

ABSTRACT

A laboratory experiment was undertaken to investigate the effects of storage temperature on storage life and quality of mangoes. The mango fruit cultivars Tommy Atkins, Haden, Kent and Keitt were used for the study in a completely randomized experimental design. The storage temperatures were 5, 8, 10 and 12°C. The results of the study showed that storage temperature and mango cultivars significantly ($P \leq 0.01$) affected the incidence and severity of chilling injury in mango. Chilling injury developed in all the mango cultivars under study stored at temperatures of $\leq 12^\circ\text{C}$, though the severity significantly ($P \leq 0.01$) varied with cultivar. The mango cultivars stored well for 7 weeks at 12°C without the development of physiological disorders and after storage, the fruit underwent normal ripening process with colour (carotenoids and anthocyanins) development, high total soluble solids and low titratable acidity. It was concluded that in order to extend the shelf-life and marketing period of mango, the fruit should be stored at 12°C and 90-95%RH, because the fruit will not suffer from chilling injury and will undergo normal ripening process. For the mango cultivar Kent, it could initially be stored at 10°C for 3 weeks and then transferred to 12°C, this will extend the shelf life of the fruit for more than 7 weeks, hence extending the marketing period and availability of the fruit beyond the harvesting period.

Keywords: Mango, storage temperature, cultivars, chilling injury, postharvest shelf life

1. INTRODUCTION

Postharvest loss in mango is estimated in the range of 25-40% since harvested fruit have the ability to respond metabolically to the environment in which it is stored [1]. Storability is affected by many factors such as cultivar, stage of maturity, size, grading, harvesting method, handling, packaging and mode of transport. Mango producers in Africa and India are confronted with three problems that are closely related to each other which are inadequate

30 postharvest control methods, deterioration of fruit quality due to fruit flies, and a saturation of
31 the national markets leading to wastage and lower prices [1, 2]. During the period of high
32 production, surpluses far exceeds the off take capacity of the usual markets which forces
33 growers to distress sales. Long term storage under such conditions is very important. Long
34 term storage could also be an important factor in processing industries which are currently
35 gaining popularity to enable the uniform rate of processing. The extension of storage life
36 under cool temperatures reduces respiration rate and lowers the production of ethylene. Mature
37 mangoes do not store well for periods longer than 2-3 weeks in air at the optimum non-
38 chilling temperature of 12^oC [3]. Fruit softening occurs very rapidly and is one of the main
39 causes of quality deterioration during postharvest handling. Excessive softening renders
40 mangoes more susceptible to impact and compression bruises and establishment of
41 postharvest pathogens. Consequently, there is need for development of transport and storage
42 conditions to delay softening [4].

43 However, mango being a subtropical crop is susceptible to chilling injury at low
44 temperatures [1]. Chilling injury causes economic losses during storage and transport of
45 mangoes. Chilling injury symptoms include scalding, surface pitting, poor aroma, uneven
46 ripening, poor colour development and increased susceptibility to diseases [5, 6-8]. Chilling
47 injury can be related to the enzymatic browning of activities of polyphenoloxidase (PPO) and
48 peroxidase (PO), and the increase of phenolic compounds [9]. Chilling injury is the main
49 disorder limiting in the storage life of mangoes. Factors influencing susceptibility to injury
50 include cultivar, growing conditions, maturity when picked and postharvest handling
51 techniques, and duration of exposure to the chilling temperature [8, 10]. Mango fruits develop
52 chilling injury symptoms due to prolonged exposure to temperatures below 13°C [11].

53 A temperature range of 7-13^o C, depending on mango cultivar, growing conditions, stage of
54 maturity and postharvest handling techniques have been suggested for mango fruit storage [1,
55 10]. The lowest safe temperature for mango storage has been reported to be 7.2^o C [12].
56 However, Julie and Ceylon mango cultivars are reported to store well at 7°C for 3-4 weeks
57 and normal fruit ripening occurs [6]. Unripe physiologically mature (green) mangoes do not
58 ripen uniformly when stored at 10°C for 3 weeks, while ripe and partially ripe fruits kept well
59 up to 3 and 6 weeks, respectively [13]. It is also reported that mango fruits stored for 3 weeks
60 at 5°C or one week at 1°C did not ripen well [14]. Other researches have suggested that ripe
61 mango fruit can be stored at 7.2°C while unripe fruit should not be stored at temperatures

below 10°C [15]. Therefore, due to conflicting information on the safe storage temperature for mangoes even within the same cultivar, the objective of this study was to evaluate the effects of the low temperatures on the storage life of different mango cultivars.

