MOLINA-CORRAL, F.J., AYALA-ZAVALA, J.F., OLIVAS. G.I and G.A. GONZALEZ-AGUILA. 2011. Effect of maturity stage on the content of fatty acids and antioxidant capacity of 'Hass' avocado. *Food Research International* 44: 1231-1237.

VORSTER, L.L. 2001. Avocado production South Africa. *California Avocado Society Yearbook* 85: 51-63.

WAGHMARE, R.B., MAHAJAN P.V. and U.S. ANNAPURE. 2013. Modelling the effect of time and temperature on respiration rate of selected fresh-cut produce. *Postharvest Biology and Technology* 80: 25-30.

WANG, C.Y. 1982.physiological and biochemical responses of plants to chilling stress. *Horticultural science* 17: 173-186.

WANG, C.Y. 1993. Approaches to reduce chilling injury in fruits and vegetables. *Horticulture Review* 15: 63-95.

WANG, C.Y. 2010. Alleviation of chilling injury in tropical and subtropical fruits. Proc. 3rd International Science on Tropical. and Subtropical. Fruits Eds.: M. Souza and R. Drew. *Acta Horticulture* 864, ISHS.

WHILEY, A.W., KOHNE, J.S., ARPIA, M.L. and G.S. BENDER. 1990. Fuerte prospects with new avocado cultivars and elite rootstocks. *South African Avocado Growers Association Yearbook* 13: 16-20.

WHITE, A., WOOLF, A.B. and P. HOFMAN. 2001. AvoCare Assessment Manual. The Horticulture and Food Research Institute of New Zealand Ltd

WILLS, A.W., LEE, T.H., McGLASSON, W.B., GRAHAM, D. and E.G. HALL. 2008. Post-harvest: An Introduction to the Physiology and Handling of Fruit and Vegetables. 5th ed. CAB International, London, UK.

WOOLF, A.B., COX, K.A., WHITE, A. and I.B. FERGUSON. 2003. Low temperature conditioning treatments reduce external chilling injury of 'Hass' avocados. *Postharvest Biology and Technology* 28: 113-122

WOOLF, A.B., WHITE, A., ARPAIA, M.L. and K.C. GROSS. 2002. Avocado. *In*: GROSS, K.C., WANG, C.Y. and SALTVEIT, M. (eds.). The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks. A draft version of the revision to USDA Agriculture Handbook No. 66 (revised 2004).

WOOLF, A.B.1997. Reduction of chilling injury in stored 'Hass' avocado fruit by 38.8ºC water treatments. *Horticultural Science*. 32: 1247-1251.

YAHIA E. M. 2011. Avocado (*Persea americana* Mill.) , Autonomous University of Queretaro, Mexico and A. B. Woolf, The New Zealand Institute for Plant & Food Research, New Zealand.

ZAUBERMAN, G. and M. JOBIN-DÉCOR. 1995. Avocado (*Persea americana* Mill.) quality changes in response to low-temperature storage. *Postharvest Biology and Technology*. 5: 235-243

ZAUBERMAN, G. and Y. FUCHS. 1981. Effect of wounding on 'Fuerte' avocado ripening. *Horticultural Science* 16: 496-497.

ZAUBERMAN, G., FUCHS, Y. and M. AKERMAN. 1986. ''Peroxides activity in avocado stored at chilling temperatures.'' *Scientia Horticulture* 26: 261-265.

ZAUBERMAN, G., SCHIFFMAN-NADEL, M. and U. YANKO. 1977. The response of avocado fruit to different storage temperatures. *Horticultural Science* 12: 353-354.

ZHANG, C., DING, Z., XU, X., WANG, Q., QIN, G and S. TIAN. 2009. Crucial roles of membrane stability and its related proteins in the tolerance of peach fruit to chilling injury. *Amino Acids* 39:181-194

ZHANG, Z., HUBER, D.J. and J. RAO. 2011. Ripening delay of mid-climacteric avocado fruit in response to elevated doses of 1-methylcyclopropene and hypoxia-mediated reduction in internal ethylene concentration. *Postharvest Biology and Technology* 60: 83-91.

