ORIGINAL RESEARCH ARTICLE

Quality changes in papaya fruit under different storage temperatures and duration

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Abstract
Kenya experiences high postharvest losses in the fruit and vegetable subsector, which have been estimated at 50 percent. These losses are mainly due to poor postharvest handling practices, a lack of storage facilities, and/or poor storage conditions. Papaya (*Carica papaya* L.) is a highly perishable tropical fruit with a short shelf life and requires proper storage and handling practices due to its delicate skin texture, high moisture content, and high respiratory rates. In this study, F hybrid and Mountain variety papaya fruits were collected at Meru County in May 2022 and stored at three different temperatures (6, 16 and 24 °C) for a duration of 0, 4, 8 and 12 days to evaluate their effects on fruit quality. The data collected was separately subjected to a two-way ANOVA in a completely randomised design using the GenStat statistical software package (14th edition). Storage temperatures and durations significantly ($p < 0.05$) decreased papaya quality. Mountain fruits were firmer while F fruits had more appealing peel and flesh colors. F fruits retained more potassium (1.20 g/100g) and vitamin C (0.29 g/100g) when stored at 16 °C on day 12. The optimal storage temperature and duration for successful storage and extension of shelf life of papaya fruits was found to be 16 °C for 8 days. The F hybrid fruits were more comparable to the local papaya variety, Mountain, on the various tested parameters, which could make it suitable for consumer utilization and market exploitation in Kenya.

Keywords: *Papaya carica*, postharvest, storage temperature, fruit quality, nutrient retention

1.0 Introduction
Papaya (*Carica papaya* L.), a fruit originally grown in tropical and subtropical areas of the world, has been described as a powerhouse of nutrients (Aravind et al., 2013) which is mostly consumed for its health benefits. It is a rich source of nutrients such as pro-vitamin A carotenoids, vitamin C, B vitamins, lycopene, and dietary minerals (Kumar et al., 2019). The edible portion of the ripe papaya fruit has a high nutritional value and is rich in both macro and microminerals, which are sodium, potassium, calcium, manganese, phosphorus, iron, zinc, and magnesium (Parni & Verma, 2014). Papaya has been traditionally used as medicine as it

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has anti-inflammatory, anti-cancer, anti-hypertensive, and antibacterial properties as well as effects on gastrointestinal disorders and hypoglycemia (Aravind et al., 2013). It is a highly perishable fruit with a short shelf life and requires proper storage and handling practices due to its delicate skin texture, high moisture content, and high respiratory rates (Murakami et al., 2020).

Papaya was ranked as the 6th most important fruit, contributing 4% of the fruit's subsector in Kenya's agricultural economy (Horticultural Crops Directorate (HCD), 2017). Even though this fruit subsector is potentially growing, it has various constraints, like major food losses that mostly occur at the postharvest stage (Ridolfi et al., 2018). High postharvest losses in the fruit and vegetable subsector in Kenya, estimated at 50 percent (Kitinoja & Kader, 2015), are mainly due to poor postharvest handling practices, a lack of storage facilities, and/or poor storage conditions. Proper storage of harvested fruits for extended periods of time plays a critical role in the development and expansion of the horticultural industry (El-Ramady et al., 2015) into the domestic and export markets. Falah et al. (2015) indicated that storage conditions in tropical areas for fresh-cut fruits are important and essential for good quality and shelf-life extension of the fruits because they regulate biological processes like transpiration and respiration rates. These processes affect climacteric fruits, which mostly have a short postharvest shelf life due to their high moisture content and perishability, active metabolisms, sensitivity to low temperatures, and decay organisms, resulting in changes to the fruits' color, texture, taste, aroma, and nutritional and biochemical profiles (Kader & Yahia, 2011). The effect of these changes can be regulated by storing fruits under appropriate conditions, with more emphasis on the storage temperature.