2. MATERIALS AND METHODS

2.1 Experimental site

The experiment was conducted in the Crop Science and Production Department Laboratories of the Botswana College of Agriculture between January and April 2012. Botswana College of Agriculture is located at Sebele (latitude 24°34'S and longitude 25°57'E, altitude of 994m above sea level) and 10 km from Gaborone.

2.2 Experimental design

The experimental design was a completely randomized design with three replicates. The treatments were storage temperatures of 5, 8, 10 and 12 °C. There were four refrigerators set at 5, 8, 10, and 12 °C $\pm 0.2^{\circ}\text{C}$ plus 90-95%RH. The mango cultivars Kent, Keitt, Tommy Atkins and Haden were used for the study. Fruits were at physiological maturity (fruit were had with a green peel colour but the flesh was yellow in colour, uniform and free from blemishes). Ten fruits per treatment per replicate were used.

2.3 Dependent variables determined

The dependent variables analyzed were fruit colour (anthocyanins), titratable acidity, soluble solids content (SSC), chilling injury incidence, chilling injury severity, number of days in storage to development of chilling injury and physiological disorders other than chilling injury.

2.3.1 Titratable acidity (TTA)

The fruit pulp and skin was cut and 100g of the sample weighed, then 100 ml of distilled water was added to the sample. The mixture was then blended for five minutes. The sample was homogenized and filtered with five layers of cheese cloth to extract the juice. Twenty millilitres of the filtrate was then put in 50 ml conical flask and two drops of 1% phenolphthalein indicator was added. The sample was titrated with 0.1 N NaOH to end point, and this was done in triplicates. The results were expressed as total titratable acidity equivalents.

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92 g total titratable acidity/100ml juice = $\frac{(\text{ml base} \times 1 \times 100 \times 2 \times \text{normality of base})}{\text{ml sample}}$

93

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95 2.3.2 Soluble solids content (SSC)

96 Soluble solids content was determined using a refractometer, 10 fruits per replication were
97 pinched using a razor blade and the juice squeezed directly into the hand refractometer and
98 then the average sugar content was determined in Brix.

99 2.3.3 Fruit anthocyanin, carotenoid and chlorophyll content

100 Anthocyanin plus carotenoids and chlorophyll content of the skin was determined from two
101 discs (11mm diameter) per fruit (ten mangoes per replicate), cut from the yellowiest and
102 greenest side of the mango fruit using a cork borer and scalpel. The ten discs were then
103 | extracted in 4ml of 0.1 N HCl in Methanol at 23^{±0} C in the dark for 24 hours. Absorbance of
104 extracts was measured using a UV Visible Spectrophotometer [UV-1602 1 PC, Shimadzu,
105 RSA Pty Ltd. Co.Reg.no: 90/07641/07] at various wavelengths of 530,620,645,650, and 663
106 nm. Anthocyanins plus carotenoid content were determined according to an established
107 method [16, 17], using a molar extinction coefficient of 4.62×10^4 [18].

108 Anthocyanin plus carotenoids (nmole/cm²mango skin) = $\frac{[(A_{530}-A_{620})-0.1(A_{650}-A_{620})]}{4.62 \times 10^4}$

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110 Skin chlorophyll content was measured as absorbance at 653nm [19, 20]. The following
111 equation was used to calculate the relative total chlorophyll content [20].

112 Chlorophyll (mg/cm² of mango skin) = $24.88 \times A_{653}$

113 2.3.4 Chilling injury (CI) incidence and severity

114 Chilling injury incidence was evaluated on the number of fruit that developed CI symptoms
115 out of the total fruit used per treatment per replicate. Then the result was expressed as a
116 percentage. While severity of CI was evaluated visually on a predetermined scale from 0 to 3,
117 where 0-being no injury; 1- being slight injury (1/3 of the fruit showed some injury

symptoms); 2- moderate injury (1/3- 2/3 of the fruit showed injury symptoms); 3- severe injury (more than 2/3 of the fruit showed injury symptoms).

