EFFECTS OF IRRIGATION, 1-METHYLCYCLOPROPENE (1-MCP) AND COLD STORAGE TEMPERATURE ON QUALITY OF 'HASS' AVOCADO FRUIT

BY

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DECLARATION

I, Mamila Isaac Mareme [redacted] declare that the mini-dissertation report hereby submitted to the University of Limpopo, for the degree Master of Science in Horticulture has not been previously submitted by me or anybody for a degree at this or any other university. In addition, this is my work in design and in execution, and related materials contained herein had been duly acknowledged.

…..... ……

Signature Date

DEDICATIONS

This study is dedicated to my mother (Myna Mamila), my late father (Erick Mamila), my sisters (Audecia, Khutso, Charmaine and Zanele) and my son (Dylan).

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ABSTRACT

The South African Agricultural Sector has a mandate to reduce water use so that water can be available for other economic sectors. Thus, various water saving techniques must be continuously investigated in agricultural production to find efficient water use technique that saves water without compromising fresh fruit quality. Therefore, combined effect of irrigation method, 1-methylcyclopropene (1-MCP) and cold storage temperature on postharvest quality of 'Hass' avocado fruit was evaluated. Postharvest attributes of fruit colour, flesh firmness, ripening percentage, respiration, weight loss, body rot, stem end-rot, vascular browning, chilling injury and electrolyte leakage were assessed for 2 x irrigation methods [Full irrigation (FI) and Partial root-zone drying (PRD)], 2 x 1-methylcyclopropene (300 ng/L 1-MCP and untreated) and 2 x storage temperature (2.0 and 5.5°C) treatments. An interaction between the three treatments did not significantly ($P > 0.05$) influence fruit colour, flesh firmness, ripening percentage, fruit weight loss, body rot, stem end-rot, vascular browning, chilling injury and electrolyte leakage. Their combined effect was only significant ($P = 0.019$) on 'Hass' fruit respiration rate. The combination of full and PRD irrigation, 1-MCP and low storage temperature (2.0°C) did not negatively affect fruit quality. However, fruit stored at 2.0°C without 1-MCP treatment were affected by chilling injury when compared with fruit stored at 5.5°C. In conclusion, due to the inconclusiveness of results obtained, further studies, on the effect of these treatments especially under 5.5°C storage temperature should be carried out prior recommending the combination treatment for export markets.

Keywords: Partial root-zone drying; postharvest treatments; physico-chemical parameters; pathological diseases, physiological disorders.

CHAPTER 01
GENERAL INTRODUCTION

1.1. Background

Worldwide, irrigation water has long been identified as a limitation to the growth and expansion of agricultural production, especially in the arid and semi-arid regions (Hakim *et al*., 2019). Due to water shortages, there is a mandate for the South African agricultural sector to reduce water use. In South Africa, the agricultural sectors use 60% of the available water (Roets *et al*., 2015). Therefore, it is necessary to investigate irrigation water saving techniques, which can save water without compromising fruit quality (Zegbe *et al*., 2007).

In 'Çhok Anan' mango production, modified irrigation technique such as partial root-zone drying (PRD) have shown the potential to produce good quality while increasing water use efficiency (WUE) (Spreer *et al*., 2007). According to Spreer *et al*., (2007), PRD results in water saving of 30-50% without affecting 'Çhok Anan' mango fruit yields and quality. However, water saving techniques such as deficit irrigation was found to cause fruit physiological disorders on 'Hass' avocado fruit; and therefore, other water saving technique such as PRD was innovated (Kruger *et al*., 2015).

Neuhaus *et al*. (2007) defined PRD as a modified form of deficit irrigation (DI). In each irrigation event only one part of the root zone is irrigated while the other part is left to dry to certain soil water content before rewetting by shifting irrigation to the dry side (Ahmadi *et al*., 2010). Partial root-zone drying had no negative effect on fruit crops such as; 'Catelao' grape berries (Dos Santos *et al*., 2003), 'Cripps Pink' (Wan Zaliha and Singh, 2009) apple and 'Ercole' tomato fruit (Giuliani *et al*., 2017). However, the interaction of PRD, 1-methylcyclopropene (1-MCP) and cold storage temperature has not yet been tested on 'Hass' avocado fruit.

Generally, fruit deteriorates rapidly when untreated with postharvest treatments such as 1-MCP and cold storage temperature (Sun *et al*., 2003). In harvested fruit, metabolic processes enhanced by ethylene production and 1-MPC plus cold storage ensures maintenance of fruit quality by reducing ethylene production (Watkin *et al*., 2010; Pesis *et al*., 2003). Barry and Giovannoni (2007) defined ethylene as a gaseous plant hormone which plays a key regulatory role in ripening of many fruits. Fruit ripening is delayed through storing fruit under low temperature storage (Pesis *et al*.,

2003). However, ‘Hass’ avocado fruit stored at less than 5˚C temperatures become prone to the development of physiological disorders such as external and internal chilling injury (Hershkovitz *et al*., 2009). Thus, this study was conducted to evaluate combined effect of irrigation method, 1-MCP and cold storage temperature on postharvest quality of ‘Hass’ avocado fruit.

1.2. Problem statement

South African avocado industry (SAAI) continues to grow, hence; irrigation water has become highly demanded for production (DAFF, 2015). Due to high demand of irrigation water, it is important to seek alternative strategies to reduce water usage in avocado production without impacting fruit quality negatively (Dennis and Dennis, 2012). Modified irrigation technique such as partial root-zone drying (PRD) have shown the potential to produce good quality produce and increase water use efficiency (WUE) on ‘Chok Anan’ mango (Spreer *et al*., 2007). Avocado tree is a high-water consumption crop which requires approximately 8000 - 9000 m^3 of irrigation water, compared to other fruit crops including citrus which requires approximately 500 - 600 m^3 (DAFF, 2015; Panigrahi *et al*., 2008). Water shortage has greatly affected production of avocado fruit in South Africa during 2014 - 2016 seasons. South Africa’s exports of avocado contributed 2.98% in 2014/15 while in 2015/2016 season it contributed 1.7% of the fresh fruit exports due to water shortage encountered (DAFF, 2015). Improving water saving irrigation method can serve as an alternative to improve yield, fruit quality and WUE (Sepaskhah and Ahmadi, 2010). Therefore, reducing water use while increasing productivity of good quality fruit will not only result in water and cost savings to the grower, but will also result in sustainable future expansion of the avocado industry.

1.3. Motivation of the study

The practice of partial root-zone drying by farmers may ensure availability of water to other economic sectors, including domestic and industrial users (FAO, 2015). Atkinson *et al*. (2011) described PRD as a technique that reduces irrigation water amount to less than the potential crop evapotranspiration, and may control water stress level to maintain fruit quality (Neuhaus *et al*., 2007). Therefore, application of partial root-zone drying technique may reduce water use and improve fruit quality. Quality of fruit produced under PRD technique may be maintained through subjecting fruit to low storage temperature storage and 1-MCP (Minas *et al*., 2013; Woolf *et al*., 2005).

Maintenance of fruit quality is crucial for prolonging shelf life and maximise export market opportunities since fruit of good quality get the highest preference (DAFF, 2018; Watkins, 2006).

Storage temperature delays fruit deterioration through manipulating metabolic and physiological processes such as respiration and ripening (Zhao *et al*., 2019). However, low storage temperatures induce physiological disorders on avocado fruit, therefore; application of 1-MCP to reduce physiological disorders, pathological diseases and delay ethylene production that enhances ripening is crucial (Pesis *et al*., 2003; Watkins *et al*., 2010). There is currently limited literature on the interaction between irrigation, 1-MCP and storage temperature on quality of 'Hass' avocado fruit. Therefore, an interaction between partial root-zone drying, 1-MCP and storage temperature may produce good quality avocado fruit to maximize supply to export market while reducing water use.

1.4. Aim

The aim of the study was to determine suitability of PRD as a water conserving irrigation method with post-harvest treatments that maintain 'Hass' avocado fruit quality.

1.5. Objective

To evaluate combine effect of PRD, 1-MCP and cold storage temperature on postharvest quality of 'Hass' avocado fruit.

1.6. Hypothesis

Partial root-zone drying, 1-MCP and cold storage temperature would have effect on the quality of 'Hass' avocado fruit.

1.7. Format of the mini dissertation

Following the description and detailed outlining of the research problem in Chapter 01, the work done and not yet done on the problem statement is reviewed in Chapter 02. Then, methodology on how trials were conducted is outlined in Chapter 03 and findings addressing each variable are also explained and methodically discussed in Chapter 04. In Chapter 05, findings in all chapters are summarised and integrated to provide the significance and future recommendations with respect to future research,

culminating in a conclusion which tied the entire study together. Citations in the text and reference listing adopted the Harvard referencing style.

CHAPTER 02
LITERATURE REVIEW

2.1. INTRODUCTION

In a number of agricultural crops, PRD has been shown to improve water use efficiency without compromising fruit quality (Stoll *et al*., 2000). Partial root-zone drying is a strategy that consists of irrigating only one half of the root zone in each irrigation event, both root zones are alternatively irrigated (Dodd *et al*., 2015). According to Donkin (2012), avocado trees are a drought sensitive crop, which yields poorly when subjected to short periods of water shortage. However, Chartzoulakis *et al*., (2002) stated that water stress sensitivity is cultivar dependent, and found that 'Hass' was more sensitive to water stress than 'Fuerte' avocado. Water stress reduces calcium partitioning to 'Hass' avocado fruit, consequently leading to increasing postharvest disorders such as; vascular browning and grey pulp (Blakey, 2011). Therefore, PRD was been found to be the potential tool to save water and produce good quality fruit crops (Roets *et al*., 2015). Additionally, postharvest treatments such as 1-MCP and cold storage temperature helps in maintaining postharvest fruit quality produced from PRD irrigation during exportation or storage (DAFF, 2015). However, there's limited literature on the effect of PRD on avocado under South African climatic conditions.

2.2. Work done on the identified research problem

2.2.1. Effect of irrigation, 1-MCP and cold storage temperature on fruit colour

<u>Effect of PRD on fruit skin colour</u>

Avocado fruit 'Hass' changes colour from green to black or purple as a sign of fruit ripening after cold storage (Magwaza and Tesfay, 2015). According to Cox *et al*. (2004), 'Hass' avocado fruit skin colour change is a result of chlorophyll loss and anthocyanin accumulation during ripening. Furthermore, Katy *et al*. (2003) found that 'Hass' avocado fruit changes peel colour from green to purple with a decrease in lightness, chroma and hue angle during ripening. However, fruit skin colour development can also be affected by water stress (Alcobendas *et al*., 2013). In 'Chok Anan' mango fruit harvested from PRD irrigated trees, an insignificant colour change was observed, whereby; exocarp and mesocarp of the mango fruit showed normal

and standard changes by turning yellow (Spreer *et al*., 2007). Contrary, skin colour of 'Petopride' tomato fruit from PRD irrigated plants showed higher red colour intensity (lower hue angle), presumably due to increased contents of anthocyanins and phenols induced by water stress conditions when compared with the control (Haghighi *et al*., 2013). In addition, anthocyanin and phenols were significantly high on PRD treated 'Catelao' grape berries when compared with deficit irrigation and normally irrigated fruit (Dos Santos *et al*., 2003). Moreover, Castellarin *et al*. (2007) investigated deficit irrigation on 'Merlot' grape fruit cultivar, and found the monomeric anthocyanin have been sensitive to endogenous abscisic acid (ABA) induced by water deficit conditions, particularly, cyanidin-3-*O*-glucoside.

Effect of 1-MCP and cold storage temperature of colour change

In fruit crops, ethylene enhances anthocyanin accumulation and chlorophyll degradation enzymes such as; phenylalanine ammonia lyase (PAL) and chlorophyllase resulting in colour change (Cheng *et al*., 2012). During storage and ripening, ethylene and anthocyanin related enzyme activities were enhanced by higher storage temperatures (Severo *et al*., 2015). Niu *et al*. (2017) found that high temperature storage (20-35°C) increased 'Red Beauty' plum fruit anthocyanins concentration. In 'Red Beauty' plums, high storage temperature increased the cyanidin-3-*O*-glucoside anthocyanin, which is responsible for red colour development (Niu *et al*., 2017). According to Cheng *et al*., (2012), high storage temperature enhances ethylene production, which triggers anthocyanin accumulation and chlorophyll degradation enzyme such as chlorophyllase. However, studies have shown that application of postharvest treatments such as 1-MCP (300 nl l^{-1}) and cold storage (5.0°C) for 3.5 weeks retained 'Pinkerton' avocado fruit colour by suppressing enzyme activities and delaying anthocyanin accumulation (Hershkovitz *et al*., 2005). It may be assumed that, 1-MCP and storage temperature delayed the onset of the climacteric peaks of CO_2 and ethylene production, which reduced chlorophyllase activities to delay colour change (Cheng *et al*., 2012).

In 'Ankara' pears, 1-MCP (250 and 500 ppb) and cold storage temperature (0 and 5°C) retained colour when compared with untreated fruit (Kurubas and Erkan, 2018). It may be assumed that, 1-MCP and cold storage temperature reduced 1-aminocyclopropane carboxylic acid (ACC) oxidase enzyme activity from initiating oxidation process to form

ethylene from ACC Adrian *et al*. (2015). In 'Hass' avocado fruit, delayed colour development can be attributed to application of 1-MCP and cold storage temperature, which enhance reduction in chlorophyllase enzyme activity and anthocyanin (cyanidin 3-*O*-glucoside) biosynthesis (Severo *et al*., 2015). The anthocyanin (cyanidin 3-*O*-glucoside) is responsible for colour development in most fruit crops such as avocado; the accumulation of cyanidin 3-*O*-glucoside was associated with increased ethylene production in Pinkerton avocado fruit (Hershkovitz *et al*., 2005). Therefore, the application of 1-MCP and cold storage temperature reduced the ACC synthesis which delayed ethylene production and colour development (Adrian *et al*., 2015).

2.2.2. Effect of irrigation, 1-MCP and cold storage temperature on firmness and ripening percentage

<u>Effect of PRD on fruit firmness and ripening percentage</u>

According to Pedreschi *et al*. (2016), firmness parameter is used to test fruit softness during ripening. Firmness is a good predictor fruit readiness to eat during ripening (Cox *et al*., 2004). In 'Hass' avocado fruit, softening increase with ripening days, and avocado firmness is associated with calcium accumulation (Pedreschi *et al*. 2016). According to White and Broadley (2003), water stress conditions induced by PRD irrigation limits calcium uptake, which leads to low Ca accumulation in the fruit tissues (mesocarp). Furthermore, Rosales *et al*. (2009) reported that water deficit enhances cell wall pectin solubilisation and reduce the calcium concentration, which is responsible for cell wall structure maintenance and fruit firmness (Hocking *et al*., 2016).