Storage temperature has been described as the most important environmental factor influencing the deterioration of harvested commodities (Kader, 2013). Deterioration rate increases mostly for fruits stored above their optimum storage temperatures; therefore, temperature management is important during the postharvest handling activities in order to maintain their nutritional quality, reduce qualitative and quantitative losses, and extend their postharvest life (Yahia et al., 2011). Ghait et al. (2016) reported that storage temperature influences the uptake and metabolism of mineral nutrients in the fruits as a result of an increasing transpiration rate. Temperature extremities, higher or lower than the ideal ones, can result in either fruit deterioration or chilling injury disorders, which will negatively affect its nutritional quality and biochemical composition. In a study by Rivera-Pastrana et al. (2010), total phenolics and carotenoids of 'Maradol' papaya were influenced by postharvest storage temperature, as ripe papaya stored at 25 ˚C had more carotenoids while fruits stored at low chilling temperatures of 1 ˚C had more phenolics. Similar results have been reported on the effects of different storage temperatures and durations on the physiochemical properties and nutritional composition of bananas and papaya fruits (Ghait et al., 2016). Lack of knowledge on the optimal storage temperature for papaya in Kenya has partially resulted in its huge postharvest losses since there is limited scientific knowledge and research on its optimum storage requirements to help retain its nutritional quality before it reaches consumers or is transported for export markets. Therefore, the aim of this study is to evaluate the effects of different storage temperatures and durations on the fruit quality of papaya.

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2.0 Materials and methods

2.1 Experimental design and site

The experimental design was a 3x4x2 factorial arrangement conducted in the Food Biochemistry laboratory at Jomo Kenyatta University of Agriculture and Technology (JKUAT). The study utilized a completely randomized design with three storage temperatures (6, 16, and 24 °C), four storage days (0, 4, 8, and 12 days), and two papaya varieties (Mountain, a local variety, and F hybrid), with three replications. Papaya fruits were harvested in May 2022 from Meru County, located in the eastern region of Kenya on the Upper Highlands, at a latitude of 0.0515° N and 37.6456° E longitude and an elevation of 1600 m above sea level. The average annual temperature of the region is approximately 20.1 °C, with an average annual rainfall of around 550mm.

2.2 Papaya fruit preparation

Ripe papaya fruits were harvested when they reached 25% yellow color and transported to the Food Biochemistry Laboratory at JKUAT. Upon arrival, the fruits were washed with a mixture of water and diluted vinegar (acetic acid) to remove debris and microorganisms and then stored at different temperatures according to the experimental design. The fruits were removed from storage every four days, cut, deseeded, and homogenized using a fruit blender. The homogenized papaya samples were stored at -20 ˚C for two weeks before analysis.

2.3 Determination of physical characteristics of papaya

2.3.1 Fruit firmness

Fruit firmness was measured at three different spots in the center of each papaya fruit stored at different temperatures and durations, following the method described by Morais and Argañosa (2010). An 8-mm probe attached to a penetrometer (Sun Rheo meter Compac-100, Sun Scientific Co., Ltd., Japan) was used to penetrate the fruit to a depth of 10 mm. The force required to penetrate the papaya was measured in Newtons (N).

2.3.2 Peel and flesh colour

Peel and flesh colors of the papaya fruits stored at different temperatures and durations were measured at three different points along the central portion of the fruit using a handheld Minolta color meter (Chroma meter CR-200b, Kyoto, Japan) that was calibrated using a black and white tile. Color differences were determined following the method described by McLellan et al. (1995), where L*, a*, and b* values were recorded, and the mean hue angle was calculated by converting the a* and b* values using the following formula:

$$\text{Hue angle (H°)} = \tan^{-1}(b^*/a^*)$$

2.4 Determination of proximate contents of papaya

2.4.1 Moisture content

Moisture dishes were washed and dried at 105 °C for one hour in a cabinet dryer, and their weight was recorded prior to fruit drying. Two grams of fresh papaya pulp were weighed and placed inside the dried dishes before drying them for three hours. After cooling the samples, the final dry weight was recorded following the method described by Cunniff (1999). The

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moisture contents of the papaya fruits were determined using the formula below:

Moisture content (%) = (dry weight – dish weight)/ (fresh weight – dish weight) x 100

2.4.2 Total carbohydrates

The total carbohydrate contents of the two papaya pulp samples were calculated by subtracting the amounts of moisture, protein, fat, ash, and crude fiber contents from 100%, as described by Cunniff (1999), using the following formula:

Total carbohydrate contents (%) = 100 minus (moisture + crude protein + crude fat + ash + crude fiber).