Chilling injury index (CII) was calculated by the following equation;

$$\text{CII} = \frac{[(\text{no of fruits with no injury} \times 0) + (\text{no of fruits with slight injury} \times 1) + (\text{no of fruits with moderate injury} \times 2) + (\text{no of fruits with severe injury} \times 3)]}{\text{No of fruits sampled}}$$

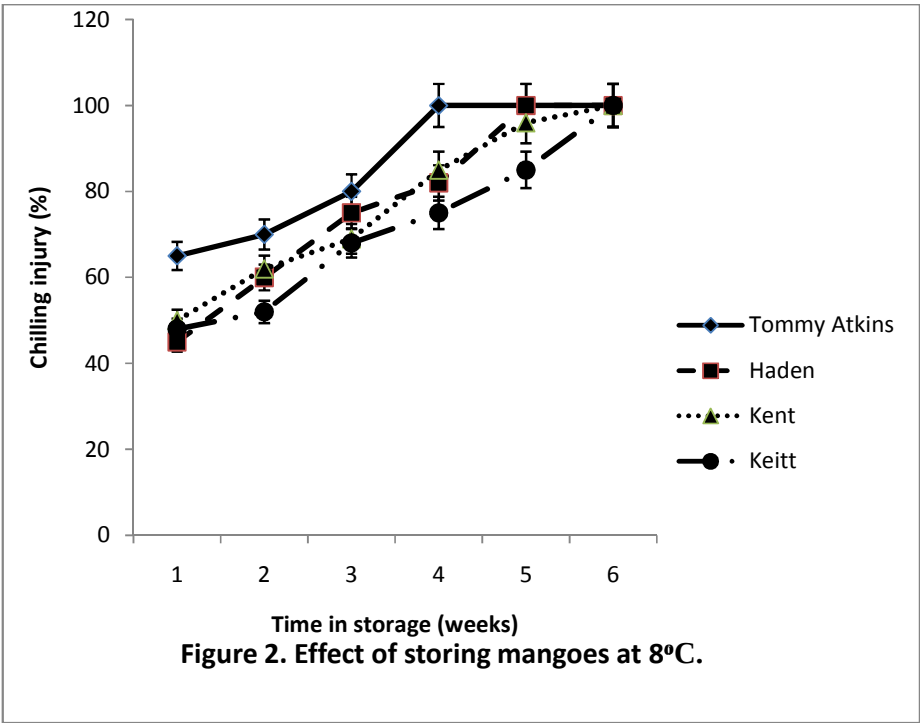
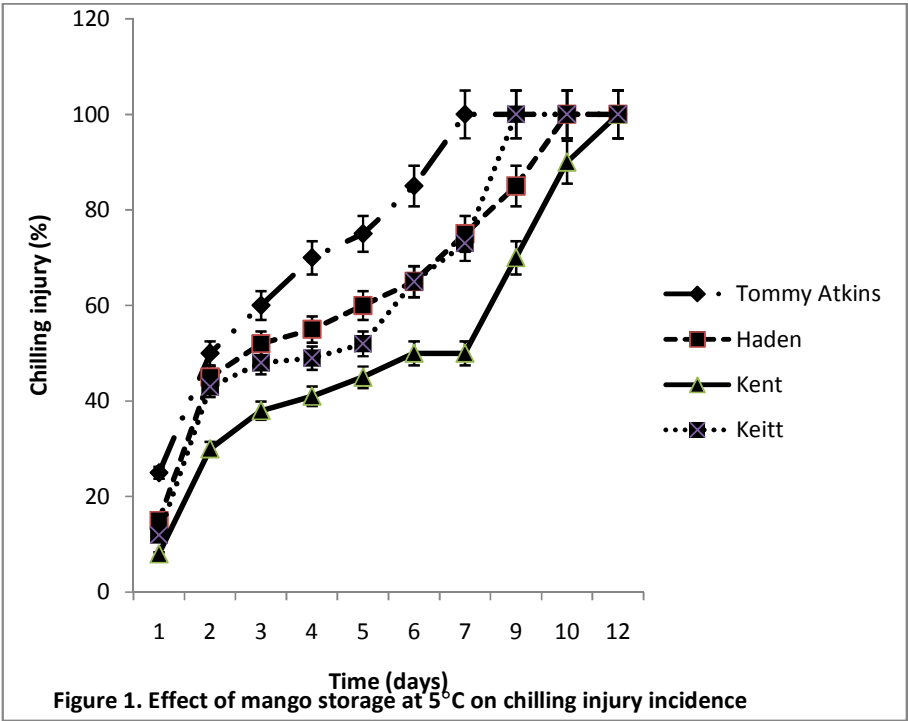
2.4 Data Analysis