Wan Zaliha and Singh (2009) reported that firmness loss of 'Cripps Pink' apple fruit harvested from PRD irrigated trees was lower than from fully irrigated trees, presumably due to reduction in cellular hydration and increased flesh compactness. Contrary, Zegbe *et al*. (2016) found that 'Royal gala' apples harvested from PRD irrigated trees had higher firmness when compared with fully irrigated trees; it may be assumed that, these findings were due to no water stress effect imposed on fruit apple fruit. In 'Pectomech' tomato water deficit irrigation induced water stress, which resulted in less absorption of soil minerals by the tree; and therefore, deficit irrigation was found to reduce absorption of several nutrients including calcium (Ca), magnesium (Mg) and potassium (K^+) (Agbemafle *et al*., 2015). Mineral deficiency on 'Batsch' peach was

associated with the direct effect of reduced transpiration rates induced by water stress conditions (Abrisqueta *et al*., 2011). Giuliani *et al*. (2017) conducted a study on effects of PRD irrigation on tomato fruit 'Ercole' and 'Genius' and found that induced water stress led to increased abscicic acid (ABA) synthesis and enhanced ethylene production. It may be assumed that, increased ABA levels induced by pre-harvest water stress increased ethylene synthesis and resulting in increased 'Hass' avocado fruit ripening (Kassim *et al*., 2013).

Effect of 1-MCP and cold storage temperature on fruit firmness and ripening percentage

Decrease in firmness during different ripening stages is a good indicator of fruit's readiness to eat (Cox *et al*., 2004). Fruit ripening is associated with change in chemical composition conversion, for instance starch converted to sugar. Generally, ripening is the process by which fruit attain their desirable flavour, quality, colour and palatable nature (Watkin, 2006). Moretti *et al*. (2013) reported that a slow and continuous decrease of 'Cherry' tomato fruit firmness is correlated with climacteric ethylene production. Moreover, softening of fruit at ripening stage and senescence (degradation of cell walls) is induced by an increase of ethylene production and respiration rate (Miranda *et al*., 2002). In 'Redchief Delicious' apples, firmness retention was found to be influenced by 1-MCP treatment and cold storage temperature (5.0˚C) (Mir *et al*., 2001). Firmness retention was due to the inhibition of cell walls degradation and reduced hydrolysis of water-soluble pectin by 1-MCP and storage temperature (Taye *et al*., 2019). Daulagala and Daundasekera (2016) reported similar findings on 'Hass' avocado fruit, whereby, softening of 1-MCP treated fruit and stored under +2˚C was delayed. In 'Tower II' avocado fruit, cell wall degrading enzymes (polygalacturonase and cellulose) were reduced by 1-MCP and low temperature storage (Jeong *et al*., 2002). In addition, fruit softening increased with ripening days; it may be assumed that, increased ethylene production enhanced pectin solubility which caused rapid cell wall degradation and ripening of 'Hass' avocado fruit (Pedreschi *et al*., 2019; Hershkovitz *et al*., 2005).

2.2.3. Effect of irrigation, 1-MCP and cold storage temperature on fruit respiration rate

Effect of PRD on respiration rate

In climacteric fruit crops, water stress causes earlier ethylene production, leading to earlier ripening (Gindaba, 2014). In 'Hass' avocado tree, water stress might induce increased ethylene synthesis due to increased ABA concentrations Kassim *et al*. 2013). In fruit crops, an increased ethylene would result in increased respiration rate; and subsequently, enzyme activities, which causes hydrolysis and breakdown of cell wall components to induce fruit softening or ripening (Martinez-Romero *et al*., 2007). According to Blakey (2011), water stress hastened ethylene production leading to an earlier climacteric peak in 'Hass' avocado. Moreover, ethylene production pathway is highly reliant on water for biochemical reactions (Lechaudel and Joas, 2007; Blakey, 2011). There is dearth of information on the effect of PRD on respiration rate in most fruit crops particularly avocado; therefore, there is limited information on this topic.

Effect of 1-MCP and cold storage temperature on fruit respiration rate

The application of 1-MCP and low storage temperature reduces respiration rate by reducing ethylene production (Xuan and Streif, 2014). In avocado fruit 'Hass', the application of 1-MCP and cold storage temperature (1 and 5.5˚C) reduced respiration rate (Kok, 2011). Xuan and Streif (2014) reported that 1-MCP reduced ethylene production and respiration rate of 'Jonagold' apple fruit stored under controlled atmosphere. Moreover, low temperature storage reduced 'Roma VF' tomato fruit respiration rate and ethylene production due to retarded metabolic rate (Getinet *et al*., 2011). Therefore, low respiration rate was maintained by 1-MCP and low temperature storage through reducing ethylene production and metabolic activities (Kok, 2011).

2.2.4. Effect of irrigation, 1-MCP and cold storage temperature on fruit weight loss

Effect of PRD on fruit weight loss

In avocado fruit, weight loss is associated with water loss; and significantly, affects fruit ripening and reduces storage-life (Blakely, 2011). In horticultural crops including avocado fruit crop, water loss is crucial during ripening, therefore, minimising and managing water loss during storage-life and ripening is necessary in order to maintain fruit quality (Wills *et al*., 2008). In Granny Smith' apple fruit harvested from PRD irrigated trees, weight loss was found to be low during storage and delayed ripening (Durovic *et al*., 2012). Moreover, Van Hooijdonk *et al*. (2007) found that weight loss rate was reduced on 'Pacific Rose' apples subjected PRD irrigation, and stored under 0± 0.5˚C (10 weeks). Contrary, PRD had no effect on weight loss of 'Golden Delicious'

postharvest water loss (Zegbe and Serna-Perez, 2011). Correlation between weight loss and irrigation is not yet fully documented, however, Hifny *et al*. (2012) found “Valencia” orange citrus fruit weight loss be influenced by increased storage period rather pre-harvest irrigation method.

Effect of 1-MCP and cold storage temperature on fruit weight loss

In climacteric crops such as; 'Kensington' mango (Hofman *et al*., 2001) and ‘Hass’ avocado (Lemmer *et al*., 2002), 1-MCP reduce weight loss rate on by delaying the onset of respiratory climacteric. In ‘Hass’ avocado fruit, standard postharvest treatments such as 1-MCP and cold storage temperature delayed ethylene production, which improved fruit desiccation and further prevented early ripening (Kok, 2011). Daulagala and Daundasekera (2016) reported that 1-MCP and storage temperature (±2˚C) retained weight of ‘Pollock’ avocado fruit during ripening. Similar results reported by Salvador *et al*. (2004), observed that ‘Rojo Brillante’ persimmon treated with 1-MCP and kept at 1˚C showed a slower weight loss rate. Taye *et al*. (2019) investigated effect of 1-MCP on ‘Unicorn’ cherry tomato. In climacteric fruit such as plums, reduction in weight loss rate when treated with 1-MCP may be attributed to slow respiration rate and maintenance of tissue rigidity (Dong *et al*., 2002).

2.2.5. Effect of irrigation, 1-MCP and cold storage temperature on fruit electrolyte leakage and electrical conductivity

Effect of PRD on electrolyte leakage and electrical conductivity

According to Gonzalez and Barrett (2010), electrolyte leakage involves measuring membrane integrity as a result of electrolytes that dissociate into ions and leaking through cellular membrane channels. In chilling sensitive crops such as mango fruit, electrolyte leakage (EL) and electrical conductivity (EC) occurs along with chilling injury percussed by low temperatures that cause fluidity disruption and order of the membrane lipids (Gonzalez and Barrett, 2010). In ‘Hass’ avocado fruit, external chilling injury was highly correlated with increased skin tissue electrolyte leakage (Woolf *et al*., 2005). While in avocado fruit ‘Arad’ and ‘Ettinger’ increased chilling injury with increased electrolyte leakage Hershkovitz *et al*. (2009). White and Broadly (2003) stated that weaker cell membranes were induced by low calcium accumulated in fruit harvested from PRD irrigated tress. Hocking *et al*. (2016) described calcium as an

important element in strengthening membrane structures in fruits. However, there's dearth of literature on effect of PRD on electrolyte leakage.

Effect of 1-MCP and cold storage temperature on fruit electrolyte leakage and electrical conductivity

In 'Hami' melon fruit, 1-MCP was responsible for inhibiting electrolyte leakage (EL) during storage and assumed to have been due to delayed climacteric ethylene production (Li *et al*. 2011). Furthermore, Gonzalez-Aguilar *et al*. (2000) associated increased electrolyte leakage with cells plasma membrane integrity loss during cold storage temperature (2.0˚C) of 'Fortune' mandarin fruit. In most reported cases, EL occurs as a result of cold damage disrupting the order of the membrane lipids and eventually increasing membrane permeability (Dorria *et al*., 2010). In 'Bloody Butcher' and 'Money Maker' tomato fruit, an increase in electrolyte leakage was highly correlated with chilling injury stored under 6˚C for 7 days (Biswas *et al*., 2012). In 'Castlemart' tomato pericarp discs, high electrolyte leakage was found to be enhanced by low storage temperature (2.5˚C); findings may be attributed to pectin solubility, which caused rapid cell wall degradation (Saltveit, 2002). However, fruit maturity has a large influence on plasma membrane integrity and solute leakage (Alessandro *et al*., 2014).

2.2.6. Effect of PRD, 1-MCP and cold storage temperature on physiological disorders

According to Al-amrani *et al*., (2020), physiological disorders associated with browning reactions are induced by oxidation of the enzyme polyphenol oxidase (PPO). Browning of the mesocarp may occur when polyphenol oxidase (PPO) it catalyses the oxidation of *o-quinone* in the fruit mesocarp to a brown melanin pigment (Hershkovits *et al*., 2009). During partial root-zone drying (PRD), abscicic acid is released for plant functions such as stomatal conductance. However, tissue tolerance to chilling injury may be reduced. Hence, physiological disorder incidences are increased (Gindaba, 2014). Furthermore, internal and external chilling injury could also be caused by temperatures below 13˚C (Crisosto *et al*., 2003). Hershkovitz *et al*. (2009) defined chilling injury as an irreversible and permanent damage to cells due to low temperature storage that is below freezing point of the fruit. Chilling injury on avocado can be spotted by manifestation of blackening of the exocarp, pitting and discoloration of mesocarp (Crisosto *et al*., 2003). Moreover, chilling injury is dependent on duration of disclosure to low temperature, cultivar and maturity stage (Kok, 2011). Prolonged

exposure of avocado fruit to low temperature can result in higher severity of chilling injury incidences (Van Rooyen and Bower, 2006). Sivankalyani *et al*. (2015) stated that 'Hass' avocado is more resistant to chilling injury when compared with 'Ettinger' avocado fruit under low storage temperature of 1.1 and 5.0˚C. However, Woolf *et al*. (2005) reported that 1-MCP reduced vascular browning and chilling injury in 'Hass' avocado fruit (stored under 5.5˚C for 4-5 weeks).

2.2.7. Effect of PRD, 1-MCP and cold storage temperature on pathological diseases

Partial root-zone drying irrigation has the ability to reduce fruit calcium concentration and to some extend reduce cell wall and membrane stability making fruit vulnerable to pathogen attack (Sun *et al*., 2013). In 'Petopride' tomato fruit, pathological diseases (blossom-end rot and body rot) of PRD irrigated plants were found to be higher than fully irrigated tomato plants due to low fruit calcium concentration (Zegbe *et al*., 2006). According to Nxumalo *et al*. (2019), high calcium concentration accumulation increased resistance of avocado fruit to pulp spot due to vital role stabilization of fruit cell walls and membranes by calcium. Fruit rot related pathological symptoms such body rot and stem end-rot reduce the fruit market value, the symptoms become comprehensibly expressed when fruit is ripe (Galsurker *et al*., 2018). For this reason, it is impossible to tell that unripe fruit will develop rots; the symptoms are a sign of manifestation of fungal pathogens. However, the application of postharvest treatments such as 1-MCP and storage temperature to unripe fruit can suppress development of pathological diseases (Galsurker *et al*., 2018).

In 'Fuerte' avocado fruit stored at 5˚C, the application of 1-MCP treatment reduced fungal pathogen rot (Diskin *et al*., 2015). Storage temperature of >6˚C increased incidences of pathological diseases on 'Hass' avocado fruit (Perkins *et al*., 2020). According to Galsurker *et al*. (2018), 1-MCP prevents pathogenic fungus from colonizing the phloem and xylem of the fruit stem-end while storage temperature of 5.5˚C provides favourable environmental conditions for pathological diseases to develop and grow at rapid rate (Leandro *et al*. 2003). Therefore, combination of 1-MCP and cold storage suppresses pathological disease development storage during fruit storage.

2.3. Work not yet done on the research problem

The application of partial root-zone drying as irrigation method during pre-harvest, 1-MCP and storage temperature after harvest is a combination of three factors which was not yet investigated on ‘Hass’ avocado fruit. However, PRD, 1-MCP and storage temperature have been individually investigated. This study intends on investigating the response of ‘Hass’ avocado fruit when irrigated with PRD system, applied with 1-MCP and storage temperature.

CHAPTER 03
METHODOLOGY AND ANALYTICAL PROCEDURES

3.1. Experimental sites

Avocado fruit were harvested from Avo Valley Farm in Nelspruit (25°29’39" S; 30°55’54" E), on fourteen-year-old ‘Hass’ avocado trees grafted on ‘Duke 7’ rootstocks and planted at a spacing of 4 x 4 m (625 trees per hectare). Harvested fruit were packed into boxes and transported to the Agricultural Research Council-Tropical and Subtropical Crops (ARC-TSC) postharvest laboratory in Nelspruit (25˚C 28' 0" S, 30˚ 58' 0" E) for storage and analysis.

3.2. Research design and treatments

The experiment consists of three treatment factors, viz: 2 irrigation methods (PRD and full irrigation/control), 2 concentrations of 1-MCP (300 and 0 mg) and 2 cold storage temperatures (2 and 5.5˚C). The experiment was carried out as 2 x 2 x 2 factorial experiment in Completely Randomized Design (CRD) with 6 replicates.

3.3. Research procedures

For each avocado tree selected for experiment with PRD treatment half of the root-zone of each data tree was irrigated, while the other half was left dry (Figure 3.1). The wet and dry sides were alternated at three-week intervals initially using micro sprinklers with a delivery rate of 40 L/h. The micro-sprinklers wetted only in 180˚ radius, only one-half of the root-zone was watered at the time. The dry half was covered with plastic sheets to exclude rainwater. The plastic sheets were white on top to reflect heat hence; soil temperature was not affected. For the control, the root-zone was fully irrigated at delivery rate of 40 L/h. Soil moisture was determined using soil moisture probe from a depth of 0-60 cm, the soil’s easily available water wasn’t allowed to deplete more than 50-60%. Irrigation wasn’t applied if rainfall exceed 5.5 mm. At the field, uniform in size and free of any visible peel defects fruit were harvested randomly from the inside and outside of tree canopies as the representative of each treatment. At postharvest laboratory fruit from trees of each irrigation treatment were divided in two batches. Thereafter, 15 fruit were placed into small boxes with six replicates per treatment. Each replicate per treatment was treated with 1-Methylcyclopropene (1-MCP) and other treatment was not treated, both treatments

were subjected to cold storage temperature of 2 and 5.5˚C for 28 days. After withdrawal from cold storage, ripening of 'Hass' avocado fruit was conducted at the ripening room set at 21˚C.