2.5 Determination of biochemical composition of papaya

2.5.1 Vitamin C

The ascorbic acid content of the papaya samples was determined using the high-performance liquid chromatography (HPLC) method described by Vikram et al. (2005) with slight modifications. Two grams of the papaya pulp sample were extracted with 20 ml of 0.8% metaphosphoric acid and centrifuged at 10,000 rpm. The supernatant was filtered and diluted with 10 mL of 0.8% metaphosphoric acid, and the resulting solution was passed through a 0.45 µm filter. A Shimadzu UV-Visible spectrophotometer (Shimadzu Corp., Kyoto, Japan) detector was used to detect ascorbic acid. A calibration curve was prepared using various concentrations (0, 20, 40, 60, 80, and 100 µg/ml) of ascorbic acid standards, and 20 µL of each diluted sample was injected into the HPLC machine. The results were recorded in g/100 g of the dried fruit sample.

2.5.2 Total soluble solids content

The total soluble solids (TSS) content of the papaya pulp juices was measured in triplicate using a hand refractometer (Model 500 Atago, Tokyo, Japan) following the method of Gil et al. (2006). Briefly, the juice from each sample was extracted and placed on the refractometer prism surface, and the reading was taken at room temperature in degrees Brix (°Bx).

2.5.3 Total titratable acidity

The total titratable acidity (TTA) content of the two papaya pulp juices (from each storage temperature and the different days) was determined using the titration method in triplicates. The papaya pulp juice (10g) was diluted with 50 ml of distilled water, and 10ml of the diluted juice was titrated with 0.1 N sodium hydroxide with phenolphthalein (1% in 95% ethanol) used as an indicator (Cunniff, 1999). The TTA results were expressed as a percent citric acid equivalent using the following formula:

% Citric Acid Equivalent = Sample Reading (ml)*Dilution factor (0.064) *100/sample weight (g)

2.6 Determination of mineral composition of papaya fruits

2.6.1 Potassium and Iron contents

Dry ashing and an atomic absorption spectrophotometer (AAS) (Shimadzu AA-7000, Shimadzu Corp., Kyoto, Japan) were used for mineral quantification of the papaya pulp samples (Singh et

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al., 2015). Five grams of the papaya pulp samples were put in clean, dry crucibles and charred in the oven for 30 minutes, then put in a muffle furnace at 550 °C for eight hours to turn to ash and later allowed to cool at room temperature. The ash was diluted with 20 ml of 0.5 N nitric acid, filtered, and diluted with 100 ml of distilled water. The potassium and iron mineral standards were also prepared to make the calibration curve; absorbances were read using the AAS instrument, and their results were recorded as mg/100 g of the dried sample.

2.7 Data analysis

The data collected was analyzed using a two-way analysis of variance (ANOVA), which was performed separately for each papaya variety or hybrid. The purpose of the ANOVA was to evaluate the effects of postharvest temperatures and storage duration on the nutrient retention of the fruits. The GenStat statistical software package (14^{th} edition) was used to conduct the ANOVA. Statistical differences between means were determined using Fisher's protected least significant difference (LSD) at a significance level of $p < 0.05$.

3.0 Results

3.1 Physical characteristics of papaya fruits

3.1.1 Firmness

Temperature and storage duration significantly ($p < 0.05$) affected papaya firmness, with Mountain fruits being firmer than F fruits at all temperatures. Fruits stored at 16 and 24 °C showed a gradual decrease in firmness over the storage period, while no significant results were observed at 6 °C. Mountain fruits remained firmer than F fruits under all conditions, with F fruits becoming soft (0.52 N) by day 8. No data was collected for day 12 under 24 ˚C, as the fruits had spoiled (see Table 1).