Analysis of variance was performed on the data collected using the general linear models, procedure of the statistical analysis system (SAS) programme. Multiple comparisons among means was performed using the protected least significant difference at $P = 0.05$.

3. RESULTS

3.1 Chilling injury

The results of this study showed that mango cultivar and storage temperature significantly ($P \leq 0.01$) influenced the development (incidence) and severity of chilling injury in mango (Figures 1- 4). As storage temperature decreased below 12°C , the incidence and severity of chilling injury significantly ($P \leq 0.01$) increased. Chilling injury symptoms of skin pitting, poor colour development, poor aroma and surface lesions developed in all the mango cultivars under study stored at temperatures of $\leq 8^{\circ}\text{C}$ (Figures 1, 2, 4), though severity varied with cultivar. All mango cultivars stored at temperatures less than 12°C suffered from chilling injury and the development of the symptoms of chilling injury varied with cultivars and duration of storage from 2 to 21 days. The mango cultivars Kent, Haden and Keitt stored at 10°C did not develop chilling injury symptoms until after 21 days (Figure 3). However, the mango cultivar Tommy Atkins developed chilling injury symptoms after 14 days of storage at 10°C . The results also showed that the mango cultivar Tommy Atkins was the most susceptible to chilling injury (Figures 1- 3). While the mango cultivar Kent was more tolerant to chilling injury than Haden, Keitt and Tommy Atkins (Figures 1- 3). Though, Kent was more tolerable to chilling injury at storage temperatures of 5 to 10°C , its level of tolerance was not significantly ($P \leq 0.05$) different from that of Haden and Keitt (Figures 1-3). All mango cultivars under study showed no signs of chilling injury when stored at 12°C .



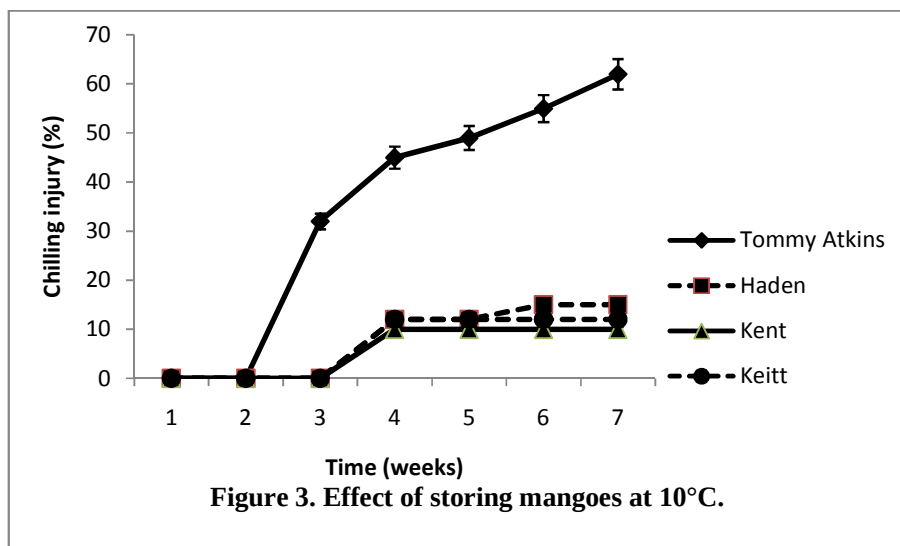
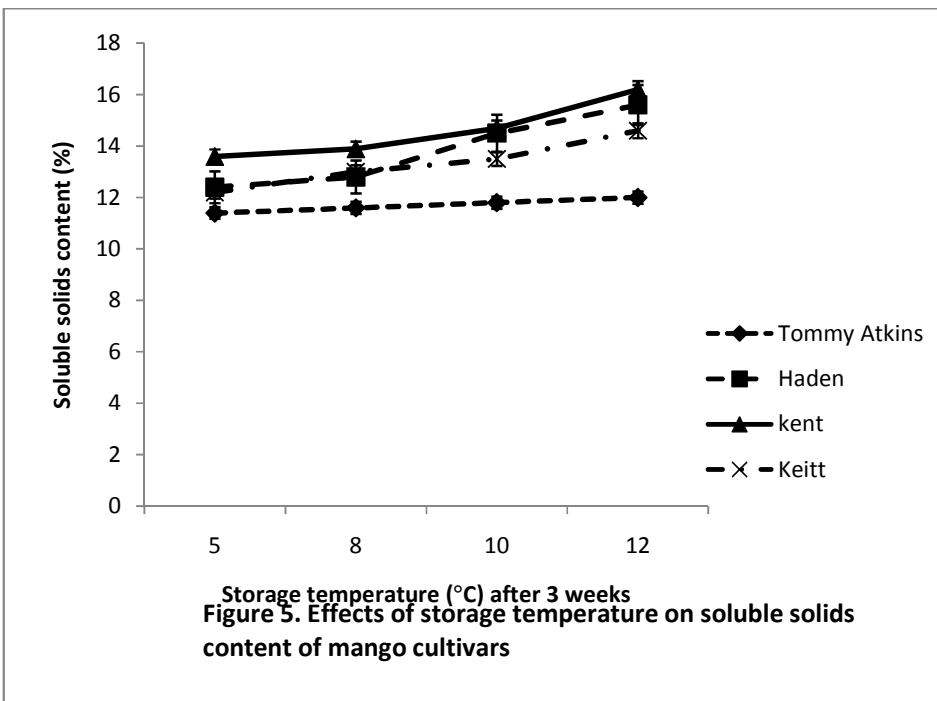