APPENDICES

Appendix 1 ANOVA table for moisture content of ‘Reed’ avocado fruit at mid- and late harvest time

Source of variation	d.f.	s.s.	m.s.	V.r.	F pr.
Replication stratum	5	11.417	2.283	0.77	
Harvest time	1	6.750	6.750	2.29	0.191
Residual	5	14.750	2.950		
Total	11	32.917			

Appendix 2 ANOVA table for the effect of harvest time, post-harvest storage, ripening temperature and ripening time on the fruit weight loss of ‘Reed’ avocado fruit

Source of variance	**d.f.**	**(m.v.)**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication stratum	2		18.175	9.088	3.04	
Harvest time	1		67.356	67.356	22.56	<.001
Storage temperature	1		12.089	12.089	4.05	0.047
Ripening temperature	2		136.226	68.113	22.81	<.001
Ripening day	4		564.481	141.120	47.27	<.001
Harvest time*Storage temp	1		19.648	19.648	6.58	0.012
Harvest time*Ripening temp	2		17.603	8.802	2.95	0.057
Storage temp*Ripening temp	2		68.084	34.042	11.40	<.001
Harvest time*Storage*Ripening day	4		2.696	0.674	0.23	0.923
Storage temp*Repining day	4		12.330	3.083	1.03	0.395
Ripening temp*Repining day	5	(3)	49.756	9.951	3.33	0.008
Harvest time*Storage temp*Ripening temp	2		25.153	12.576	4.21	0.018
Harvest time*Storage temp*Repining day	4		4.739	1.185	0.40	0.810
Harvest time*Ripening temp*Repining day	5	(3)	4.755	0.951	0.32	0.901
Storage temp*Ripening temp*Repining day	5	(3)	37.847	7.569	2.54	0.034
Harvest time*Storage temp*Ripening temp*Repining day	5	(3)	12.896	2.579	0.86	0.508
Residual	94	(24)	280.639	2.986		
Total	143	(36)	1083.123			

Appendix 3 ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on the fruit firmness of ‘Reed’ avocado fruit

Source of variance	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		18.06	9.03	0.79	
Harvest time	1		39.47	39.47	3.47	0.066
Storage temp	1		1510.44	1510.44	132.84	<.001
Ripening temp	2		1141.75	570.87	50.21	<.001
Ripening day	4		18695.96	4673.99	411.08	<.001
Harvest time*Storage temp	1		38.91	38.91	3.42	0.067
Harvest time*Ripening temp	2		754.83	377.42	33.19	<.001
Storage temp*Ripening temp	2		8.98	4.49	0.40	0.675
Harvest time*Storage temp*Ripening day	4		25.00	6.25	0.55	0.700
Storage temp*Repining day	4		230.24	57.56	5.06	<.001
Ripening temp*Repining day	5	(3)	450.76	90.15	7.93	<.001
Harvest time*Storage temp*Ripening temp	2		481.11	240.56	21.16	<.001
Harvest time*Storage temp*Repining day	4		69.90	17.48	1.54	0.198
Harvest time*Ripening temp*Repining day	5	(3)	305.80	61.16	5.38	<.001
Storage temp*Ripening temp*Repining day	5	(3)	446.87	89.37	7.86	<.001
Harvest time*Storage temp*Ripening temp*Repining day	5	(3)	166.71	33.34	2.93	0.017
Residual	94	(24)	1068.78	11.37		
Total	143	(36)	19292.83			

Appendix 4: ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on the respiration rate of ‘Reed’ avocado fruit

