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Evaluation of the morphological and quality characteristics of new papaya hybrid lines in Kenya

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Papaya (*Carica papaya* L.) is among the most grown fruit crops worldwide with high economic and nutritional value. In Kenya, the papaya industry relies heavily on imported varieties and farmers' selected seed whose quality is not known. Therefore, the morphological and quality characteristics of mature fruits of eight newly developed papaya hybrids and their control, Sunrise solo were assessed using papaya descriptors (International Board for Plant Genetic Resources). The results showed significant differences in fruit sizes among the newly developed papaya hybrid lines and the control, Sunrise solo with Line 4 having the longest and heaviest fruits. Fruits from Sunrise solo, lines 2, 3, 7 and 8 ranged from small to medium in size, while those of lines 4 and 6 were large. Line 1 had the shortest shelf life of 4 days while Line 7 had the longest shelf life of 11 days. The total soluble solids (TSS) varied from 7.4 in Line 8 to 12.3% in Lines 5 and 7. Hence, most newly developed papaya hybrids Lines showed traits that were comparable to or exceeded those of Sunrise and could be suitable for both local and export markets. However, there is a need to evaluate and characterize the newly developed papaya hybrid lines in different agro-ecological zones in order to monitor the influences of the environment, pests and diseases.

Key words: *Carica papaya* L., new papaya hybrid lines, morphological characteristics, shelf life, fruit quality.

INTRODUCTION

Papaya (*Carica papaya* L.) belonging to the family Caricaceae and order Brassicales, is among the most widely grown fruit crops worldwide. Papaya is native to tropical America but it is currently grown in all tropical and subtropical countries (Nakasone and Paull, 1998; OECD, 2005; FAOSTAT, 2018). It is a trioecious medium sized crop plant with the potential to produce fruits throughout the year (Nakasone and Paull, 1998; OECD, 2005; Teixeira da Silva et al., 2007). Papaya fruits range from 10 to 50 cm in length and the shapes may vary according

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to the varieties (Storey, 1969). The fruit weight also varies substantially and may range from 0.2 to 12 kg depending on the environment and variety (Imungi and Wabule, 1990; OECD, 2005; Chan and Paull, 2008; Nakasone and Paull, 1998; Das, 2013; Yogiraj et al., 2014; Ayele et al., 2017). In Kenya, fruit weights of between 0.23 and 1.3 kg have been reported (Imungi and Wabule, 1990).

Papaya fruits have high economic and nutritional value (Imungi and Wabule, 1990; Nakasone and Paull, 1998; OECD, 2005; Ming et al., 2008). It is grown for a variety of products including juice, wine, jams, candies and dried fruits. The ripe fruits are eaten fresh while the green fruits are cooked as vegetables. The latex of green fruits contains papain which is a proteolytic enzyme used in beverage, food and product of chewing gum, chill-proofing beer, tenderizing meat and for treating digestive disorders (Nakasone and Paull, 1998; Workneh, 2012; Rahman, 2013; Azad et al., 2014). Papaya is a very wholesome fruit and an excellent source of vitamins A and C (Imungi and Wabule, 1990; Nakasone and Paull, 1998; Wijaya and Chen, 2013). The intake of 100 g per day from any papaya variety would satisfy more than recommended dietary allowances of Vitamin C for all age groups (NAS, 1980).