Figure 4. Chilling injury symptoms of pitting and uneven ripening

3.2 Total soluble solids (TSS)

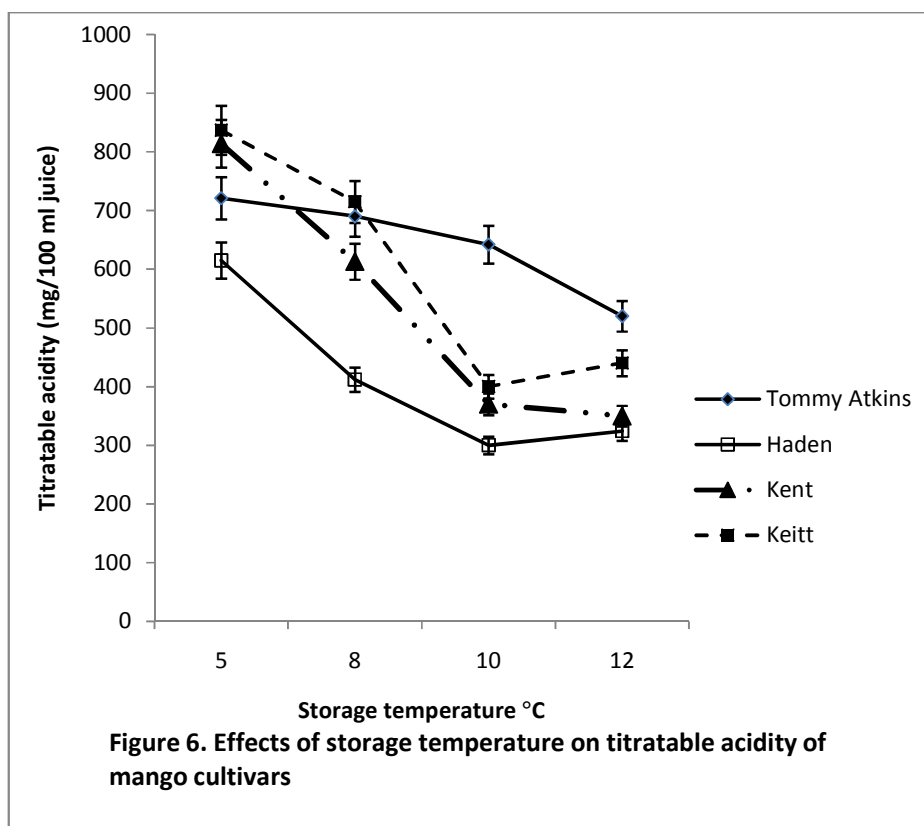
Storage temperature significantly ($P \leq 0.05$) affected the soluble solids content of the four mango cultivars under study (Figure 5). In general, as storage temperature decreased from 12 to 5°C, soluble solids content (SSC) decreased reflecting the stage of fruit ripeness (Figure 5). The mango cultivar Kent had significantly ($P \leq 0.05$) higher SSC than Keitt and Tommy Atkins (Figure 5). However, the mango cultivars Keitt and Haden did not differ in their SSC, but higher than that of Tommy Atkins. Tommy Atkins had significantly ($P \leq 0.05$) lower SSC than Kent, Keitt or Haden at all the storage temperatures under study (Figure 5). The average SSC of fruits of all cultivars stored at 5°C was 12.4% which was very close to the SSC of 12.2% observed at the start of the study indicating fruit ripening had not taken place to a greater degree.