3.1.2 Peel and flesh hues

In this experimental study, the peel and flesh hues of papaya fruits were significantly affected by different storage temperatures and duration ($p < 0.05$). Higher temperatures and longer storage times resulted in decreased color intensity for both the peel and flesh. However, there was no significant change in flesh color for fruits stored at 16 °C, or for Mountain fruits stored at 24 °C. Mountain papaya fruits did not show a significant change in peel color when stored at 6 °C, but color changes were observed at 16 °C and 24 °C. The F hybrid peel colors were significantly different at 24 °C, changing from green (116.80°) to yellow (80.45°) (Table 1).

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Table 1. Changes on papaya firmness (N), peel and flesh hues (°) of F hybrid and Mountain variety stored at 6, 16 and 24 °C for 0, 4, 8 and 12 days.

Papaya	Temperature	Days	Parameters		
			Firmness	Flesh	Peel
Mountain variety	6	0	4.24^{a}	78.36^{a}	116.80^{a}
		4	4.28^{a}	69.64^{bc}	112.38^{a}
		8	4.26^{a}	66.64^{c}	113.24^{a}
		12	4.04^{a}	75.37^{ab}	111.46^{a}
	16	0	4.24^{a}	78.36^{a}	116.80^{a}
		4	2.33^{b}	70.86^{a}	108.85^{ab}
		8	1.34^{bc}	78.28^{a}	100.61^{bc}
		12	0.78^{c}	71.30^{a}	95.22^{c}
	24	0	4.24^{a}	78.36^{a}	116.80^{a}
		4	3.27^{b}	76.88^{a}	99.77^{b}
		8	0.91^{c}	66.81^{a}	80.45^{c}
		12	-	-	-
	Anova results	Temperature (T)	<0.001	<0.001	<0.001
		Days (D)	<0.001	<0.001	<0.001
		T x D	<0.001	<0.001	<0.001
F hybrid	6	0	3.77^{a}	85.95^{a}	120.00^{a}
		4	3.89^{a}	85.73^{ab}	119.90^{a}
		8	4.27^{a}	82.12^{b}	96.20^{a}
		12	4.68^{a}	72.03^{c}	110.80^{a}
	16	0	3.77^{a}	85.95^{a}	120.00^{a}
		4	1.53^{b}	84.74^{a}	112.50^{a}
		8	1.30^{b}	84.47^{a}	102.90^{a}
		12	0.83^{b}	83.69^{a}	98.30^{a}
	24	0	3.77^{a}	85.95^{a}	120.00^{a}
		4	1.56^{b}	84.98^{a}	102.80^{b}
		8	0.52^{b}	72.14^{b}	79.00^{c}
		12	-	-	-
	Anova results	Temperature (T)	<0.001	<0.001	<0.001
		Days (D)	<0.001	<0.001	<0.001
		T x D	<0.001	<0.001	<0.001

Means followed by the same letters within each storage temperature are not significantly different at P < 0.05 level using Fisher's protected least significant difference (LSD) test. No recordings were taken (-) due to fruits spoilage.

3.2 Proximate contents of papaya fruits

3.2.1 Moisture content

In this experimental study, significant differences in moisture content ($p < 0.05$) were observed for papaya fruits stored at different temperatures and durations. For both Mountain and F fruits, moisture content increased over time when stored at 6 °C, but gradually decreased for fruits stored at 16 °C and 24 °C (Table 2).

3.2.2 Carbohydrates

Storage temperatures and duration significantly affected ($p < 0.05$) the carbohydrate contents of Mountain and F papaya fruits. Carbohydrate content significantly increased at 16 °C for both

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fruits but decreased when stored at 24 °C. Mountain fruits did not show a significant change in carbohydrate content, whereas F fruits had significant changes at both 16 °C and 24 °C (Table 2).

3.2.3 Mineral composition of papaya fruits

3.2.3.1 Potassium and Iron

In this experimental study, storage temperatures and duration significantly affected ($p < 0.05$) the potassium and iron contents of F and Mountain papaya fruits. Mountain fruits had significant changes in both potassium and iron contents, while F fruits showed non-significant iron contents at 16 °C. At harvest (day 0), F fruits had higher potassium and lower iron contents compared to Mountain fruits. However, both fruits showed an increase in potassium contents and a decrease in iron contents with an increase in storage duration and temperature (Table 2).