Figure 3.1: Experimental sites showing of partial root-zone drying (PRD) irrigation and full irrigation method.

3.4. Data collection

3.4.1. Skin colour

Colour was determined before and after cold storage as explained by Maftoonazad and Ramaswamy (2008). Objectively, colour was determined using a Chromameter (CR- 400, Konica Minolta, and model: DFM50, Osaka, Japan) (Figure 3.2) and subjectively using avocado eye colour rating (1-6) (Figure 3.3). Data was expressed in lightness (L*), chroma (C) and hue angle (*h*°). Chroma (C) and hue angle was determined as as previously described by McGuire (1992).

$$C = \sqrt{a^2 + b^2}\ hue\ angle = \tan^{-1}(\frac{b}{a}) \quad (1)$$

Where:

a* = Redness or greenness and

b* = Yellowness or blueness.

Figure 3.2: Chromameter used to measure objectively hue angle, chroma and peel lightness

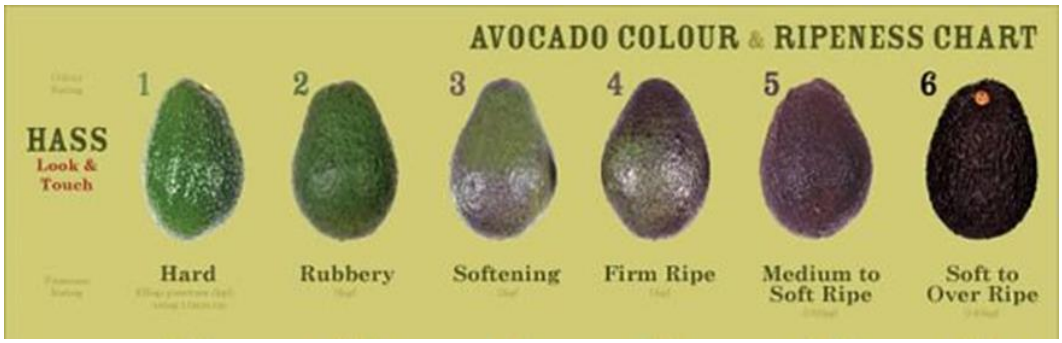

Figure 3.3: Eye colour scale (1-6) used to assess eye colour subjectively (White *et al*., 2009)

3.4.2. Respiration rate

Selected 'Hass' avocado fruits were weighed then incubated in a 1 L glass jar container (Figure 3.4) for an hour. After 1 hour of fruit incubation the concentration of carbon dioxide concentration (CO_2) was measured using a Map-Pak gas analyser (AGC Map-Pak Analyser Range, German) (Figure 3.4). Subsequently, the headspace CO_2 concentration was converted through considering the volume and mass of the fruit, free space in the jar and as well as the ambient CO_2 concentration to obtain respiration rate which is expressed as µmol CO_2 kg^{-1} h^{-1}.

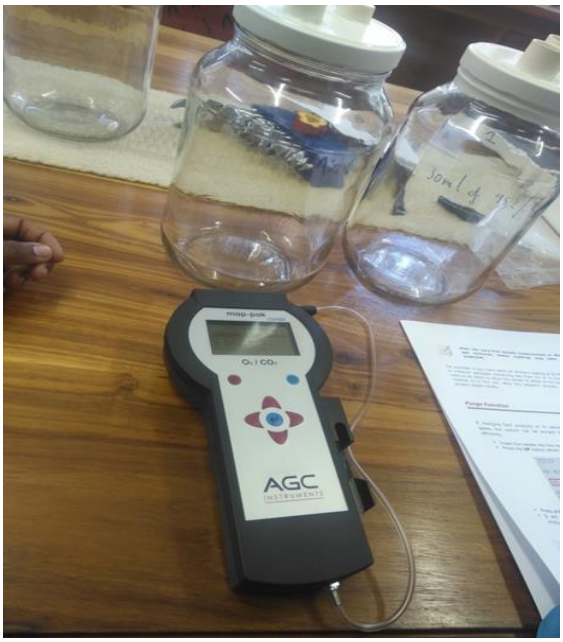

Figure 3.4: Map-Pak gas analyser with glass jar used to measure CO_2 concentration

3.4.3. Ripening percentage

Fruit were evaluated for ripening percentage during ripening period, firmness (SU) readings were used to evaluate ripening. Fruit which showed eating soft stage (an average reading of ≤ 25 SU) were considered ripe. Therefore, ripening percentage was calculated as:

$$\text{Ripening \%} = \frac{Number\ of\ ripe\ fruit}{Number\ of\ evaluated\ fruit}\ X\ 100 \quad (2)$$

3.4.4. Fruit weight loss

Fruit weight loss was evaluated after cold storage and during ripening using a weighing scale (Scaltec, SBA, Heilingenstadt) (Figure 3.5). Fruit weight after cold storage denotes initial fruit mass and during ripening denotes final fruit mass, the difference in fruit initial mass and final mass was calculated and expressed in percentage (Maftoonazad and Ramaswamy, 2008).

$$\text{Weight loss \%} = \frac{M_0 - M_1}{M_0}\ X\ 100 \quad (3)$$

Where:

M_0 = mass of avocado fruit before storage

M_1 = mass of avocado fruit after storage

Figure 3.5: Fruit weighing scale used to measure fruit weight

3.4.5. Firmness

Fruit firmness was measured after cold storage and during ripening using a non-destructive automated Sinclair IQ^{TM} desktop firmness machine (Model: 51DFTB, International LTD, Jorrold, Bowthorpa, Nonwich, NR5, 9.D, England) (Figure 3.6). Each selected fruit was placed on top Sinclair disc to measure four equatorial parts of the fruit and results were recorded in Sinclair units (SU). Data was calculated and expressed in percentage as previously described by Delwiche and Sarig (1991).

Firmness (%) = $\frac{F_0 - F_1}{F_0} X\ 100$ (4)

Where:

F_0 = firmness before storage

F_1 = firmness after storage

Figure 3.6: Sinclair IQTM desktop firmness machine used to measure fruit softness

3.4.6. Determination of electrical conductivity (EC)

After 28 days, fruit were taken out of cold storage and electrical conductivity (EC) was tested. Three avocado fruit from each selection were used for the determination of EC after cold storage and during termination of the trial. Avocado fruit were tested for EC following the method of Montoya *et al*. (1994). A 10 mm in diameter cork-borer was used to remove sample disks from the fruit, samples were put inside a glass tuber and 10 ML of distilled water was added inside. Glass tubers were subjected to a tuber holder which was put on the shaker for 3 hours. After shaking for 3 hours, the initial electrolyte leakage (EC1) was measured using an electrical conductivity meter (model: HI 9033, Hanna instruments, Johannesburg, RSA) (Figure 3.7). After taking the first EC, samples were boiled in a hot water bath for 1 hour, thereafter; allowed to cool to ambient temperature. After cooling samples, second electrolyte leakage (EC2) was measured. Electrolyte leakage was expressed as percentage using the following formula as described previously by Montoya *et al*. (1994):

$$EC\% = \left(\frac{EC2}{EC1}\right) X\ 100 \qquad (5)$$

Figure 3.7: Electric conductivity (EC) meter used to measure membrane permeability

3.4.7. Physiological disorder and pathological diseases

At the ripen stage, fruit were cut open using a knife blade and evaluated for selected physiological disorders such as vascular browning (using hedonic scale 0-3) and chilling injury. External chilling injury (CI) was expressed as:

$$\text{Chilling injury \%} = \frac{Number\ of\ fruit\ with\ chilling\ injury\ symptoms}{Total\ number\ of\ fruit\ evaluated}\ X\ 100 \quad (6)$$

Furthermore, pathological diseases such as body rot and stem end-rot were also evaluated using a hedonic scale (0-3). After assessing fruit using hedonic scale, data was converted to percentage where 0 = 0% (none); 1 = 10% (moderate); 2 = 25% and 3 = 50% (severe).

3.5. Data analysis

Collected data was subjected to GenStat 18th version (VSN International, 2015) to generate analysis of variance (ANOVA) and the differences between treatments mean were tested using Duncan's New Multiple Range Test (DNMRT) at 5% level of significance.

CHAPTER 04

RESULTS AND DISCUSSION

4.1. RESULTS

4.1.1. Fruit skin colour attributes

Peel lightness (L)

Highly significant results were observed on irrigation ($P = 0.005$), 1-Methylcyclopropene (1-MCP) ($P < 0.001$) and ripening days ($P < 0.001$). Contrary, cold storage temperature had no significant effect on fruit peel lightness (L). An interaction between irrigation system, 1-Methylcyclopropene (1-MCP), storage temperature and ripening days did not significantly ($P > 0.05$) influence fruit peel lightness (L). Furthermore, highly significant differences ($P<0.001$) on interactions between 1-MCP and ripening days, temperature and ripening days, and irrigation system, storage temperature and ripening days were also observed (Appendix 1). Avocado fruit 'Hass' from trees subjected to PRD irrigation, treated with 300 ng/L 1-MCP, subsequently; stored under 5.5°C showed high peel lightness (35.2, 34.1, 32.3, 28.3 and 23.9) during 0, 2, 4, 6 and 8 ripening days, respectively. In contrast, fruit from fully irrigated trees and not treated with 1-MCP, thereafter; stored under 2°C showed low skin lightness (35.8, 35.2, 28.9 and 27.2) during ripening days (Table 4.1).

Generally, fruit from full irrigation and treated with 300 ng/L 1-MCP, thereafter, stored under 2.0°C exhibited high peel lightness. However, fruit from full irrigation and treated with 300 ng/L 1-MCP, thereafter; stored under 2.0°C showed slight decline with prolonged ripening days. Whereas, fruit from PRD irrigation and not treated with 1-MCP, afterwards; stored under 5.5°C showed low peel lightness during ripening.

Fruit from full irrigation, treated with 300 ng/L 1-MCP, thereafter; stored under 5.5°C showed higher peel lightness when compared with peel lightness of fruit from PRD irrigation and not treated with 1-MCP, afterwards; stored under 2°C during ripening. Furthermore, fruit harvested from fully irrigated trees and not treated with 1-MCP, thereafter; stored under 5.5°C exhibited low peel lightness. Contrary, fruit from PRD irrigation and treated with 300 ng/L 1-MCP, thereafter; stored under 2°C exhibited high peel lightness during ripening days.

Skin chroma

Fruit skin chroma was not significantly influenced by irrigation (P = 0.074), 1-MCP (P = 0.352) and cold storage temperature (P = 0785). However, highly significant results were observed from ripening days (P < 0.001). An interaction between irrigation system, 1-MCP, storage temperature and ripening days had no significant effect (P > 0.05) on fruit skin chroma (C) (Appendix 2). Nonetheless, 'Hass' avocado fruit from PRD irrigated trees and treated with 300 ng/L 1-MCP, thereafter; stored under 5.5°C showed higher skin chroma. Additionally, skin chroma values (35.6-6.8) showed a significant declined during 0, 2, 4, 6 and 8 ripening days, respectively. However, fruit from fully irrigated trees, not treated with 1-MCP, afterwards; stored under 2°C showed lower skin chroma during 0, 2, 4 and 6 ripening days, respectively and skin chroma values (21.7-15.7) showed a slight decline (Table 4.1) during ripening.

Moreover, fruit from full irrigation and treated with 300 ng/L 1-MCP, thereafter; stored under 2°C exhibited high skin chroma. However, during day 0 and 2 decline in skin chroma was slight with prolonged ripening days. Whereas, skin chroma of fruit from PRD irrigation and not treated with 1-MCP, subsequently; stored under 5.5°C showed low values during ripening. Additionally, fruit from PRD irrigation and not treated with 1-MCP, subsequently; stored under 5.5°C showed a considerable decline in skin chroma.

Furthermore, fruit from full irrigation, treated with 300 ng/L 1-MCP, afterwards; stored at 5.5°C showed higher skin chroma. However, fruit from PRD irrigation and not treated with 1-MCP, subsequently; stored at 2°C showed low skin chroma during ripening. Moreover, fruit from full irrigation and not treated with 1-MCP, thereafter; stored under 5.5°C exhibited lower skin chroma when compared with skin chroma of fruit from PRD irrigated tress and treated with 300 ng/L 1-MCP, afterwards; stored under 2°C during ripening days.

Skin hue angle (*h*°)

Individually, 1-MCP and ripening days showed highly significant differences (P < 0.001) on skin hue angle. An interaction between irrigation system, 1-MCP, storage temperature and ripening days did not significantly (P > 0.05) influence fruit skin hue angle (*h*°). Additionally, highly significant differences (P < 0.001) were observed on

interaction of ripening days with temperature and 1-MCP, respectively. Furthermore, an interaction between irrigation type, storage temperature and ripening days showed a highly significant effect ($P < 0.001$) on fruit skin hue angle (*h*°) during ripening (Appendix 3). Fruit from PRD irrigation and treated with 300 ng/L 1-MCP, thereafter; stored under 5.5°C showed skin higher hue angle (179.1, 179.0, 156.7, 90.2, 54.9 and 49.0) during ripening. However, the fruit skin hue angle (156.7, 90.2 and 54.9) declined significantly after day 2. Contrary, fruit harvested from fully irrigated and not treated with 1-MCP, thereafter; stored under 2.0°C showed lower skin hue angle (146.5, 120.1, 95.6 and 75.4) during ripening and fruit showed a significant decline in skin hue angle (120.1, 95.6, and 75.4) after day 0 (Table 4.1).

Moreover, fruit from full irrigation and treated with 300 ng/L 1-MCP, afterwards; stored under 5.5°C showed higher skin hue angle during ripening days. However, during day 0 and 2, skin hue angle declined slightly. Whereas, skin hue angle of fruit from PRD and not treated with 1-MCP, subsequently; stored under 2.0°C showed lower values and values showed a considerable decline in skin hue angle during ripening days.

Fruit from full irrigation, treated with 300 ng/L 1-MCP, thereafter; stored under 2°C showed higher skin hue angle. Contrary, fruit from PRD irrigation and not treated with 1-MCP, afterwards; stored under 5.5°C exhibited low skin hue angle during ripening. Moreover, fruit from full irrigation and not treated with 1-MCP, subsequently; stored under 5.5°C exhibited low skin hue angle. Whereas, fruit from PRD irrigation and treated with 300 ng/L 1-MCP, thereafter; stored under 2.0°C exhibited high skin hue angle during ripening days.