3.3 Titratable acidity

Titrateable acidity (TA) significantly ($P \leq 0.05$) decreased in all the mango cultivars and storage temperatures after three weeks (Figure 6). As storage temperature increased, TA significantly decreased ($P \leq 0.05$) from an average of 747 mg/100 ml juice at 5°C to 409

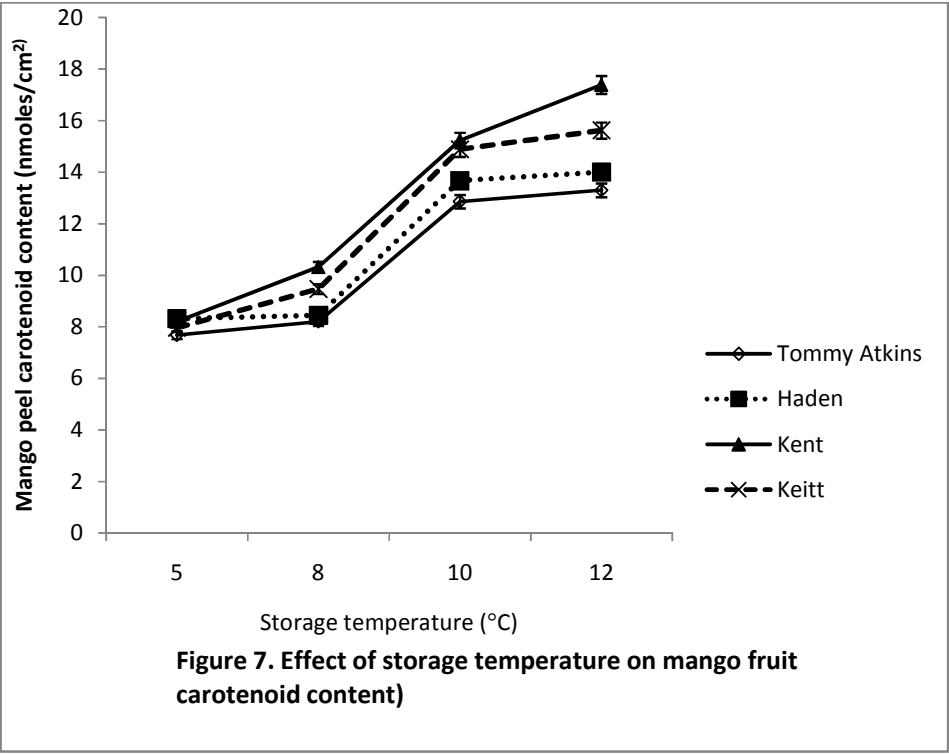
mg/100 ml juice at 12°C. Haden had significantly ($P \leq 0.05$) lower TA than Kent, Tommy Atkins and Keitt under the different storage temperatures under study (Figure 6). Tommy Atkins had significantly ($P \leq 0.05$) higher TA at storage temperatures of 10 and 12°C, respectively, than Kent, Keitt or Haden (Figure 6).