Source of variance	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		1.11319	0.55660	16.27	
Harvest time	1		2.41123	2.41123	70.50	<.001
Storage temp	1		0.16543	0.16543	4.84	0.030
Ripening temp	2		9.75941	4.87971	142.67	<.001
Ripening day	4		23.53183	5.88296	172.01	<.001
Harvest time*Storage temp	1		0.00420	0.00420	0.12	0.727
Harvest time*Ripening temp	2		0.12675	0.06338	1.85	0.162
Storage temp*Ripening temp	2		0.43161	0.21580	6.31	0.003
Harvest time*Storage temp*Ripening day	4		2.95880	0.73970	21.63	<.001
Storage temp*Repining day	4		3.54217	0.88554	25.89	<.001
Ripening temp*Repining day	5	(3)	5.43797	1.08759	31.80	<.001
Harvest time*Storage temp*Ripening temp	2		0.82844	0.41422	12.11	<.001
Harvest time*Storage temp*Repining day	4		3.60622	0.90156	26.36	<.001
Harvest time*Ripening temp*Repining day	5	(3)	1.48721	0.29744	8.70	<.001
Storage temp*Ripening temp*Repining day	5	(3)	0.94922	0.18984	5.55	<.001
Harvest time*Storage temp*Ripening temp*Repining day	5	(3)	0.64816	0.12963	3.79	0.004
Residual	94	(24)	3.21496	0.03420		
Total	143	(36)	54.94054			

Appendix 5: ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on the ripening percentage of 'Reed' avocado fruit

Source of variance	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		527.9	264.0	1.27	
Harvest time	1		756.5	756.5	3.63	0.060
Storage temp	1		21894.7	21894.7	105.12	<.001
Ripening temp	2		26433.4	13216.7	63.45	<.001
Ripening day	4		235601.3	58900.3	282.78	<.001
Harvest time*Storage temp	1		905.4	905.4	4.35	0.040
Harvest time*Ripening temp	2		8983.7	4491.9	21.57	<.001
Storage temp*Ripening temp	2		5979.7	2989.8	14.35	<.001
Harvest time*Storage temp*Ripening day	4		844.8	211.2	1.01	0.404
Storage temp*Repining day	4		6407.0	1601.8	7.69	<.001
Ripening temp*Repining day	5	(3)	10820.0	2164.0	10.39	<.001
Harvest time*Storage temp*Ripening temp	2		1522.6	761.3	3.65	0.030
Harvest time*Storage temp*Repining day	4		1246.0	311.5	1.50	0.210
Harvest time*Ripening temp*Repining day	5	(3)	4595.0	919.0	4.41	0.001
Storage temp*Ripening temp*Repining day	5	(3)	18913.5	3782.7	18.16	<.001
Harvest time*Storage temp*Ripening temp*Repining day	5	(3)	1485.9	297.2	1.43	0.222
Residual	94	(24)	19579.5	208.3		
Total	143	(36)	265918.2			

Appendix 6 ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on lightness (L *) of ‘Reed’ avocado fruit

Source of variance	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	5		81.699	16.340	5.64	
Harvest time	1		30.686	30.686	10.59	0.001
Storage temp	1		376.903	376.903	130.12	<.001
Ripening temp	2		105.864	52.932	18.27	<.001
Ripening day	4		876.546	219.137	75.65	<.001
Harvest time*Storage temp	1		288.005	288.005	99.43	<.001
Harvest time*Ripening temp	2		10.592	5.296	1.83	0.163
Storage temp*Ripening temp	2		111.364	55.682	19.22	<.001
Harvest time*Storage temp*Ripening day	4		90.137	22.534	7.78	<.001
Storage temp*Repining day	4		128.444	32.111	11.09	<.001
Ripening temp*Repining day	5	(3)	188.374	37.675	13.01	<.001
Harvest time*Storage temp*Ripening temp	2		57.865	28.933	9.99	<.001
Harvest time*Storage temp*Repining day	4		89.201	22.300	7.70	<.001
Harvest time*Ripening temp*Repining day	5	(3)	28.142	5.628	1.94	0.088
Storage temp*Ripening temp*Repining day	5	(3)	107.078	21.416	7.39	<.001
Harvest time*Storage temp*Ripening temp*Repining day	5	(3)	53.457	10.691	3.69	0.003
Residual	235	(60)	680.707	2.897		
Total	287	(72)	2528.642			