Skin eye colour

During ripening, fruit skin eye colour was significantly ($P < 0.05$) influenced by irrigation, 1-MCP and ripening days individually. An interaction between irrigation system, 1-MCP, storage temperature and ripening days did not significantly ($P > 0.05$) influence fruit skin eye colour. However, highly significant differences ($P < 0.001$) were observed on an interaction between ripening days with temperature and 1-MCP, respectively (Appendix 4). Fruit harvested from fully irrigated trees and treated with 300 ng/L 1-MCP, thereafter; stored under 2°C showed low skin eye colour (1, 1, 1.8, 3.5, 4.5, and 5.5) only during 0, 2 and 6 ripening days, respectively. However, skin eye colour of fruit showed no significant increase during day 0 and 2. Contrary, fruit from

PRD irrigation and not treated with 1-MCP, subsequently; stored under 5.5°C showed high skin eye colour (1, 2.2 and 3.6) during ripening. Additionally, skin eye colour increased significantly after day 0 (Table 4.1).

In general, fruit from full irrigation and not treated with 1-MCP, thereafter; stored under 2°C showed higher skin eye colour during ripening days. While fruit from PRD irrigation and treated with 300 ng/L 1-MCP, afterwards; stored under 5.5°C exhibited low skin eye colour. However, fruit skin eye colour showed no significant change during day 0 and 2. Whereas, skin eye colour of fruit from PRD irrigation and treated with 300 ng/L 1-MCP, afterwards; stored under 5.5°C showed significant increase after day 0.

Fruit from full irrigation and treated with 300 ng/L 1-MCP, thereafter; stored under 5.5°C showed low skin eye colour during ripening. Whereas, fruit from PRD irrigation and not treated with 1-MCP, subsequently; stored under 2°C exhibited high skin eye colour during ripening. Skin eye colour of fruit from full irrigation and treated with 300 ng/L 1-MCP, thereafter; stored under 5.5°C showed significant increase at day 4 Whereas Skin eye colour of fruit from PRD irrigation and not treated with 1-MCP, subsequently; stored under 2°C showed increase at day 2.

Lastly, fruit from full irrigation and not treated with 1-MCP, afterwards; stored under 5.5°C showed higher skin eye colour. Conversely, fruit from PRD irrigation and treated with 300 ng/L 1-MCP, subsequently; stored under 2°C showed low skin eye colour. Additionally, skin eye colour of fruit from PRD irrigation and treated with 300 ng/L 1-MCP, thereafter; stored under 2°C showed significant increase at day 4. While, fruit from full irrigation and not treated with 1-MCP, afterwards; stored under 5.5°C showed significant increase at day 2.

Table 4.1: Effect of irrigation, 1-MCP application and storage temperature on 'Hass' avocado fruit

Irrigation method	1-MCP concentration (ng/L)	Storage temperature (˚C)	Ripening time	Colour parameters			
				Lightness (L*)	Chroma (C)	Hue angle (*h**)	Eye colour
Full irrigation	0	2.0	0	35.8kl	21.7ab	146.5m-q	1a
	300			35.4kl	22.9ab	179.1q	1a
	0	5.5		36.7l	22.2ab	147.0m-q	1a
	300			36.9l	22.4ab	179.2q	1a
PRD	0	2.0		35.7jkl	23.2ab	147.2m-q	1a
	300			34.9l	23.6ab	179.1q	1a
	0	5.5		35.6kl	24.3ab	147.2m-q	1a
	300			35.2kl	23.8ab	179.1q	1a
Full irrigation	0	2.0	2	35.2kl	17.1ab	120.1j-n	1.8abc
	300			35.0kl	20.4ab	179.1q	1.0a
	0	5.5		34.7kl	16.6ab	119.9j-n	1.9abc
	300			36.3lk	20.0ab	179.1q	1.0a
PRD	0	2.0		33.3jkl	14.9ab	130.5k-o	1.6ab
	300			36.3l	21.2ab	179.1q	1.0a
	0	5.5		34.3jkl	15.9ab	106.1h-m	2.2bcd
	300			34.1jkl	17.8ab	179.0q	1.0a
Full irrigation	0	2.0	4	28.9ghi	15.7ab	95.6g-l	3.40efg
	300			34.0jkl	16.1ab	160.4npq	1.8abc
	0	5.5		29.2ghi	15.2ab	106.8h-m	3.4efg
	300			35.7kl	18.7ab	159.9npq	1.8abc
PRD	0	2.0		28.9ghi	6.4a	98.0g-l	3.3def
	300			34.1jkl	17.1ab	167.6oq	1.5ab
	0	5.5		28.5gh	8.2a	92.4g-k	3.6e-h
	300			32.2ijk	13.5ab	156.7npq	2.0abc
	0	2.0		27.2fgh	14.9ab	75.4e-i	4.9i-m

Full	300			28.2gh	5.8a	112.4i-n	3.5e-h
irrigation	0	5.5		*	*	*	*
	300			28.9ghi	6.8a	138.6l-p	2.8cde
PRD	0	2.0	6	26.7d-g	4.5a	82.1e-j	4.4g-k
	300			30.8hij	12.2ab	111.6h-n	3.5e-h
	0	5.5		*	*	*	*
	300			28.3gh	7.8a	90.2f-k	4.0f-j
Full	0	2.0		*	*	*	*
irrigation	300			27.1efg	4.2a	68.0d-h	4.5g-k
	0	5.5		*	*	*	*
	300			23.7a-f	6.1a	52.7cef	4.8i-m
PRD	0	2.0	8	*	*	*	*
	300			26.4c-g	5.2a	53.2cef	5.0j-m
	0	5.5		*	*	*	*
	300			23.9a-f	6.8a	54.9c-g	4.9i-m
Full	0	2.0		*	*	*	*
irrigation	300			23.3a-d	4.1a	34.0a-e	5.5k-o
	0	5.5		*	*	*	*
	300			22.2a	5.2a	49.2b-f	5.0j-m
PRD	0	2.0	10	*	*	*	*
	300			23.8a-f	3.9a	30.5abc	5.7l-o
	0	5.5		*	*	*	*
	300			*	*	*	*

**Fruit ripened and experiment terminated. Within a column, values with different letters are significantly different at* P ≤ 0.05*. Mean separation by Duncan's New Multiple Range Test (DNMRT).*

4.1.2. Fruit firmness loss

Avocado fruit harvested from fully irrigated trees and not treated with 1-MCP, thereafter; stored under 2.0˚C showed high firmness loss (0.0, 21.1, 30.6 and 55.25) during 0, 2, 4 and 6 ripening days, respectively (Figure 4.1 A). Whereas, fruit from PRD irrigation, treated with 300 ng/L 1-MCP, afterwards; stored under 5.5˚C exhibited

lower firmness loss (0.0, 13.36, 28.89, 50.10 and 63.91) during 0, 2, 4, 6 and 8 ripening days, respectively (Figure 4.1 B).

Furthermore, fruit from PRD irrigation and not treated with 1-MCP, afterwards; stored under 5.5˚C showed high firmness loss during ripening. Whereas, fruit from full irrigation treated with 300 ng/L 1-MCP, thereafter; stored under 2.0˚C showed low firmness during ripening days. However, slight increased on firmness loss of fruit from full irrigation, treated with 300 ng/L 1-MCP, afterwards; stored under 2.0˚C was observed from day 6. While, from PRD irrigation and not treated with 1-MCP, afterwards; stored under 5.5˚C fully softened at day 4.

Fruit harvested from fully irrigated trees and not treated with 1-MCP, subsequently; stored under 5.5˚C showed high firmness loss during ripening. Whereas, fruit from PRD irrigation and treated with 300 ng/L 1-MCP, afterwards; stored under 2.0˚C exhibited low firmness loss during ripening days.

Moreover, fruit from fully irrigated trees, treated with 300 ng/L 1-MCP, subsequently; stored under 5.5˚C showed low firmness loss. Additionally, firmness loss of fruit showed a slight increase during ripening days. Fruit from PRD irrigation and not treated with 1-MCP, afterwards; stored under 2.0˚C demonstrated high values of firmness loss during ripening days. However, fruit from both interactions exhibited indistinguishable firmness loss percentage (22%), afterwards; firmness loss increased significantly.

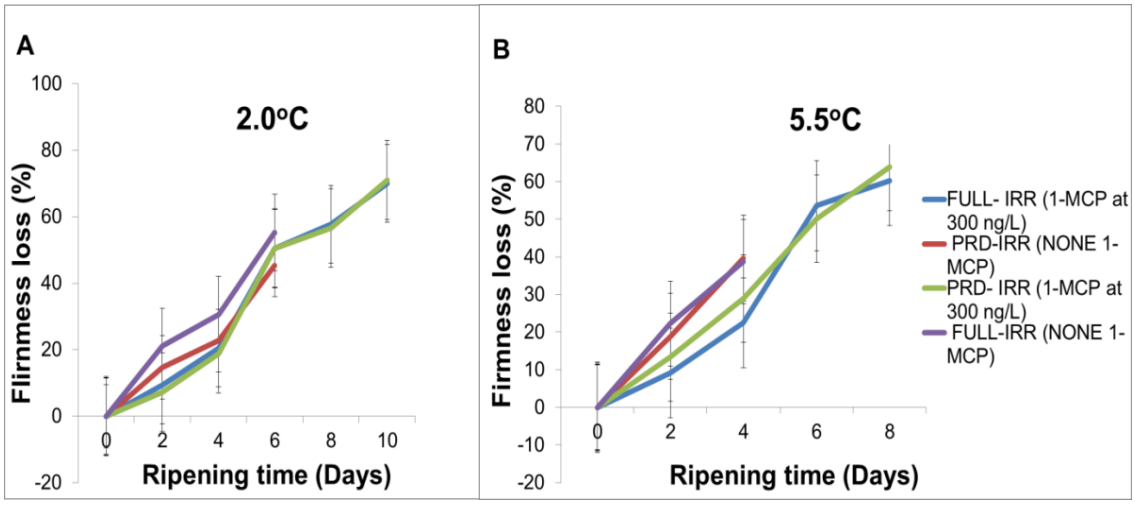

Figure 4.1: Effect of PRD, 1-MCP and storage temperature [2.0˚C (**A**) and 5.5˚C (**B**)] on firmness loss of 'Hass' avocado fruit. Vertical bars are standard errors (se) below and above the mean.

4.1.3. Ripening percentage

Avocado fruit 'Hass' harvested from fully irrigated trees, treated with 300 ng/L 1-MCP, and subsequently; stored under 2.0˚C did not ripen during day 0, 2, 4, 6 and 8. However, a higher ripening percentage (53.3%) was observed at day 10 (Figure 4.2 A). Contrary, fruit from PRD irrigation and not treated with 1-MCP, thereafter; stored under 5.5˚C only showed no ripening percentage (0%) during day 0. However, fruit commenced ripening (60 and 86.7%) during day 2 and 4, respectively (Figure 4.2 B).

In general, fruit from PRD irrigated trees and not treated with 1-MCP, afterwards; stored under 2.0˚C had higher ripening percentage. While, low ripening percentage was observed on fruit from fully irrigated trees and treated with 300ng/L 1-MCP, subsequently; stored under 5.5˚C. Moreover, fruit from PRD irrigation and treated with 300 ng/L, subsequently; stored under 2.0˚C had lower ripening percentage. Whereas, fruit from full irrigation and not treated with 1-MCP, afterwards; stored under 5.5˚C showed high ripening percentage. In addition, high ripening percentage was observed on fruit from fully irrigated trees, not treated with 1-MCP, thereafter; stored under 2.0˚C. Contrary, fruit harvested from PRD irrigated trees and treated with 1-MCP, subsequently; stored under 5.5˚C had low ripening percentage.

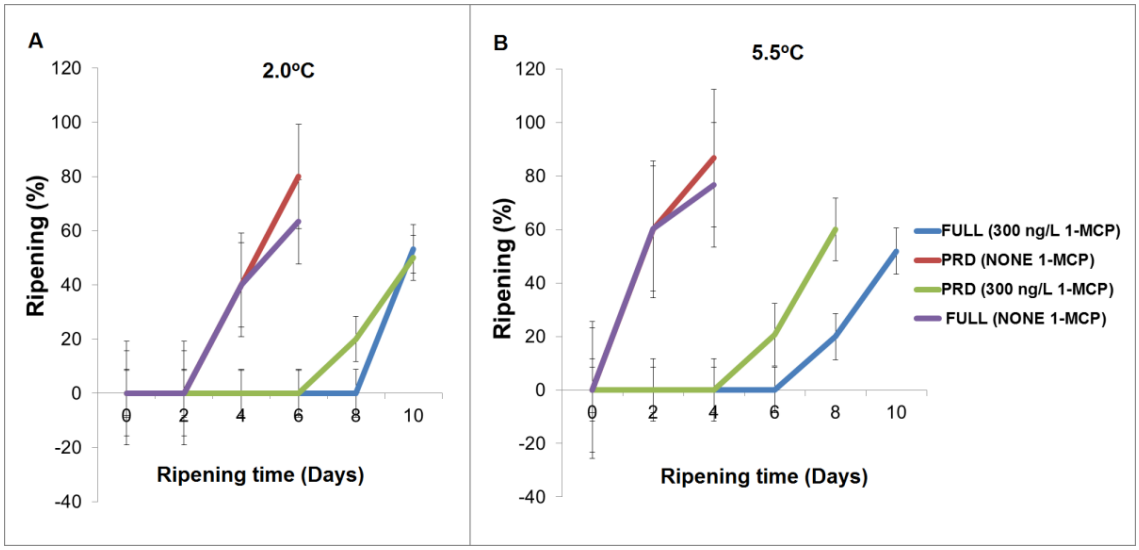

Figure 4.2: Effect of PRD, 1-MCP and storage temperature [2.0°C (**A**) and 5.5°C (**B**)] on ripening percentage of 'Hass' avocado fruit. Vertical bars are standard errors (se) below and above the mean.

4.1.4. Fruit respiration rate

Respiration rate of fruit increased significantly at day 2 and decreased at day 6 (Figure 4.3 A and B). Avocado fruit 'Hass' harvested from fully irrigated trees and not treated with 1-MCP, thereafter; stored under 2.0°C showed higher respiration rate (1527, 2835, 3074 and 1638 µmol CO_2 Kg^{-1} hr^{-1}) during ripening days (0, 2, 4 and 6), respectively. Contrary, low values of respiration rate (516, 493, 507, 646 and 466 µmol CO_2 Kg^{-1} hr^{-1}) fruit from PRD irrigated trees and treated with 300 ng/L 1-MCP, and subsequently; stored under 5.5°C were observed during ripening days (0, 2, 4, 6, and 8), respectively. Furthermore, fruit from PRD irrigation and treated with 300 ng/L 1-MCP, thereafter; stored under 5.5°C showed low respiration rate during day 2 and started to increase during day 4 until it decreased again during day 8.