3.4 Carotenoid content

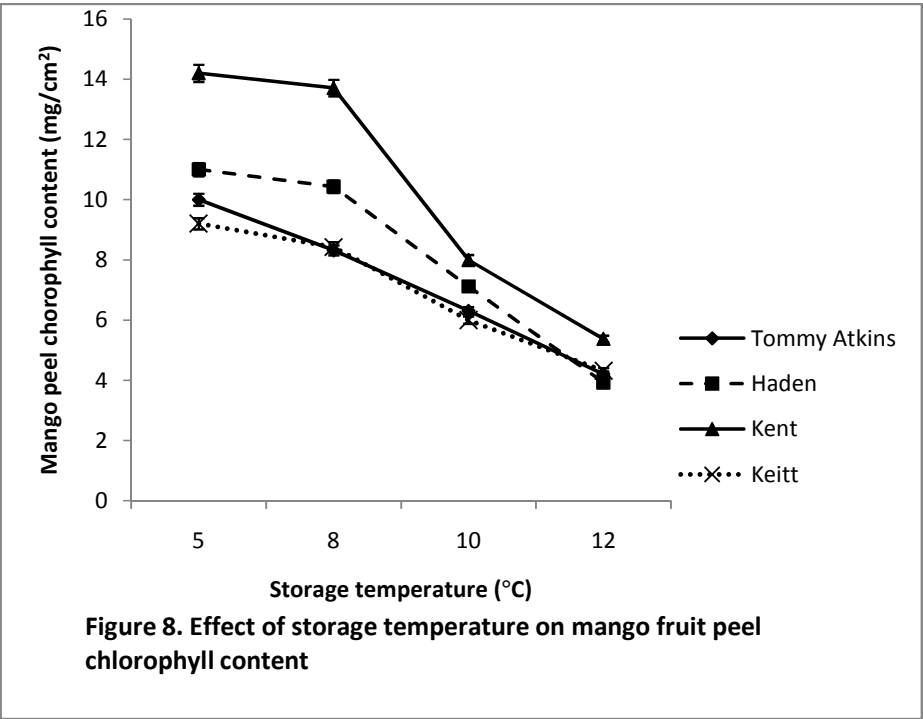
Figures 7 and 8, showed that changes in fruit peel (skin) occurred in all storage temperatures and mango cultivars. As storage temperature increased from 5 to 12°C, the peel carotenoid content increased from 8.04 to 15.08 nmol/cm², while the peel chlorophyll content decreased from 11.1 to 4.46 mg/cm², respectively (Figure 7, 8), indicating fruit ripening occurred in all storage temperatures after 3 weeks of storage. There were also significant ($P \leq 0.05$) peel carotenoid and chlorophyll contents among cultivars at all storage temperatures under study (Figure 7, 8). Kent had the highest peel carotenoid content than Keitt, Haden and Tommy Atkins in all the storage temperatures (Figure 7). However, Tommy Atkins had

192 significantly higher peel chlorophyll content than Haden, Keitt or Kent in all storage
193 temperatures (Figure 8).



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4. DISCUSSION

4.1 Storage temperature and mango cultivar on chilling injury

Mango is a tropical and climacteric fruit usually harvested at physiological maturity. Once harvested the fruits are handled at various temperatures during storage, transportation and marketing. However, most fruits that are of tropical or subtropical in origin are reported to be chilling sensitive [7, 21-23]. These fruits are injured after a period of exposure to chilling temperature below 10-15°C, but above their freezing temperatures. The results of this study showed that mango cultivar and storage temperature significantly influenced the incidence and severity of chilling injury in mango. As storage temperature decreased below 12°C, the incidence and severity of chilling injury increased. Chilling injury symptoms of skin pitting, poor colour development, poor aroma and surface lesions developed in all the mango cultivars under study stored at temperatures of $\leq 12^{\circ}\text{C}$, though severity varied with cultivars and duration of storage from 2 to 21 days. The mango cultivars Kent, Haden and Keitt stored at 10°C did not develop chilling injury symptoms until after 21 days. The mango cultivar Tommy Atkins developed chilling injury symptoms after 14 days of storage at 10°C and it was the most susceptible cultivar to chilling injury. While the mango cultivar Kent was the most tolerant to chilling injury. Chilling injury symptoms such as scalding, surface pitting, poor aroma, uneven ripening, poor colour development and increased susceptibility to diseases in mangoes at temperatures below 10°C [5-7]. Chilling injury has been related to the enzymatic browning of activities of polyphenoloxidase (PPO) and peroxidase (PO), and the increase of phenolic compounds [9]. Reports on the temperature below which there is a risk of chilling injury in mangoes vary widely for the same cultivar from 7°C to 13°C [10, 14, 24]. This variation can be explained by differences in cultivars, growing conditions, maturity at harvest and postharvest handling techniques, and duration of exposure to the chilling temperature [8, 10]. Several events have been proposed as likely candidates for the primary cause of chilling injury, including a phase transition in membrane lipids, an alteration in the substrate specificity of a regulatory enzyme, a change in the cytoskeletal structure, or an increase in cytosolic calcium [21]. After a prolonged exposure of sensitive species to chilling, the primary response would lead to secondary events which include loss of membrane