Appendix 7: ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on chroma (C *) of 'Reed' avocado fruit

Source of variance	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	5		18679.9	3736.0	5.20	
Harvest time	1		15924.3	15924.3	22.17	<.001
Storage temp	1		46816.4	46816.4	65.18	<.001
Ripening temp	2		5561.3	2780.6	3.87	0.022
Ripening day	4		115751.0	28937.8	40.29	<.001
Harvest time*Storage temp	1		34386.0	34386.0	47.87	<.001
Harvest time*Ripening temp	2		1623.8	811.9	1.13	0.325
Storage temp*Ripening temp	2		24234.9	12117.5	16.87	<.001
Harvest time*Storage temp*Ripening day	4		8799.1	2199.8	3.06	0.017
Storage temp*Repining day	4		10979.3	2744.8	3.82	0.005
Ripening temp*Repining day	5	(3)	16617.3	3323.5	4.63	<.001
Harvest time*Storage temp*Ripening temp	2		5110.6	2555.3	3.56	0.030
Harvest time*Storage temp*Repining day	4		6557.1	1639.3	2.28	0.061
Harvest time*Ripening temp*Repining day	5	(3)	3819.3	763.9	1.06	0.381
Storage temp*Ripening temp*Repining day	5	(3)	9622.1	1924.4	2.68	0.022
Harvest time*Storage temp*Ripening temp*Repining day	5	(3)	559.4	111.9	0.16	0.978
Residual	235	(60)	168799.6	718.3		
Total	287	(72)	415901.3			

Appendix 8: ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on hue angle (h^{o}) of ‘Reed’ avocado fruit

Source of variance	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	5		3651.7	730.3	3.10	
Harvest time	1		3817.1	3817.1	16.19	<.001
Storage temp	1		4639.9	4639.9	19.68	<.001
Ripening temp	2		548.2	274.1	1.16	0.315
Ripening day	4		15915.8	3979.0	16.87	<.001
Harvest time*Storage temp	1		63985.3	63985.3	271.34	<.001
Harvest time*Ripening temp	2		295.8	147.9	0.63	0.535
Storage temp*Ripening temp	2		1526.9	763.5	3.24	0.041
Harvest time*Storage temp*Ripening day	4		1043.8	260.9	1.11	0.354
Storage temp*Repining day	4		1775.6	443.9	1.88	0.114
Ripening temp*Repining day	5	(3)	4054.0	810.8	3.44	0.005
Harvest time*Storage temp*Ripening temp	2		3676.0	1838.0	7.79	<.001
Harvest time*Storage temp*Repining day	4		21490.4	5372.6	22.78	<.001
Harvest time*Ripening temp*Repining day	5	(3)	3015.1	603.0	2.56	0.028
Storage temp*Ripening temp*Repining day	5	(3)	2875.0	575.0	2.44	0.035
Harvest time*Storage temp*Ripening temp*Repining day	5	(3)	2785.4	557.1	2.36	0.041
Residual	235	(60)	55415.8	235.8		
Total	287	(72)	147333.1			

Appendix 9: ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on eye colour of 'Reed' avocado fruit

Source of variance	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	5		6.0229	1.2046	4.15	
Harvest time	1		1.5612	1.5612	5.38	0.021
Storage temp	1		11.4902	11.4902	39.60	<.001
Ripening temp	2		2.3991	1.1995	4.13	0.017
Ripening day	4		58.9680	14.7420	50.81	<.001
Harvest time*Storage temp	1		11.8562	11.8562	40.87	<.001
Harvest time*Ripening temp	2		0.6467	0.3234	1.11	0.330
Storage temp*Ripening temp	2		1.9712	0.9856	3.40	0.035
Harvest time*Storage temp*Ripening day	4		1.8875	0.4719	1.63	0.168
Storage temp*Repining day	4		4.2863	1.0716	3.69	0.006
Ripening temp*Repining day	5	(3)	3.4741	0.6948	2.39	0.038
Harvest time*Storage temp*Ripening temp	2		1.6433	0.8216	2.83	0.061
Harvest time*Storage temp*Repining day	4		3.8111	0.9528	3.28	0.012
Harvest time*Ripening temp*Repining day	5	(3)	1.7028	0.3406	1.17	0.323
Storage temp*Ripening temp*Repining day	5	(3)	3.6507	0.7301	2.52	0.030
Harvest time*Storage temp*Ripening temp*Repining day	5	(3)	1.9920	0.3984	1.37	0.235
Residual	235	(60)	68.1806	0.2901		
Total	287	(72)	148.3194			