In general, fruit from full irrigation, treated with 300 ng/L 1-MCP, afterwards; stored under 2.0°C showed low respiration rate during ripening. However, high respiration rate was observed on fruit which were harvested from PRD irrigation and not treated with 1-MCP, subsequently; stored under 5.5°C. Moreover, fruit from both treatments showed erratic respiration rate throughout ripening period.

Fruit from both treatments generally showed inconsistency with regard to respiration rate throughout ripening days. In addition, fruit from full irrigation and not treated with 1-MCP, subsequently; stored under 5.5°C showed high respiration rate. Whereas, fruit from PRD irrigation and treated with 300 ng/L 1-MCP, afterwards; stored under 2.0°C exhibited low respiration rate. Moreover, fruit from full irrigation and treated with 300 ng/L 1-MCP, thereafter; stored under 5.5°C showed low respiration rate. Contrary, fruit from PRD irrigation, not treated with 1-MCP, and subsequently; stored under 2.0°C exhibited high respiration rate. However, intermittent respiration rate was observed on fruit from both treatments throughout ripening days.

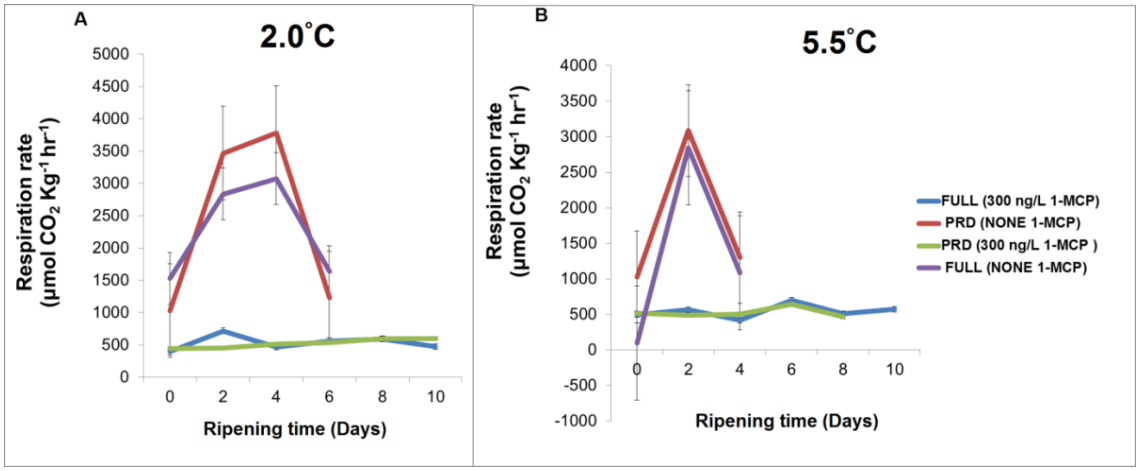

Figure 4.3: Effect of PRD, storage temperature [2.0˚C (**A**) and 5.5˚C (**B**)] and 1-MCP on respiration rate of 'Hass' avocado fruit. Vertical bars are standard errors (se) below and above the mean.

4.1.5. Fruit weight loss

Avocado fruit 'Hass' harvested from trees which were subjected to full irrigation and not treated with 1-MCP, thereafter; stored under 2.0˚C exhibited low weight loss (0.0, 1.441, 2.934 and 4.271%) during ripening days (0, 2, 4 and 6), respectively. Whereas, fruit from PRD irrigated trees and treated with 300 ng/L 1-MCP, subsequently; stored under 5.5˚C showed high weight loss (0.0, 1.184, 1.698, 4.987 and 5.728%) during 0, 2, 4, 6 and 8 ripening days, respectively (Figure 4.4 A and B).

In general, fruit harvested from fully irrigated trees and not treated with 1-MCP, afterwards; stored under 5.5˚C showed high weight loss when compared with fruit from PRD irrigation and treated with 300 ng/L 1-MCP, and subsequently; stored under 2.0˚C. Consequently, fruit from PRD irrigation and treated with 300 ng/L 1-MCP, thereafter; stored under 2.0˚C showed increased weight loss during day 6. Whereas fruit from full irrigation and not treated with 1-MCP, thereafter; stored under 5.5˚C showed significant increase during day 2.

Moreover, fruit from full irrigation and treated with 300 ng/L 1-MCP, afterwards; stored under 5.5˚C showed low weight loss during ripening. Contrary, fruit from PRD irrigation and not treated with 1-MCP, thereafter; stored under 2.0˚C exhibited higher weight loss during ripening. Low weight loss was observed on fruits harvested from fully irrigated trees and treated with 300 ng\L 1-MCP, thereafter; stored under 2.0˚C.

Whereas, high weight loss was observed on fruit harvested from PRD irrigation trees and not treated with 1-MCP, and subsequently; stored under 5.5°C.

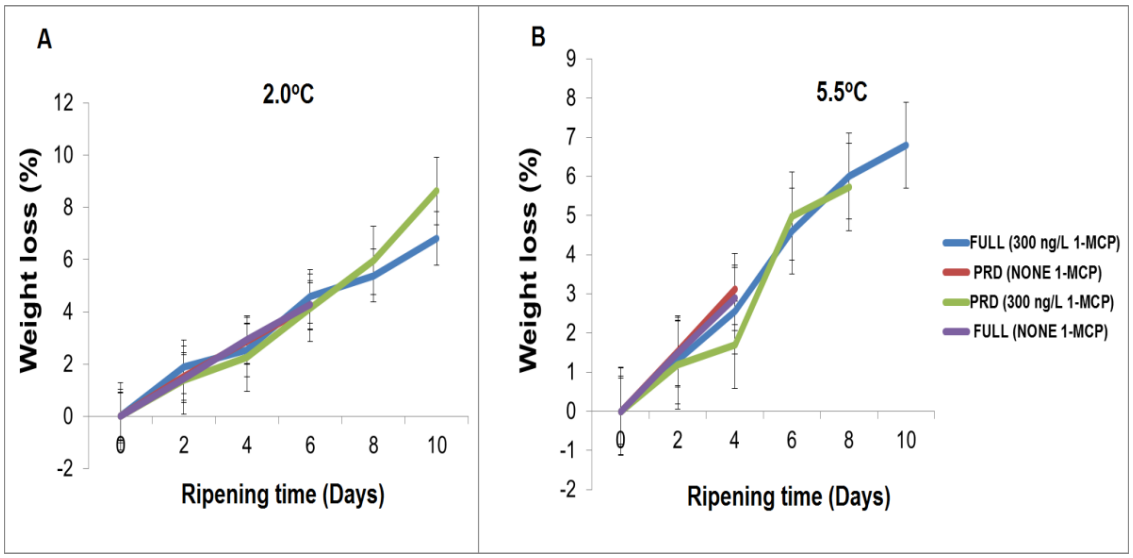

Figure 4.4: Effect of PRD, storage temperature [2.0°C (**A**) and 5.5°C (**B**)] and 1-MCP on weight loss of 'Hass' avocado fruit. Vertical bars are standard errors (se) below and above the mean.

4.1.6. Electrolyte leakage

Fruit harvested from fully irrigated tress and treated with 300 ng/L 1-MCP, thereafter; stored under 2.0°C showed high EC (12.92%). Whereas, fruit from PRD irrigated trees and not treated with 1-MCP, subsequently; stored under 5.5°C showed low EC (20.42%) (Figure 4.5). Furthermore, fruit from PRD irrigation and not treated with 1-MCP, afterwards; stored under 2.0°C showed low EC (23.64%). Contrary, fruit from full irrigation and treated with 300 ng/L 1-MCP, thereafter; stored under 5.5°C showed higher EC (10.32%).

Moreover, fruit harvested from PRD irrigated trees and treated with 300 ng/L 1-MCP, afterwards; stored under 2.0°C exhibited 12.22% EC. Whereas, fruit from full irrigation and not treated with 1-MCP, thereafter; stored under 5.5°C also showed similar EC value (15.13%). Furthermore, fruit from full irrigation and not treated with 1-MCP, afterwards; stored under 2.0°C showed high EC (17.04%). Contrary, fruit harvested from PRD irrigated trees and treated with 300 ng/L 1-MCP, subsequently; stored under 5.5°C showed low EC (9.26%).

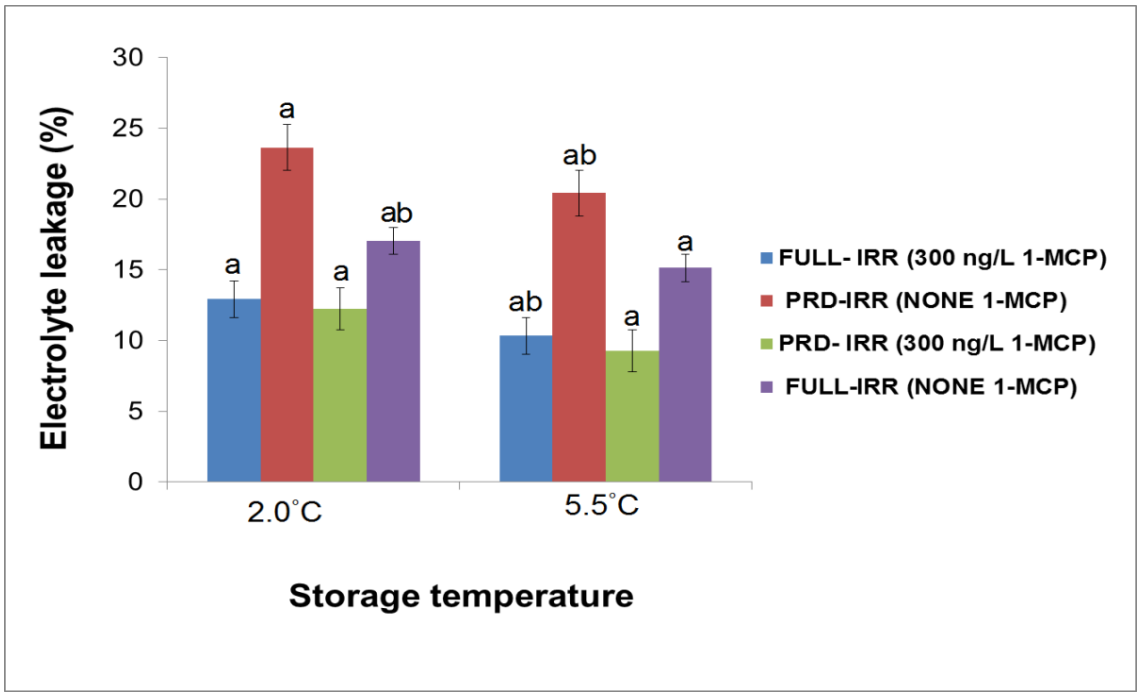

Figure 4.5: Effect of PRD, 1-MCP and storage temperature on electrolyte leakage of 'Hass' avocado fruit. Means with same letter do not differ significantly. Vertical bars are standard errors (se) below and above the mean.

4.1.7. External chilling injury

Fruit harvested from fully irrigated trees, not treated with 1-MCP, and subsequently; stored under 2.0˚C showed higher incidences of chilling injury (46.78 %). Whereas, fruit from PRD irrigation and treated with 300 ng/L 1-MCP, thereafter; stored under 5.5˚C showed no signs of chilling injury (0 %) (Table 4.2). Generally, fruit from PRD irrigated trees, treated with 300 ng/L 1-MCP, afterwards; stored under 2.0˚C showed no incidences of external chilling injury. Contrary, fruit from full irrigation and not treated with 1-MCP, thereafter; stored under 5.5˚C showed higher infestation of external chilling injury. Moreover, fruit from full irrigation and treated with 300 ng/L 1-MCP, subsequently; stored under 2.0˚C showed no incidence of chilling injury. While, fruit from PRD irrigation and not treated with 1-MCP, afterwards; stored under 5.5˚C exhibited higher external chilling injury. Chilling injury incidences were higher on fruit from PRD irrigation and not treated with 1-MCP, thereafter; stored under 2.0˚C. Whereas, fruit harvested from fully irrigated trees, treated with 300 ng/L 1-MCP, and subsequently; stored under 5.5˚C showed no chilling injury.

4.1.8. Vascular browning

Furthermore, fruit harvested from trees which were subjected to PRD irrigated trees, not treated with 1-MCP, and subsequently; stored under 2.0˚C showed manifestation of vascular browning incidences (6%). While, no incidences of vascular browning (0%) were observed on fruit from fully irrigated trees and treated with 300 ng/L 1-MCP, thereafter; stored under 5.5˚C (Table 4.2).

Generally, fruit harvested from fully irrigated trees and treated with 300 ng/L 1-MCP, afterwards; stored under 2.0˚C showed no incidences of vascular browning. Whereas, fruit from PRD irrigated trees, not treated with 1-MCP, and subsequently; stored under 5.5˚C higher incidences of vascular browning. Moreover, fruit from PRD irrigation and treated with 300 ng/L 1-MCP, afterwards; stored under 2.0˚C exhibited higher vascular browning incidences. Conversely, fruit from fully irrigated trees, not treated with 1-MCP, thereafter; stored under 5.5˚C showed low incidences of vascular browning. Lastly, fruit from full irrigation and not treated with 1-MCP, subsequently; stored under 2.0˚C showed low incidences of vascular browning. While, high incidences of vascular browning were observed on fruit from PRD irrigated trees, treated with 300 ng/L 1-MCP, afterwards; stored under 5.5˚C.

4.1.9. Body rot

Avocado fruit ‘Hass’ harvested from fully irrigated trees and treated with 300 ng/L 1-MCP, afterwards; stored under 2.0˚C showed no incidences of body rot (0%). Contrary, ‘Hass’ avocado fruit from PRD irrigation, not treated with 1-MCP, and subsequently; stored under 5.5˚C showed high incidences of body rot (13%) (Table 4.2). In general, fruit from PRD irrigation and not treated with 1-MCP, thereafter; stored under 2.0˚C showed no incidences of body rot. Similarly, fruit from full irrigation trees and treated with 300 ng/L 1-MCP, afterwards; stored under 5.5˚C also showed no incidences of body rot. Moreover, fruit harvested from PRD irrigated trees and treated with 300 ng/L 1-MCP, subsequently; stored under 2.0˚C showed higher incidences of body rot. Contrary, fruit from full irrigation, not treated with 1-MCP, thereafter; stored under 5.5˚C showed no incidences of body rot.

Fruit harvested from fully irrigated trees and not treated with 1-MCP, afterwards; stored under 2.0˚C showed not incidences of body rot. In similar fashion, fruit from PRD

irrigation, treated with 300 ng/L 1-MCP, and subsequently; stored under 5.5°C also showed no incidences of body rot.