Table 2: Changes on papaya carbohydrates (%), moisture (%), iron (mg/100g) and potassium (g/100g) levels of F hybrid and Mountain variety stored at 6, 16 and 24 °C for 0, 4, 8, 12 days.

Papaya	Temperature	Days	Parameters			
			Carbohydrates	Moisture	Iron	Potassium
Mountain variety	6	0	69.43^{a}	92.40^{c}	14.76^{a}	0.10^{d}
		4	58.90^{b}	94.42^{b}	7.49^{d}	0.82^{a}
		8	55.43^{b}	94.71^{b}	9.88^{c}	0.57^{c}
		12	62.55^{ab}	95.36^{a}	10.88^{b}	0.71^{b}
	16	0	69.43^{a}	92.40^{a}	14.76^{a}	0.10^{d}
		4	68.49^{a}	92.50^{a}	5.19^{c}	0.53^{c}
		8	72.72^{a}	91.70^{a}	5.93^{b}	0.81^{a}
		12	69.90^{a}	91.50^{a}	3.93^{d}	0.73^{b}
	24	0	69.43^{a}	92.40^{ab}	14.76^{a}	0.10^{c}
		4	72.55^{a}	93.40^{a}	7.52^{b}	0.58^{a}
		8	62.02^{a}	91.70^{b}	4.16^{c}	0.52^{b}
		12	-	-	-	-
	Anova results	Temperature (T)	<0.001	<0.001	<0.001	<0.001
		Days (D)	<0.001	<0.001	<0.001	<0.001
		T x D	<0.001	<0.001	<0.001	<0.001
F hybrid	6	0	64.98^{a}	92.34^{c}	6.77^{c}	0.71^{c}
		4	67.32^{a}	94.73^{b}	9.34^{b}	1.98^{a}
		8	63.10^{a}	95.35^{ab}	5.84^{c}	0.99^{b}
		12	65.04^{a}	95.84^{a}	12.07^{a}	0.91^{b}
	16	0	64.98^{b}	92.34^{a}	6.77^{a}	0.71^{b}
		4	77.08^{a}	90.32^{c}	18.35^{a}	1.20^{a}
		8	77.19^{a}	89.55^{d}	3.16^{a}	1.00^{a}
		12	77.33^{a}	91.44^{b}	3.47^{a}	1.20^{a}
	24	0	64.98^{b}	92.34^{a}	6.77^{a}	0.71^{b}
		4	61.33^{b}	90.34^{b}	2.77^{c}	1.12^{a}
		8	78.46^{a}	90.25^{b}	4.72^{b}	0.60^{b}
		12	-	-	-	-
	Anova results	Temperature (T)	<0.001	<0.001	0.008	<0.001
		Days (D)	<0.001	<0.001	0.024	<0.001
		T x D	<0.001	<0.001	0.002	<0.001

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Means followed by the same letters within each storage temperature are not significantly different at P < 0.05 level using Fisher's protected least significant difference (LSD) test. No recordings were taken (-) due to fruits spoilage.

3.3 Biochemical composition of papaya fruits

3.3.1 Vitamin C

In the experiment, storage temperature and duration significantly affected ($p < 0.05$) the amount of vitamin C in Mountain and F papaya fruits. Both fruits showed a gradual decrease in vitamin C content with an increase in temperature and duration, with F fruits initially having higher vitamin C content (8.73 g/100 g) than Mountain fruits at day 0. Storage at 16 °C resulted in higher vitamin C content for both fruits (Table 3).

3.3.2 Total soluble solids and titratable acidity of papaya fruits

The total soluble solids (TSS), total titratable acidity (TTA), and ratio of Mountain and F fruits were significantly influenced by storage temperatures and durations, according to the findings of the research. Papaya fruits stored at a temperature of 16 °C exhibited non-significant TSS results, with an initial Brix value of 8.73° for F fruits and 0.16% TTA for the Mountain fruits. The TSS levels increased over time, but at day 12, a decrease was observed (as shown in Table 3). The statistical significance level of $p < 0.05$ suggests that the observed effects of storage temperatures and durations on TSS, TTA, and ratio are likely to be genuine and not just random variation.