Appendix 10: ANOVA table for effect of harvest time, post-harvest storage, ripening temperatures and ripening time on electrolyte leakage of ‘Reed’ avocado fruit

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	50.423	25.212	3.09	
Harvest time	1	13.018	13.018	1.59	0.254
Storage temp	1	5.822	5.822	0.71	0.431
Harvest time*Storage temp	1	0.085	0.085	0.01	0.922
Residual	6	49.024	8.171		
Total	11	118.372			

Appendix 11 ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on chilling injury of ‘Reed’ avocado fruit

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	2284.0	1142.0	3.70	
Harvest time	1	771.6	771.6	2.50	0.128
Storage temp	1	7901.2	7901.2	25.60	<.001
Ripening temp	2	293.2	146.6	0.47	0.628
Harvest time*Storage temp	1	493.8	493.8	1.60	0.219
Harvest time*Ripening temp	2	12608.0	6304.0	20.43	<.001
Storage temp*Ripening temperature	2	5293.2	2646.6	8.58	0.002
Harvest time*Storage temp*Ripening temp	2	3719.1	1859.6	6.03	0.008
Residual	22	6790.1	308.6		
Total	35	40154.3			

Appendix 12 ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on incidence of vascular browning on 'Reed' avocado fruit

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	571.0	285.5	1.48	
Harvest time	1	933.6	933.6	4.84	0.039
Storage temp	1	69.4	69.4	0.36	0.555
Ripening temp	2	2422.8	1211.4	6.28	0.007
Harvest time*Storage temp	1	933.6	933.6	4.84	0.039
Harvest time*Ripening temp	2	1034.0	517.0	2.68	0.091
Storage temp*Ripening temp	2	324.1	162.0	0.84	0.445
Harvest time*Storage temp*Ripening temp	2	478.4	239.2	1.24	0.309
Residual	22	4243.8	192.9		
Total	35	11010.8			

Appendix 13 ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on incidence of stem-end rot on 'Reed' avocado fruit

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	879.6	439.8	0.64	
Harvest time	1	7901.2	7901.2	11.55	0.003
Storage temp	1	3734.6	3734.6	5.46	0.029
Ripening temp	2	740.7	370.4	0.54	0.589
Harvest time*Storage temp	1	277.8	277.8	0.41	0.531
Harvest time*Ripening temp	2	61.7	30.9	0.05	0.956
Storage temp*Ripening temp	2	1172.8	586.4	0.86	0.438
Harvest time*Storag temp*Ripening temp	2	3518.5	1759.3	2.57	0.099
Residual	22	15046.3	683.9		
Total	35	33333.3			

Appendix 14 ANOVA table for effect of harvest time, post-harvest storage, ripening temperature and ripening time on incidence of body rot on 'Reed' avocado fruit

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	324.1	162.0	0.73	
Harvest time	1	378.1	378.1	1.71	0.204
Storage temp	1	4081.8	4081.8	18.47	<.001
Ripening temp	2	7916.7	3958.3	17.91	<.001
Harvest time*Storage temp	1	625.0	625.0	2.83	0.107
Harvest time*Ripening temp	2	1034.0	517.0	2.34	0.120
Storage temperature*Ripening temp	2	3996.9	1998.5	9.04	0.001
Harvest time*Storage temp*Ripening temp	2	1435.2	717.6	3.25	0.058
Residual	22	4861.1	221.0		
Total	35	24652.8			