4.1.10. Stem end-rot

Fruit harvested from fully irrigated trees, treated with 300 ng/L 1-MCP, and subsequently; stored under 2.0°C showed higher stem end-rot incidences (13%). Contrary, fruit from PRD irrigation and not treated with 1-MCP, thereafter; stored under 5.5°C showed no evidence of stem end-rot (0%) (Table 4.2). In general, fruit from PRD irrigation, not treated with 1-MCP, afterwards; stored under 2.0°C showed high manifestation of stem end-rot. Whereas, fruit from full irrigation and treated with 300 ng/L 1-MCP, thereafter; stored under 5.5°C had no stem end-rot incidences. Moreover, fruit from PRD irrigation and treated with 300 ng/L 1-MCP, subsequently; stored under 2.0°C exhibited low stem end-rot incidences. Contrary, higher incidences of stem end-rot were observed on fruit from full irrigation, not treated with 1-MCP, afterwards; stored under 5.5°C. Fruit harvested from fully irrigated trees, not treated with 1-MCP, and subsequently; stored under 2.0°C showed no evidence of stem end-rot. While, fruit from PRD irrigation and treated with 300 ng/L 1-MCP, thereafter; stored under 5.5°C exhibited higher incidences of stem end-rot.

Table 4.2: Effect of irrigation, 1-MCP and storage temperature on body rot, vascular browning and Stem end-rot.

Irrigation method	**1-MCP concentration (ng/L)**	**Storage temperature (˚C)**	**Diseases**			
			Physiological diseases (%)		Pathological diseases (%)	
			Chilling injury	Vascular browning	Body rot	Stem end-rot
Full irrigation	0	2.0	46.7b	0.0a	0.0a	0.0a
	300		0.0a	3.3a	0.0a	13.3abc
	0	5.5	3.3a	10.0a	0.0a	15.0abc
	300		0.0a	0.0a	0.0a	0.0ab
PRD	0	2.0	80.0c	6.7a	0.3a	5.0abc
	300		0.0a	16.7ab	6.7ab	5.0abc
	0	5.5	26.7bc	33.3b	13.3b	16.7ac
	300		0.0a	6.7a	0.0a	3.3abc

**Within a column, values with different letters are significantly different* at P ≤ 0.05*. Mean separation by Duncan's New Multiple Range Test (DNMRT).*

4.2. DISCUSSION

4.2.1. Effect of irrigation, 1-MCP and cold storage temperature on skin colour parameters (L*, C* and h^o)

Partial root-zone drying (PRD) is water saving technique which involves irrigating only half of the root-zone while leaving the other half of root-zone dry in each irrigation event (Sepaskhah and Ahmadi, 2010). The PRD treatment was found to advance fruit maturation, promote skin colour development and induce sugar translocation from the vegetative organs to fruit in crops like tomato (Haghighi *et al*., 2013), mango (Spree *et al*., 2007), grape (De la Hera *et al*., 2007) and apple (Zegbe *et al*., 2016). In addition, Francaviglia *et al*. (2013) found that PRD treatment improved peel colour and total soluble solid (TSS) of apple fruit 'Gala and Fuji' by modifying the tree canopy size and triggering the transfer of assimilates from the leaves to fruit.

In this study, the fruit lightness (L*), chroma (C*) and Hue (h^o) of the peel decreased over time, from an initial value of 36.9, 24.3 and 179.2, respectively, to final value of 22.2, 4.1 and 30.5, respectively. Fruit from PRD exhibited lower, although not significant, hue angle (h^o) when compared with fully irrigated. These fruit attained eye colour rating 5 which was 80% peel colour change from emerald green to purple, compared to full irrigated fruit which only reached eye colour of 4.6. Zegbe *et al*. (2007) and Haghighi *et al*. (2013) studied skin colour of tomato fruit 'Petopride' from PRD treated plants and found deep red colour (lower h^o). Avocado fruit 'Hass' colour development was found to be enhanced by increased anthocyanin, particularly, *cyanidin 3-O-glucoside* (Cox *et al*. 2004). Zarrouk *et al*. (2016) investigated the effect of water deficit on anthocyanin biosynthesis of 'Aragonez' grape and found colour to have improved due to increased anthocyanins. Similar results reported by Castellarin *et al*. (2007) on 'Merlot' grape fruit cultivar, whereby, the monomeric anthocyanin, particularly cyanidin-3-O-glucoside which is responsible for the red colouration was sensitive to endogenous abscisic acid (ABA), which was induced by water deficit conditions.

According to Watkins (2006), 1-MCP is an ethylene inhibitor which binds to the ethylene receptors of plant cells and slows down the metabolic and physiological changes which are related to ripening in various horticultural crops. While, cold storage temperature disrupts metabolic activities. Generally, colour development involves

activity of enzyme such as chlorophyll peroxidase involved in chlorophyll degradation of fruit skin (Yang *et al*., 2005). Studies have shown that ethylene enhances anthocyanin accumulation and chlorophyll degradation enzyme such as chlorophyllase (Cheng *et al*., 2012). In this present study, fruit that were treated with 1-MCP showed a delay in skin colour development, thereby retaining green colour during ripening (10 days). In avocado 'Hass' fruit, delayed skin colour development can be attributed to reduction in chlorophyllase enzyme activity, which regulates the loss of green colour (Hershkovitz *et al*., 2005). Moreover, fruit stored under 5.5°C showed skin colour improvement when compared with fruit stored under 2.0°C, these findings may be attributed to high storage temperature which enhances accumulation of anthocyanin (Severo *et al*., 2015). Kurubas and Erkan (2018) investigated effect of 1-MCP and cold storage temperature on 'Ankara' pears and found that pears treated with 1-MCP, thereafter; stored under cold storage temperature showed green colour retention when compared with untreated fruit. This study assumed that delay in colour development was due to prevention of ACC oxidase enzyme and led to inhibition of oxidation process to form ethylene from ACC (Adrian *et al*., 2015; Xuewen *et al*., 2011). Furthermore, delayed colour development can be attributed to inhibited loss of in chlorophyllase enzyme activity and anthocyanin biosynthesis, which regulates the loss of green colour (Hershkovitz *et al*., 2005; Severo *et al*., 2015).

4.2.2. Effect of irrigation, 1-MCP and cold storage temperature on fruit firmness

In this study, fruit firmness values decreased after withdrawal from low temperature storage, irrespective of irrigation methods. The avocado fruit 'Hass' harvested from PRD irrigation treatment had slightly lower firmness when compared with fully irrigated avocado trees. Spreer *et al*. (2009) also reported that partial root-zone drying significantly influenced 'Chok Anan' mango fruit quality parameters such as firmness when compared with full irrigation. Hakim *et al*. (2019) found that PRD treatment improved firmness of 'Vibelco' tomato through reducing plant growth; and therefore; inducing the transfer of assimilates from the leaves to fruit. Durovic *et al*. (2015) reported that firmness of 'Granny Smith' apples from PRD and deficit irrigation (DI) was lower when compared with fruit from fully irrigated trees, presumably due to reduction in cellular hydration (swelling) and increased flesh compactness (Wan Zaliha and Singh, 2009). Contrary, Zegbe *et al*. (2016) reported that 'Royal gala' apples harvested from PRD irrigated trees had higher firmness when compared with

fully/commercial irrigated trees; it may be assumed that, due to no water stress effect imposed on fruit apple fruit. Rosales *et al*. (2009) reported that water deficit enhances the solubilisation of cell wall pectin and reduce the concentration of calcium, which is responsible for maintenance of cell wall structure and fruit firmness (Hocking *et al*., 2016).

Furthermore, 1-MCP and cold storage temperature influenced 'Hass' avocado fruit firmness during ripening. The 1-MCP treated fruit stored under both 2.0˚C and 5.5˚C showed firmness retention when compared with untreated fruit stored under 2.0˚C and 5.5˚C. Mir *et al*. (2001) studied effect of 1-MCP and cold storage temperature on firmness retention and chlorophyll fluorescence of 'Redchief Delicious' apples and found that fruit treated with 1-MCP stored under >5˚C temperatures showed a higher firmness retention. Similarly, Daulagala and Daundasekera (2016) reported that softening of 'Hass' avocado fruit treated with 1-MCP and stored under tropical ambient conditions 27 (± 2˚C) was significantly delayed. These findings may be attributed to reduced activity of cell wall degrading enzymes (polygalacturonase and cellulase) in 'Simmonds' avocado fruit (Jeong *et al*., 2002). In addition, ripening days were also assumed to be associated with firmness loss and ethylene production (Taye *et al*., 2019). Softening of fruit exposed to 1-MCP and cold storage temperature slightly increased with ripening days; it may be assumed that, increased ethylene production enhanced pectin solubility, which caused rapid cell wall degradation of 'Hass' avocado fruit (Pedreschi *et al*. 2019).

4.2.3. Effect of irrigation, 1-MCP and cold storage temperature on fruit ripening percentage

In this study, irrigation showed significant difference in terms of ripening percentage during ripening. The ripening of climacteric fruit such as 'Hass' avocado is associated with a substantial rise in endogenous ethylene levels (Paul and Pandey, 2014). The accumulation of abscicic acid (ABA) occurs concomitantly with ethylene production and might be accompanied by increased amount of ethylene precursor; 1-aminocyclopropane carboxylic acid (ACC) (Sun *et al*., 2011; Torrigiani *et al*., 2012). The enhancement of fruit ripening has been attributed to increased ABA which induced ethylene production (Sun *et al*., 2017). Previous studies showed that an accumulation of ABA in grape berries 'Cabernet Sauvignon' and 'Chardonnay' was enhanced by abiotic stresses (Deluc *et al*., 2007; Deluc *et al*., 2009). According to Giuliani *et al*.

(2017), PRD irrigation application induced water stress which led to increased abscicic acid (ABA) synthesis in tomato fruit 'Ercole' and 'Genius'. An increase in ABA levels induced by pre-harvest water stress (PRD) in avocado tree might increase ethylene synthesis, subsequently; resulting to earlier ripening of avocado fruit (Blakey *et al*., 2009; Kassim *et al*., 2013). In current study, 'Hass' avocado fruit harvested from PRD irrigation had higher ripening percentage when compared with fruit from fully irrigated trees. Lo-Bianco *et al*. (2012) found that 'Pink Lady' apple fruit from PRD irrigation had more ethylene production when compared with fruit from full irrigation. Therefore, this study suggested that fruit ripening was influenced by ethylene production which was enhanced by ABA synthesis and accumulation during PRD irrigation on fruit trees (Kobashi *et al*., 2000).

Findings of the current study showed that the effect of 1-MCP (300 ng/L) and cold storage temperature (2.0 and 5.5˚C) was found to significantly delay avocado fruit ripening when compared with untreated fruit. It may be assumed that, ripening was delayed through suppression of ethylene action and inducing low enzyme activity by 1-MCP and cold storage temperature. Ahmad *et al*. (2013) reported that treatments with 1-MCP and cold storage temperature may extend the postharvest life of the papaya 'Sekaki' fruit through delaying ripening. Ripening of 'Trust' tomato fruit was delayed through use of 1-MCP treatment, probably due to 1-MCP bound with ethylene receptors to inhibit ethylene action (Tassoni *et al*., 2006). Furthermore, Hershkovitz *et al*. (2005) reported that 1-MCP treated avocado fruit 'Ettinger', 'Hass' and 'Pinkerton stored under 5.0˚C delayed ripening, due to irreversible binding to ethylene receptors in tissues (Agarwal *et al*., 2012). In addition, the ripening of 'Florida 47' tomato fruit was delayed by 1-MCP application and 1-MCP treated fruit were tolerant to rigours of shipping better than none treated fruit (Huber *et al*., 2003). The current study determined that, avocado fruit treated with 1-MCP and stored at 2.0 and 5.5˚C showed delayed ripening up to 10 days when compared with untreated fruit which only delayed ripening by 6 days. This study suggested that an increase in ripening of fruit from PRD was due to increased ethylene production which was enhanced by ABA synthesis and accumulation during partial water-stress (Kobashi *et al*., 2000). Moreover, delay in ripening was due to 1-MCP, which bound with ethylene receptors in order to reduce metabolic activities of the fruit, and low temperature storage, which reduced activities of metabolic enzymes (Matthew *et al*., 2005).

4.2.4. Effect of irrigation, 1-MCP and cold storage temperature on fruit respiration rate

Findings of the current study showed that the effect of irrigation, 1-MCP and cold storage temperature on avocado fruit 'Hass' respiration was investigated. In terms of irrigation, fruit from PRD irrigated trees had higher respiration rate (± 3500 µmol CO_2 Kg^{-1} hr^{-1}) when compared with respiration rate (± 2500 µmol CO_2 Kg^{-1} hr^{-1}) of fruit from fully irrigated trees. Leib *et al*. (2006) found similar results for 'Fuji' apple, whereby; the respiration rate of fruit harvested from PRD irrigated trees showed higher respiration rate when compared with fruit from fully irrigated trees. Increased ABA concentrations induced by water stress (PRD) in 'Hass' avocado tree might increase enhance precursor (1-aminocyclopropane carboxylic acid) which is responsible for ethylene biosynthesis, increased ethylene synthesis might cause subsequent earlier ripening of avocado fruit (Kassim *et al*., 2013; Sun *et al*., 2011; Torrigiani *et al*., 2012). Koziskova and Goliáš (2012) associated increased respiration with ethylene production in 'Jojo' plum fruit. This study assumes that an increase in respiration of 'Hass' avocado fruit harvested from PRD irrigation might be due to increased ethylene production, which was enhanced as a result of ABA synthesis (Kassim *et al*., 2013).

Avocado fruit 'Hass' respiration rate may be reduced through use of postharvest treatments such as 1-MCP and cold storage temperature (Kok, 2011). Xuan and Streif (2014) reported that 1-MCP reduced ethylene production and respiration rate of 'Jonagold' apple fruit stored under controlled atmosphere. Moreover, Wrzodak and Gajewski (2015) conducted a study on effect of 1-MCP treatment and storage potential of 'Faustine' tomato fruit and found fruit treated with 1-MCP had reduced respiration rate when compared with untreated fruit. Saquet *et al*. (2003) suggested that a decrease in fruit respiration induced by 1-MCP might be due to suppressed activities of adenosine triphosphate (ATP) The ATP was found to be responsible for maintenance of cellular functions, including repair mechanisms of cell membranes and the ripening of fruit (Saquet *et al*., 2003).