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Table 3. Changes on vitamin C (g/100 g)*, Total soluble solids (TSS) (°) and titratable acidity (TTA) (%) of F hybrid and Mountain variety papaya fruits stored at 6, 16 and 24 °C for 0, 4, 8, 12 days.*

Papaya	Temperature	Days	Parameters			
			Vitamin C	TSS	TTA	TSS:TTA
Mountain variety	6	0	0.46b	5.30b	0.16a	33.10c
		4	0.36c	5.90a	0.13b	45.80b
		8	0.11d	5.83a	0.17a	34.70c
		12	1.21a	4.90b	0.08c	61.00a
	16	0	0.46a	5.30a	0.16a	33.10b
		4	0.17b	11.60a	0.15b	77.70b
		8	0.10c	9.87a	0.13c	77.00b
		12	0.11c	10.67a	0.08d	128.50a
	24	0	0.46a	5.30b	0.16a	33.10c
		4	0.22c	5.10b	0.09b	54.80b
		8	0.40b	9.73a	0.10b	101.90a
		12	-	-	-	-
	Anova results	Temperature (T)	<0.001	<0.001	<0.001	<0.001
		Days (D)	<0.001	<0.001	<0.001	<0.001
		T x D	0.003	<0.001	<0.001	<0.001
F hybrid	6	0	0.89a	8.73a	0.10a	88.30b
		4	0.08a	6.13b	0.10a	61.70b
		8	0.22d	5.13c	0.07b	72.70b
		12	0.28c	4.57d	0.02c	192.70a
	16	0	0.89a	8.73a	0.10c	88.30b
		4	0.06d	10.70a	0.17a	64.00c
		8	0.71b	11.13a	0.08b	87.70b
		12	0.29c	10.20a	0.09d	133.00a
	24	0	0.89a	8.73a	0.10b	88.30a
		4	0.92a	10.70a	0.14a	78.70a
		8	0.05b	8.30a	0.15a	53.80b
		12	-	-	-	-
	Anova results	Temperature (T)	<0.001	<0.001	0.004	<0.001
		Days (D)	<0.001	<0.001	<0.001	<0.001
		T x D	<0.001	<0.001	<0.001	<0.001

Means followed by the same letters within each storage temperature are not significantly different at P<0.05 level using Fisher's protected least significant Difference (LSD) test. No recordings were taken (-) due to fruits spoilage.

4.0 Discussion

Postharvest losses of fresh fruits and vegetables are commonly high, especially in the developing countries where they are produced. These losses are mainly due to all activities and/or conditions preceding fruit harvest, which eventually affect their quality (appearance, color, texture, nutritional, and biochemical composition) (Kader & Yahia, 2011) and storage life. Studies on the postharvest storage of climacteric fruits have been done to determine the effect of different temperatures on their physical and nutritional properties. Storage temperature has been described as the most important environmental factor that influences the deterioration rate of harvested commodities (Kader, 2013). In this study, F and Mountain

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papaya fruits were stored at 6, 16, and 24 ˚C for 0, 4, 8, and 12 days, which resulted in significant differences ($p < 0.05$) on their firmness, peel, and flesh hues; moisture, carbohydrate, and protein contents; total soluble solids and total titratable acidity; vitamin C, potassium, and iron contents. The differences observed between the two papaya fruits were mainly due to their genetic differences (Chávez-Pesqueira & Núñez-Farfán, 2017).