integrity, leakage of solutes, increase in the activation energy of membrane associated enzymes, disorganization of cellular and subcellular structure, dysfunction and imbalance of metabolism, accumulation of toxic substances, stimulation of ethylene production to mention a few which cascade to manifestation of a variety of chilling injury symptoms [25, 26]. Chilling injury is reported to cause membrane damage via oxidation of membrane lipids, leading to structural changes and increased membrane permeability [24-26]. Various physiological, biochemical alterations and cellular dysfunction occurs in chilling sensitive species in response to chilling stress [26].

4.2 Mango fruit changes during ripening

Fruit ripening is a highly coordinated, genetically programmed, and an irreversible phenomenon involving a series of physiological, biochemical, and organoleptic changes that lead to the development of a soft and edible ripe fruit with desirable quality attributes. A wide spectrum of biochemical changes such as increased respiration, chlorophyll degradation, biosynthesis of carotenoids, anthocyanins, essential oils, and flavor and aroma volatiles, increased activity of cell wall hydrolases, and a transient increase in ethylene production are some of the major changes involved during fruit ripening [27, 28]. The results of the current study showed that as storage temperature increased from 5 to 12°C, SSC content, carotenoid biosynthesis and chlorophyll degradation increased, but titratable acidity decreased, irrespective of cultivar, indicating fruit ripening occurred in all the storage temperatures. The fruit colour change during ripening is due to unmasking of preformed pigments by degradation of chlorophyll and/or biosynthesis of carotenoids and anthocyanins and their accumulation in vacuoles [29, 30]. The increase in SSC and decrease in titratable acidity after 3 weeks of mango fruit storage at different temperatures was attributed to increased glucogenesis and hydrolysis of polysaccharides especially starch [29, 30]. Decreased acidity and accumulation of sugars (SSC) and organic acids in mango fruits results in an excellent sugar/acid blend for edibility as fresh fruit or for processing of mango nectar. In general, total acidity decreases during ripening, though the content of one or more acids may increase. Total acidity decreases with ripening due to their utilisation as respiratory substrates especially in the Krebs (TCA) cycle [8]. Respiration is a central process in fruit metabolism. Substrate utilization is coupled with ATP formation and other synthetic reactions. Oxidative phosphorylation is the source of energy for transcription and translation that are active during certain stages of ripening. Acidity values of Alphonso mango either packed in cartons or

control decreased from 2.17 to 0.08% after 12 days of storage at ambient temperature $27 \pm 1^{\circ}\text{C}$ with 65% RH [31]. Similar changes have been reported in Neelum mango where pH and acidity decreased from 4.2 to 3.0 and 1.9 to 0.05%, respectively during storage [32].

5. CONCLUSION

Postharvest management of mangoes is important for their successful marketing. The study showed that some of the factors affecting the postharvest shelf-life of mangoes are temperature management and cultivars. It was concluded that chilling injury is the most important physiological disorder that affects the quality of mango fruits. Therefore, in order to extend the shelf-life and marketing period of mango fruits, the fruits should be stored at 12°C and 90-95%RH, because the fruit will not suffer from chilling injury and will undergo normal ripening process. For the mango cultivar Kent, it could initially be stored at 10°C for 3 weeks and then transferred to 12°C , this will extend the shelf-life of the fruit for more than 7 weeks, hence extending the marketing period and availability of the fruit beyond the harvesting period.

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