With respect to low storage temperature, Getinet *et al*. (2011) reported that low temperature storage reduced 'Roma VF' tomato respiration rate and ethylene production due to retarded metabolic rate. The current results showed that 'Hass' avocado fruit treated with 1-MCP, thereafter; stored under both 2.0 and 5.5˚C had low and uneven pattern of respiration rate during ripening. Whereas, untreated fruit stored under both 2.0 and 5.5˚C had higher and systematic respiration rate. Higher

respiration rate may be due to an increase in chemical reaction characterised by conversion of sugar (C_6 H_{12} O_6) and oxygen (O_2) to form carbon dioxide (CO_2) and water (H_2O) (Getinet *et al*., 2011). Furthermore, low respiration rate may be due to reduced ethylene production caused by application of 1-MCP and low temperature storage, as a result reduced metabolic activities (Kok, 2011).

4.2.5. Effect of irrigation, 1-MCP and cold storage temperature on fruit weight loss

Fruit weight loss mainly consists of moisture loss through transpiration and to a lesser degree, carbon dioxide loss through fruit respiration (Maguire *et al*., 2001). There was no significant effect of irrigation, 1-MCP and cold storage temperature on fruit weight loss and therefore, results for both 2.0 and 5.5˚C were presented. Fruit weight loss decreased during ripening for all treatments. Moreover, fruit weight loss for fruit from PRD tree was not significantly different from that from full irrigated tree. Previous work has shown that PRD irrigation have no significant effect on fruit weight loss. Zegbe *et al*. (2007) investigated effect PRD and storage temperature (13-18˚C for 18 days) on 'Golden Delicious' apples and found that PRD had no significant effect on fruit weight loss. Moreover, the effect of deficit irrigation (DI) was investigated on 'Braeburn' apple fruit; whereby, no differences were observed on fruit weight loss (Maguire *et al*., 2001). Similarly, pomegranate fruit 'Mollar de Elche' showed non-significant weight loss of fruit from deficit irrigation and from fully irrigated trees (Intrigliolo *et al*., 2013). Contrary, weight loss of 'Valencia' orange fruit from deficit irrigation was higher than that of fruit from fully irrigated trees (Hamdy *et al*., 2017). Therefore, this study assumed that an increase in fruit weight loss may be due to respiration and transpiration of water through peel tissue which was affected by storage temperature other than irrigation (Maguire *et al*., 2001).

In this study, 1-MCP treatment (300 ng/L) and cold storage temperature (2.0 and 5.5˚C) showed significant effect in weight loss. These findings agree with Daulagala and Daundasekera (2016), who reported that 1-MCP and storage temperature (27± 2˚C) retained weight of 'Pollock' avocado fruit during ripening. Similarly, Taye *et al*. (2019) investigated effect of 1-MCP on 'Unicorn' tomato and found that fruit treated with 1-MCP showed lower weight loss when compared to untreated. The untreated fruit increased in ethylene synthesis, eventually increased fruit respiration rate, hence; increased the rate of water loss which resulted in fruit weight loss (Bartz and Brecht, 2003). Moreover, 1-MCP was found to reduce rate of weight loss on 'Kensington'

mango (Hofman *et al*., 2001) and 'Hass' avocado (Lemmer *et al*., 2002) through delaying the onset of respiratory climacteric. Therefore, this study suggested that reduction in weight loss rate of fruit treated with 1-MCP might have attributed to slow respiration rate and maintenance of tissue rigidity of the fruit (Dong *et al*., 2002).

4.2.6. Effect of irrigation, 1-MCP and cold storage temperature on electrolyte leakage (EL)

Electrolyte leakage was used to assess the effect of irrigation, 1-MCP and cold storage temperature fruit membrane permeability. Avocado 'Hass' fruit harvested from partial root-zone drying (PRD) and full irrigated trees showed significant differences in EL after withdrawal from both cold storage temperatures. Avocado fruit 'Hass' harvested from PRD irrigated trees showed higher electrolyte leakage (9-23%) when compared with fruit harvested from fully irrigated trees, which showed lower EL (10-17%). Hershkovitz *et al*. (2009) reported that increased chilling injury coincided with increased electrolyte leakage avocado fruit 'Arad' and 'Ettinger'. These findings were in agreement with the results of current study, whereby; chilling injury was found to be higher on fruit harvested from PRD irrigated trees when compared with fully irrigated trees. White and Broadly (2003) stated that calcium is important in strengthening membrane structures, therefore; low calcium levels caused weaker cell membranes making fruit more susceptible to physiological disorders. Therefore, this study assumes that increased EL under PRD irrigation was induced by low calcium, which led to weak cell membrane and higher permeability of the membranes that increased electrolyte leakage (Dorria *et al*., 2010).

Li *et al*. (2011) investigated the efficacy of 1-MCP on hami melon fruit 'Zaohuangmi' and found that 1-MCP inhibited the increase of electrolyte leakage (EL), and assumed it was due to delayed climacteric ethylene production. In 'Hass' avocado fruit, electrolyte leakage highly correlated with chilling injury after 46 days of storage at 6°C (Biswas *et al*., 2012). In this study, 'Hass' avocado fruit harvested from both PRD and fully irrigated trees, treated with 1-MCP, thereafter; stored under both 2.0 and 5.5°C had lower electrolyte leakage (9.62-12.92%) when compared with fruit which were not treated with 1-MCP (23.64-15.13%). It may be assumed that, 1-MCP suppressed 1-aminocyclopropane-1-carboxylic acid (ACC) oxidase activity with the result that low ACC converted to ethylene, therefore; ACC content remains at the control level (Minas *et al*., 2018). Generally, both 1-MCP treated and untreated 'Hass' avocado fruit stored

under 2.0°C had higher EL than fruit stored under 5.5°C. it may be assumed that, increased electrolyte leakage of fruit is associated with loss of plasma membrane integrity of cells during cold storage (Gonzalez-Aguilar *et al*., 2000). Moreover, low storage temperature at 5.0°C enhances ACC-oxidase activity of 'Sanuki Gold' Kiwi fruit (Mworia *et al*., 2012).

4.2.7. Effect of irrigation, 1-MCP and cold storage temperature on vascular browning (VB) and external chilling injury (CI)

The combination of irrigation, 1-MCP and cold storage temperature had no significant effect on both vascular browning and chilling injury. The occurrence of both VB and CI significantly increased during ripening, and results were reported for fully ripe fruit at day 4 and 8 for all treatments. At fully ripe fruit from PRD recorded the highest incidences of both VB (33%) and CI (80%) when compared with VB (10%) and CI (46%) from fully irrigated treatment. These findings were in agreement with others Zegbe *et al*. (2006) and White and Broadly, (2003) fruit from PRD were highly prone to physiological disorders when compared with fruit from fully irrigation. It was previously postulated by White and Broadley (2003), that PRD irrigation had the ability to decrease water uptake accordingly and reduced calcium uptake leading to low Ca accumulation in the fruit tissues (mesocarp and peel). Calcium is fundamental to controlling or preventing pathological disorders, Ca achieve its action by strengthening the cell wall and membrane structure. Therefore, low available in the cell wall and membrane makes fruit susceptible to VB and CI physiological disorders (White and Broadly, 2003).

The application of postharvest treatments such as 1-MCP and cold storage temperature was effective in preventing the occurrence of physiological disorders. In this study, application of both 300 ng/L 1-MCP and cold storage temperature (2.0 and 5.5°C) suppressed physiological disorders on 'Hass' avocado fruit. Fruit not treated with 1-MCP and stored at 2.0 and 5.5°C showed high incidences of physiological disorders. It may be assumed that, 1-MCP inhibited the action of ethylene which was highly associated with physiological disorders as it was previously shown by Moo-huchin *et al*. (2013). Similar findings were reported by Woolf *et al*. (2005), who applied 50–1000 nL L^{-1} 1-MCP and stored 'Hass' avocado fruit under 5.5°C temperature for 4-5 weeks, and found that 1-MCP reduced physiological disorders (vascular browning and chilling injury). Furthermore, avocado fruit 'Hass' stored for longer than about 4

weeks under cold storage temperature without any 1-MCP treatment experienced internal diffuse flesh discoloration (Woolf *et al*., 2005). Moo-huchin *et al*. (2013) found that 1-MCP and cold storage temperature reduced incidences of internal and external chilling injury in sapodilla fruit 'Royen' (*Manilkara zapota*), assumed that 1-MCP effectively delayed ethylene production associated with chilling injury development.

Moreover, low temperature storage (2.0°C) disrupted the balance between anti-oxidants and reactive oxygen species (ROS) damaging compounds for 'Hass' avocado fruit, as a result damaged cell membrane of fruit (Tesfay *et al*., 2010). Anti-oxidants are responsible for scavenge reactive oxygen species (ROS) and maintain the balance between antioxidants and ROS in order to allow normal metabolism to continue (Gao *et al*., 2015). The application of 1-MCP treatment could reduce ROS accumulation in fruit during storage by improving the activities of superoxide dismutase (SOD) and catalase (CAT), which potent enzymatic antioxidants responsible for scavenging ROS (Feng *et al*., 2018). According to Dong *et al*. (2015), 1-MCP inhibited the lipid peroxidation of cell membrane and further contributed to alleviate oxidation damage on cell membranes during 'Yali' pear fruit storage.

4.2.8. Effect of irrigation, 1-MCP and cold storage temperature on body rot and stem end-rot (pathological diseases)

In this study, irrigation had no significant effect (P>0.05) on body rot and stem end-rot of 'Hass' avocado fruit. However, avocado 'Hass' fruit harvested from partial root-zone drying (PRD) and fully irrigated trees showed differences with regard to incidences of pathological diseases. In this study, comprehensible higher incidences of body rot (0.3-13.3%) and stem end-rot (5.0-16.7%) were observed on fruits harvested from partial root-zone drying (PRD) irrigated trees when compared with body rot (0.0%) and stem end-rot (0.0-15.0%) of fruit harvested from fully irrigated trees. Presumably, PRD treatment has the ability to reduce fruit calcium concentration and to some extend reduce cell wall and membrane stability making fruit vulnerable to pathogen attack (Hocking *et al*., 2016). Zegbe *et al*. (2006) found that 'Petopride' tomato fruit harvested from PRD irrigated plants showed higher incidences of blossom-end rot and body rot when compared with fully irrigated tomato plants, due to low calcium concentration. Present results suggest that PRD treatment was ineffective for controlling or preventing the incidence of pathological diseases which manifest during ripening.

In other studies, 1-MCP and cold storage temperature have been shown to suppress and prevent the development of pathological diseases such as body rot and stem end-rot (Galsurker *et al*., 2018). Recently, it was found that 1-MCP treatment reduced fungal pathogen rot in 'Huping' Indian jujube (Zhang *et al*., 2012) and 'Fuerte' avocado fruit (Diskin *et al*., 2015). It was also observed that storage temperature above 6˚C increases the occurrence of pathological diseases in 'Hass' avocado fruit (Perkins *et al*., 2020). The present study found that 'Hass' avocado fruit treated with 300 ng/L 1-MCP, thereafter; stored under both 2.0 and 5.5˚C resulted in lower incidences of pathological diseases when compared with untreated fruit. This suggest that application of 1-MCP prevented pathogenic fungus from colonizing the phloem and xylem of the fruit stem-end, the mechanism behind prevention is not yet well documented (Galsurker *et al*., 2018). Similar results were reported by Daulagala and Daundasekera (2016), whereby; the effect of 1-MCP treatment on postharvest quality of avocado 'Pollock' under 27±2˚C storage.

Cold storage temperature has already shown to delay and control occurrence of pathological diseases manifesting as 'Hass' avocado fruit ripen. Previous work has shown that 'Hass' avocado fruit stored at 5.5˚C promoted occurrence of pathological disease when compared with storage at 1.0˚C (Blakey *et al*., 2014). It is recognised that higher ripening temperature of >5.0˚C create conducive environment for colonization and manifestation of pathological disease (Leandro *et al*. 2003). Presently, results have shown that storage at 5.5˚C was favourable and further promoted development of pathological disease; it is in accordance after ripening fruit stored at 5.5˚C had higher body rot (13.3%) and stem end rot (16.7%) when compared with fruit stored at 2.0˚C with lower body rot (6.7%) and stem-end rot (5.0%).

CHAPTER 05
SUMMARY AND CONCLUSION

The application of irrigation, 1-MCP and cold storage temperature as treatments showed effect on physico-chemical properties of 'Hass' avocado fruit. Partial root-zone drying irrigation increased hue angle of 'Hass' avocado fruit. Moreover, 300ng/L 1-MCP treatment delayed fruit eye colour change when compared with untreated fruit. Cold storage temperature didn't significantly affect fruit colour. Firmness of fruit from

PRD irrigated trees was lower, whereas fruit ripening percentage was higher when compared with fruit harvested from fully irrigated trees. In addition, 300ng/L 1-MCP and low storage temperature (2.0˚C) delayed fruit firmness and ripening when compared with untreated fruit stored under both 2.0 and 5.5˚C.

Respiration was found to be higher on fruit from PRD irrigated trees when compared with fruit from fully irrigated trees. The application of both 1-MCP and low storage temperature reduced fruit respiration when compared with untreated fruit stored at both 2.0 and 5.5˚C. Irrigation method had no significant effect on weight loss of 'Hass' avocado fruit, however; 1-MCP and low storage temperature (2.0˚C) delayed fruit weight loss when compared with untreated fruit stored under both 2.0˚C and 5.5˚C. The pathological diseases and physiological disorders were not significantly affected by irrigation. However, 1-MCP and low storage temperature suppressed development of pathological diseases and physiological disorders. The electrolyte leakage (EL) of fruit was found to be higher on fruit from PRD irrigated trees when compared with fully irrigated trees. Moreover, 1-MCP and low storage temperature reduced EL in 'Hass' avocado fruit.

The application of PRD has been proven that it is effective and efficient on commercial scale. However, the chemical mechanisms involved on the plant during application of PRD negatively affect some of the fruit properties. For instance, the abscicic acid (ABA) enhances ethylene production which leads to early fruit ripening, disorders and softening to state the least. Therefore, more studies should be carried out in order to find a way to control the amount and mechanism ABA during the application of PRD. After harvest fruit must be treated with 1-MCP to prolong storage life.

In conclusion, PRD irrigation system improved fruit colour. Moreover, application of 1-MCP and low storage temperature has improved the storage-life of fruit through delaying metabolic process, biological process and physiological process of the fruit. Therefore, fruit quality was generally maintained by combination of these three factors viz; irrigation, 1-MCP and low storage temperature.

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APPENDICES

Appendix 1: Analysis of variance (ANOVA) for peel lightness (L) during ripening.