Fruit firmness is a measure of hardiness that has a significant postharvest effect on fruit quality, consumer preference, shelf life, and transportability, and it tends to decrease during storage and marketing (Yahia et al., 2011). In this study, papaya fruit firmness was highly reduced with an increase in temperature and storage duration. Fruits stored at 6 ˚C were firmer compared to those stored at 24 ˚C; similar results were observed by Proulx et al. (2005) and Caron et al. (2013) for papaya fruits stored at 5 °C, which had high firmness levels compared to those stored at 10 ˚C. High temperature increases the rate of biological processes like respiration and senescence, which then accelerates their deterioration activity, leading to soft and mealy fruits (Kader & Yahia, 2011). Loss of papaya fruit firmness and softening increased as the storage duration progressed, which could be due to cell wall breakdowns associated with the conversion of insoluble pectin into soluble forms (Verlent et al., 2005). Mountain fruits were firmer than F fruits regardless of temperature or day. Firmer papaya fruits have a longer shelf life as they can take more time before spoiling, either in the market or during transport. Soft papaya fruits (F) are more suitable for the processing industry to make juices, jams, purees, and some cosmetic products. Papaya peel/skin and flesh color changes were affected by temperature and storage duration, resulting in significant differences for the fruits. Fruits stored at 6 ˚C both had green peel hues, mainly due to the low chilling temperatures, hence failing to ripen and change color. Chilling injury (CI) has been described as a physiological disorder that occurs in most fruits of tropical and subtropical origin if held at temperatures above their freezing point and below 5 to 15 °C (Kader & Yahia, 2011), depending on their maturity stage. Symptoms related to CI include surface and internal discoloration, pitting, water soaking, failure to ripen, uneven ripening, hard lumps in the pulp, and heightened susceptibility to pathogen attack (Kader, 2013). These symptoms also differ within fruit varieties; Mountain fruits had more CI symptoms compared to F fruits, with warm green and yellow flesh hues for F and Mountain, respectively. Shakila and Anburani (2010) reported CI symptoms in papaya fruits stored at 5 and 10 °C after assessing the effects of storage temperatures on their quality and shelf life. Papaya fruits stored at 10 °C exhibited CI symptoms of sunken areas on the skin and decay development (Proulx et al., 2005). Fruits stored at high temperatures attained acceptable yellow colors on the peel and flesh. High temperatures increase the rate of ripening and senescence, resulting in fruit softening and color changes. These changes could be related to enzymatic or chlorophyll degradation during ripening (Zuhair et al., 2013). The fruits' peel and flesh hue angles changed over the storage duration; similar results were observed by Caron et al. (2013) as the papaya fruits' hue angles decreased after storing the fruits from day 0 to 30 days at both 5 and 10 ˚C. The visual sensation of fruit colors is the core factor that influences customer preferences upon the purchase of mature and ripe fruits (Ruslan et al., 2016) and is an indicator of freshness and flavor quality (Nishimwe et al., 2018). Both Mountain and F fruits had desirable amber flesh colors after 8 days of storage. Fruits stored at low temperatures are less desirable, as most of

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the CI symptoms are more evident after removal from storage, resulting in poor quality, short shelf life, and postharvest losses.

Fruits normally contain 80–90% water in their fresh weight, which gradually reduces after harvest if not stored in a conducive environment. Findings on the moisture contents of the two papaya fruits showed a gradual decrease due to temperature and storage duration effects. High temperatures tend to increase the transpiration and respiration rates of stored fruits resulting in rapid moisture loss; a process which initiates poor appearance and texture, a loss in marketable weight and accelerated senescence (Kader & Yahia, 2011) hence reducing their shelf life. Fruits stored at lower temperatures were firmer due to their high moisture contents; and may have a prolonged shelf life if stored at optimum conditions. Rivera-López et al. (2005) had similar results after analyzing the effects of cutting shape and storage temperature on the quality of fresh-cut papaya cv. 'maradol'. Carbohydrates are important nutrients necessary for energy production. During fruit ripening, carbohydrates are converted to sugars and some flavor volatiles, resulting in desirable fruit characteristics. The carbohydrate contents of the studied papaya fruits were significantly reduced under high temperature and storage duration. High temperatures increase the degradation and/or conversion of carbohydrates into simple sugars, fiber and starch. Fruits with high carbohydrate contents tend to have more total soluble solids, as evidenced in this study. Similar results were reported by Kamelia et al. (2019) after analyzing glucose and vitamin C on papaya with different storage times. The F-fruits had more carbohydrates and TSS compared to mountain fruits.

The papaya pulp contains most of the nutrients, which play an important role in its biological processes, especially during fruit ripening (Kumar et al., 2019) and are required for bodily functions. The availability of these nutrients or minerals is affected by storage temperatures. Results from this study showed high potassium and iron contents at lower storage temperatures (6 ˚C) which consequently decreased with an increase in temperature (16 and 24 ˚C) and storage duration (Table 2). Papaya is rich in iron (Aravind et al., 2013), which is necessary for expectant mothers as it helps with the proper functioning of haemoglobin and alleviates micronutrient deficiencies in human diets. Römheld and Kirkby (2010) described potassium as an essential nutrient that promotes sugar translocation in plants; thus, its application increases the sugar content as well as total soluble solids in the papaya fruit and decreases its titratable acidity. This conforms with the present study, as the F fruits, which had more potassium, also had high TSS values compared to Mountain fruits. Research done by Bari et al. (2006) reported mineral differences between two papaya fruit varieties on potassium and iron contents, which were similarly observed in this study.

Ascorbic acid, commonly known as vitamin C, is a water-soluble vitamin with antioxidant properties found in fruits and vegetables whose main function is to neutralize reactive oxygen singlets. The vitamin C content of fruits normally increases until their harvest time and decreases gradually while in storage (Kamelia et al., 2019) due to their instability, leaching, and oxidation into dehydroascorbic acid (Davey et al., 2000). Findings in this study revealed that an increase in temperature and storage duration reduced the amount of vitamin C in

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Mountain and F hybrid fruits. Kamelia et al. (2019) reported a rapid decrease of ascorbic acid levels on papaya fruits stored at higher temperatures due to the use of organic acids during the respiration process; while the conversion of fruit glucose at lower temperatures resulted in higher vitamin C contents. Similar reports have been made on major losses of vitamin C in different fruits when stored at higher temperatures (Pavlovska et al., 2015; Falah et al., 2015; Caron et al., 2013). Higher vitamin C contents were recorded on the F fruits regardless of temperature and storage duration. Total soluble solids for both papaya fruits increased with an increase in temperature and duration, reducing total titratable acidity and resulting in increased TSS:TTA ratios. A research study by Nishimwe et al. (2018) reported that consumer acceptance of papaya fruits depends on physicochemical properties like TSS; F fruits would be more desirable to consumers compared to Mountain Fruits as they had more TSS and less TTA. Naturally, papaya is a sweet and low-acid fruit; hydrolysis of its starch to sugars as it advances in maturation has been explained as a reason behind the increase in TSS (Benkeblia et al., 2011) and low TTA values at the end of its shelf life (Falah et al., 2015). Firmer fruits with high moisture and low carbohydrate contents tend to have lower TSS and higher TTA values, as observed in this study. Storage temperature and durations significantly influenced the papaya fruits' TTA with non-significant results recorded by Proulx et al. (2005) when determining the quality attributes limiting the postharvest life of papaya fruits at chilling and non-chilling temperatures. High TSS values were reported by Ghait et al. (2016) after storing papaya at 10 ˚C compared to 4 ˚C. The rate of fruit ripening and senescence accelerates under high storage temperatures and long durations, resulting in rapid deterioration and the production of off-flavors; hence, it is important to harvest and store fruits under optimum conditions before achieving full sweetness (Barrett et al., 2010).

5.0 Conclusion

To summarize, the experiment on papaya fruits revealed significant differences in their traits based on varying temperatures and storage durations. The optimal storage temperature and duration for successful storage and extension of shelf life of papaya fruits was found to be 16 °C for 8 days, as it helped to maintain the desired physical, nutritional, and biochemical properties compared to other storage temperatures. However, the experimental storage temperature extremes proved to be unsuitable for maintaining the fruit's quality and shelf life, particularly for the export business, as the fruits stored at high temperatures spoiled quickly and had a shorter shelf life. Interestingly, the F hybrid fruits showed comparable qualities to the local papaya variety Mountain when stored at the same temperatures and durations, indicating their potential for consumer utilization and market exploitation in Kenya.

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6.2 Conflict of interest
None.

6.3 General acknowledgment
None

6.4 Ethical consideration and clearance
None

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