Source of variation	DF	(m.v.)	SS	M S	F	P
Replication	5		84.700	16.940	7.13	
Irrigation	1		19.498	19.498	8.21	0.005
1-MCP	1		243.450	243.450	102.51	<.001
Temperature	1		6.951	6.951	2.93	0.089
Ripening days	5		7048.032	1409.606	593.56	<.001
Irrigation*1-MCP	1		3.169	3.169	1.33	0.250
Irrigation*temperature	1		0.353	0.353	0.15	0.700
1-MCP*temperature	1		14.960	14.960	6.30	0.013
Irrigation*ripening days	5		26.583	5.317	2.24	0.052
1-MCP*ripening days	3	(2)	178.464	59.488	25.05	<.001
Temperature*ripening days	5		79.476	15.895	6.69	<.001
Irrigation*1-MCP*temperature	1		43.552	43.552	18.34	<.001
Irrigation*1-MCP*ripening days	3	(2)	16.915	5.638	2.37	0.072
Irrigation*temperature*ripening days	4	(1)	55.796	13.949	5.87	<.001
1-MCP*temperature*ripening days	2	(3)	4.714	2.357	0.99	0.373
Irrigation*1-MCP*temperature*ripening days	2	(3)	3.371	1.685	0.71	0.493
Residual	180	(55)	427.470	2.375		
Total	221	(66)				

Appendix 2: Analysis of variance (ANOVA) for chroma (C) during ripening.

Source of variation	DF	(m.v.)	SS	M S	F	P
Replication	5		948.0	189.6	0.52	
Irrigation	1		1175.1	1175.1	3.24	0.074
1-MCP	1		315.4	315.4	0.87	0.352
Temperature	1		26.9	26.9	0.07	0.785
Ripening days	5		15722.7	3144.5	8.67	<.001
Irrigation*1-MCP	1		117.0	117.0	0.32	0.571
Irrigation*temperature	1		92.8	92.8	0.26	0.613
1-MCP*temperature	1		793.4	793.4	2.19	0.141
Irrigation*ripening days	5		1207.9	241.6	0.67	0.650
1-MCP*ripening days	3	(2)	2234.0	744.7	2.05	0.108
Temperature*ripening days	5		1422.9	284.6	0.78	0.562
Irrigation*1-MCP*temperature	1		2155.6	2155.6	5.94	0.016
Irrigation*1-MCP*ripening days	3	(2)	2259.9	2155.6	2.08	0.105
Irrigation*temperature*ripening days	4	(1)	1816.7	454.2	1.25	0.291
1-MCP*temperature*ripening days	2	(3)	489.4	244.7	0.67	0.511
Irrigation*1-MCP*temperature*ripening days	2	(3)	653.7	326.8	0.90	0.408
Residual	180	(55)	65280.1	362.7		

Total	221	(66)	89203.7			

Appendix 3: Analysis of variance (ANOVA) for hue (h^o) during ripening.

Source of variation	**DF**	**(m.v.)**	**SS**	**M S**	**F**	**P**
Replication	5		3928.6	785.7	3.27	
Irrigation	1		1367.8	1367.8	5.69	0.018
1-MCP	1		143701.2	143701.2	597.67	<.001
Temperature	1		82.6	82.6	0.34	0.558
Ripening days	5		835323.0	167064.6	694.84	<.001
Irrigation*1-MCP	1		44.3	44.3	0.18	0.668
Irrigation*temperature	1		1240.1	1240.1	5.16	0.024
1-MCP*temperature	1		0.3	0.3	0.00	0.974
Irrigation*ripening days	5		4419.0	883.8	3.68	0.003
1-MCP*ripening days	3	(2)	13050.8	4350.3	18.09	<.001
Temperature*ripening days	5		6923.2	1384.6	5.76	<.001
Irrigation*1-MCP*temperature	1		67.7	67.7	0.28	0.596
Irrigation*1-MCP*ripening days	3	(2)	239.1	79.7	0.33	0.803
Irrigation*temperature*ripening days	4	(1)	6316.6	1579.1	6.57	<.001
1-MCP*temperature*ripening days	2	(3)	614.1	307.1	1.28	0.281
Irrigation*1-MCP*temperature*ripening days	2	(3)	396.8	198.4	0.83	0.440

Residual	180	(55)	43278.5	240.4
Total	221	(66)		

Appendix 4: Analysis of variance (ANOVA) for fruit skin eye colour during ripening.

Source of variation	**DF**	**(m.v.)**	**SS**	**M S**	**F**	**P**
Replication	5		3.2245	0.6449	2.78	
Irrigation	1		0.9919	0.9919	4.27	0.040
1-MCP	1		47.0387	47.0387	202.46	<.001
Temperature	1		0.2573	0.2573	1.11	0.294
Ripening days	5		889.7574	177.9515	765.92	<.001
Irrigation*1-MCP	1		0.0987	0.0987	0.42	0.515
Irrigation*temperature	1		1.0704	1.0704	4.61	0.033
1-MCP*temperature	1		0.0280	0.0280	0.12	0.729
Irrigation*ripening days	5		2.2217	0.4443	1.91	0.094
1-MCP*ripening days	3	(2)	17.2479	5.7493	24.75	<.001
Temperature*ripening days	5		8.0493	1.6099	6.93	<.001
Irrigation*1-MCP*temperature	1		0.0384	0.0384	0.17	0.685
Irrigation*1-MCP*ripening days	3	(2)	0.6382	0.2127	0.92	0.435
Irrigation*temperature*ripening days	4	(1)	4.0496	1.0124	4.36	0.002
1-MCP*temperature*ripening days	2	(3)	0.8689	0.4344	1.87	0.157

Irrigation*1-MCP*temperature*ripening days	2	(3)	0.2439	0.1219	0.52	0.593
Residual	180	(55)	41.8209	0.2323		
Total	221	(66)	615.7550			

Appendix 5: Analysis of variance (ANOVA) for fruit firmness loss % during ripening.

Source of variation	**DF**	**(m.v.)**	**SS**	**M S**	**F**	**P**
Replication	5		1000.37	200.07	7.04	
Irrigation	1		208.70	208.70	7.34	0.007
1-MCP	1		12.78	12.78	0.45	0.503
Temperature	1		22.68	22.68	0.80	0.373
Ripening days	5		154965.99	30993.20	1090.73	<.001
Irrigation*1-MCP	1		369.33	369.33	13.00	<.001
Irrigation*temperature	1		63.43	63.43	2.23	0.137
1-MCP*temperature	1		372.29	372.29	13.10	<.001
Irrigation*ripening days	5		122.84	24.57	0.86	0.506
1-MCP*ripening days	3	(2)	28084.90	9361.63	329.46	<.001
Temperature*ripening days	5		334.41	66.88	2.35	0.042
Irrigation*1-MCP*temperature	1		5.17	5.17	0.18	0.670
Irrigation*1-MCP*ripening days	3	(2)	111.76	37.25	1.31	0.272

Irrigation*temperature*ripening days	4	(1)	344.71	86.18	3.03	0.019
1-MCP*temperature*ripening days	2	(3)	235.00	117.50	4.14	0.018
Irrigation*1-MCP*temperature*ripening days	2	(3)	17.30	8.65	0.30	0.738
Residual	180	(55)	5114.72	28.42		
Total	221	(66)	133277.71			

Appendix 6: Analysis of variance (ANOVA) for ripening percentage during ripening.

Source of variation	**DF**	**(m.v.)**	**SS**	**M S**	**F**	**P**
Replication	5		1611.9	322.4	2.27	
Irrigation	1		263.8	263.81.86	0.175	
1-MCP	1		52385.3	52385.3	368.80	<.001
Temperature	1		18178.7	18178.7	127.98	<.001
Ripening days	5		137935.9	27587.2	194.22	<.001
Irrigation*1-MCP	1		295.7	295.7	2.08	0.151
Irrigation*temperature	1		301.4	301.4	2.12	0.147
1-MCP*temperature	1		4494.3	4494.3	31.64	<.001
Irrigation*ripening days	5		750.0	150.0	1.06	0.387
1-MCP*ripening days	3	(2)	49137.1	16379.0	115.31	<.001
Temperature*ripening days	5		44178.9	8835.8	62.21	<.001
Irrigation*1-MCP*temperature	1		185.0	185.0	1.30	0.255
Irrigation*1-MCP*ripening days	3	(2)	275.8	91.9	0.65	0.586
Irrigation*temperature*ripening days	4	(2)	486.4	162.1	1.14	0.334

1-MCP*temperature*ripening days	2	(3)	13153.1	6576.5	46.30	<.001
Irrigation*1-MCP*temperature*ripening days	2	(3)	283.8	141.9	1.00	0.370
Residual	175	(60)				
Total	215	(72)	191109.3			

Appendix 7: Analysis of variance (ANOVA) for respiration rate during ripening.

Source of variation	**DF**	**(m.v.)**	**SS**	**M S**	**F**	**P**
Replication	5		123008	24602	0.80	
Irrigation	1		363195	363195	11.77	<.001
1-MCP	1		92936765	92936765	3012.71	<.001
Temperature	1		28227000	28227000	915.03	<.001
Ripening days	5		36792374	7358475	238.54	<.001
Irrigation*1-MCP	1		440414	440414	14.28	<.001
Irrigation*temperature	1		1355490	1355490	43.94	<.001
1-MCP*temperature	1		30707930	30707930	995.45	<.001
Irrigation*ripening days	5		2996626	599325	19.43	<.001
1-MCP*ripening days	3	(2)	35220951	11740317	380.58	<.001
Temperature*ripening days	5		19847358	3969472	128.68	<.001
Irrigation*1-MCP*temperature	1		1722223	1722223	55.83	<.001
Irrigation*1-MCP*ripening days	3	(2)	2956173	985391	31.94	<.001

Irrigation*temperature*ripening days	4	(1)	71001	17750	0.58	0.681
1-MCP*temperature*ripening days	2	(3)	18266980	9133490	296.08	<.001
Irrigation*1-MCP*temperature*ripening days	2	(3)	248727	124364	4.03	0.019
Residual	180	(55)	5552681	30848		
Total	221	(66)	233417730			

Appendix 8: Analysis of variance (ANOVA) for fruit weight loss % during ripening.

Source of variation	**DF**	**(m.v.)**	**SS**	**M S**	**F**	**P**
Replication	5		6.9581	1.3916	2.64	
Irrigation	1		4.3553	4.3553	8.26	0.005
1-MCP	1		0.1883	0.1883	0.36	0.551
Temperature	1		0.2678	0.2678	0.51	0.477
Ripening days	5		1800.6081	360.1216	683.29	<.001
Irrigation*1-MCP	1		2.4058	2.4058	4.56	0.034
Irrigation*temperature	1		0.5222	0.5222	0.99	0.321
1-MCP*temperature	1		0.2497	0.2497	0.47	0.492
Irrigation*ripening days	5		19.9676	3.9935	7.58	<.001
1-MCP*ripening days	3	(2)	8.9532	2.9844	5.66	<.001
Temperature*ripening days	5		7.1320	1.4264	2.71	0.022
Irrigation*1-MCP*temperature	1		0.1226	0.1226	0.23	0.630
Irrigation*1-MCP*ripening days	3	(2)	1.5788	0.5263	1.00	0.395
Irrigation*temperature*ripening days	4	(1)	9.2122	2.3031	4.37	0.002

1-MCP*temperature*ripening days	2	(3)	1.1174	0.5587	1.06	0.349
Irrigation*1-MCP*temperature*ripening days	2	(3)	2.0538	1.0269	1.95	0.145
Residual	180	(55)	94.8677	0.5270		
Total	221	(66)	1287.5137			

Appendix 9: Analysis of variance (ANOVA) for body rot % during ripening.

Source of variation	**DF**	**SS**	**M S**	**F**	**P**
Replication	5	804.81	160.96	2.33	
Irrigation	1	260.09	260.09	3.77	0.059
1-MCP	1	12.80	12.80	0.19	0.669
Temperature	1	60.67	60.67	0.88	0.354
Irrigation*1-MCP	1	59.59	59.59	0.86	0.358
Irrigation*temperature	1	15.84	15.84	0.23	0.635
1-MCP*temperature	1	220.84	220.84	3.20	0.081
Irrigation*1-MCP*temperature	1	364.09	364.09	5.27	0.027
Residual	41	2831.85	69.07		
Total	53	4630.59			

Appendix 10: Analysis of variance (ANOVA) for vascular browning % during ripening.

Source of variation	DF	SS	M S	F	P
Replication	5	2564.8	513.0	2.53	
Irrigation	1	1973.7	1973.7	9.72	0.003
1-MCP	1	330.0	330.0	1.62	0.210
Temperature	1	488.9	488.9	2.41	0.128
Irrigation*1-MCP	1	85.5	85.5	0.42	0.520
Irrigation*temperature	1	66.1	66.1	0.33	0.571
1-MCP*temperature	1	1684.0	1684.0	8.29	0.006
Irrigation*1-MCP*temperature	1	533.9	533.9	2.63	0.113
Residual	41	8326.9	203.1		
Total	53	16053.7			

Appendix 11: Analysis of variance (ANOVA) for chilling injury (CI) % during ripening.

Source of variation	DF	SS	M S	F	P
Replication	5	941.7	188.3	0.66	
Irrigation	1	2408.3	2408.3	8.38	0.006
1-MCP	1	18408.3	18408.3	64.06	<.001
Temperature	1	7008.3	7008.3	24.39	<.001
Irrigation*1-MCP	1	2408.3	2408.3	8.38	0.006
Irrigation*temperature	1	75.0	75.0	0.26	0.613
1-MCP*temperature	1	7008.3	7008.3	24.39	<.001
Irrigation*1-MCP*temperature	1	75.0	75.0	0.26	0.613
Residual	35	10058.3	287.4		
Total	47	48391.7			

Appendix 12: Analysis of variance (ANOVA) for stem end-rot % during ripening.

Source of variation	DF	SS	M S	F	P
Replication	5	1370.4	274.1	2.12	
Irrigation	1	9.3	9.3	0.07	0.790
1-MCP	1	189.4	189.4	1.46	0.233
Temperature	1	91.2	91.2	0.70	0.406
Irrigation*1-MCP	1	77.1	77.1	0.60	0.444
Irrigation*temperature	1	73.3	73.3	0.57	0.456
1-MCP*temperature	1	1285.7	1285.7	9.94	0.003
Irrigation*1-MCP*temperature	1	125.0	125.0	0.97	0.331
Residual	41	5304.6	129.4		
Total	53	8525.9			

Appendix 13: Analysis of variance (ANOVA) for electrical conductivity (EC) % during ripening.

Source of variation	DF	SS	M S	F	P
Replication	5	16.107	3.221	0.45	
Irrigation	1	58.858	58.858	8.16	0.007
1-MCP	1	9.127	9.127	1.27	0.268
Temperature	1	10.263	10.263	1.42	0.241
Irrigation*1-MCP	1	33.071	33.071	4.58	0.039
Irrigation*temperature	1	65.386	65.386	9.06	0.005
1-MCP*temperature	1	41.385	41.385	5.74	0.022
Irrigation*1-MCP*temperature	1	3.187	3.187	0.44	0.511
Residual	35	252.491	7.214		
Total	47	489.876			