Papaya shows a wide variation in many traits including fruits, plant stature and leaf characteristics (Ocampo et al., 2006; Aikpokpodion, 2012), some of which are exploited in the development of commercial papaya cultivars. The commercial papaya cultivars are generally classified as inbred gynodioecious lines, typified by the Hawaiian Solo lines (Storey, 1969) out-crossing dioecious populations, such as the Australian papaws; F1 hybrids, including the Tainung series (Taiwan), Eksotika II (Malaysia), and Rainbow (Hawaii); or occasionally even clones, such as Hortus Gold in South Africa (Kim et al., 2002). Many commercial papaya cultivars developed in different parts of the world were introduced into Kenya. These include ‘Kapoho solo’ (Storey, 1969), ‘Waimanalo’, ‘77’, ‘116’, ‘273’ from Hawaii, ‘Cavite’, introduced from the Philippines, ‘417’, ‘418’ and ‘455’ from India, 457 from Indonesia and ‘Kiru’ from Tanzania. Locally developed papaya cultivars included ‘Kitale’, ‘Malindi’ and ‘PP1’ (Imungi and Wabule, 1990; Asudi et al., 2013). Recent evidence also indicates that various commercial cultivars such as ‘US’, ‘Redlady’, ‘Sunrise’, ‘Sunrise-Solo’ and ‘Honey dew’ originating from Asia and America, are regularly imported as seeds by commercial papaya growers in Kenya. Some of the commercial papaya cultivars reported in the 1990s (Imungi and Wabule, 1990) no longer exist (Asudi et al., 2010) probably due to the disappearance or selection or importation of new cultivars into the country.

Globally, Asia is the leading papaya producing continent with 56.27% of the global production, followed by America (33.12%) and Africa with 10.50% production (FAOSTAT, 2018). In Kenya, papaya is popular and economically important and it is grown for domestic use as well as for commercial purpose on both small and large scale with majority of growers being small-scale farmers (Asudi, 2010). Papaya is ranked sixth after banana, mangoes, pineapples, avocado and watermelon, and accounts only for 4% of the revenue generated by the fruit’s subsector in the country (Horticultural Crops Directorate, 2016). The area under production and yields have also decreased rapidly from 9,346 to 8,112 ha and from 127,782 to 107,591 tons representing a 13 and 16% drop, respectively. The decline is due to lack of quality planting materials arising from genetic erosion due to open pollination in papaya, lack of established seed producers, insect pests and diseases such as ringspot viruses. Papaya fruit production in Kenya also relies on imported varieties and farmers’ selected seeds (Asudi, 2010; Horticulture Crops Directorate, 2016) whose quality is not known. In addition, since the introduction of papaya fruits in Kenya, little attempts have been made to develop improved papaya variety with superior quality attributes and that are adapted locally. Hence, the researchers have developed new papaya hybrid lines using some of the commercial papaya cultivars and accessions collected locally with divergent morpho-agronomic traits in Kenya (Asudi et al., 2010) with good quality fruits. However, the quality characteristics of these new papaya hybrids have not been documented. Therefore, the objectives of this study were to evaluate the morphological and quality characteristics of the fruits of the newly developed papaya hybrid lines.

MATERIALS AND METHODS

Study area

The study was carried out at the JKUAT main campus situated in Juja (1°5′ 29″ S, 37°0′39″ E and 1521.3 m above sea level), 36 km northeast of Nairobi, Kenya.

Source of papaya fruits

Eight papaya hybrid lines and the control (‘Sunrise solo’) were used in the experiment. The papaya hybrids were developed as a result of selection of papaya seeds collected all over Kenya by Asudi et al. (2010). The seeds were extracted, germinated and grown in screen house and then cross-bred. Line 1 was developed from a cross between a local papaya from Manyani (MAN1) and Sunrise solo. Line 2 was from a cross of local papaya from Voi (VOI4) and local papaya from Kilifi (ST2). Line 3 was bred from a cross between a local papaya from Voi (VOI5) and a local papaya collected from JKUAT farm (BLOCK A). Line 4 was developed as a result of a cross between VOI5 and Sunrise solo, Line 5 between a local papaya from Mombasa (MT/M7) and (VOI4), Line 6 between a local papaya from Voi (KIBBELEPTIC) and Sunrise solo, Line 7 between (VOI4) and (BLOCK A), and Line 8 from a cross between a local papaya from Manyani (MAN2) and Sunrise Solo.

Experimental design

The plants were planted in an open field in a complete randomized

Table 1. The morphological and quality characteristic of new papaya hybrids.

Hybrid	Fruit weight (g)	Fruit length (cm)	fruit diameter (cm)	Internal cavity length (cm)	Internal cavity diameter (cm)	TSS (°brix)
Sunrise solo	544 ± 56.3^{cd}	12.3 ± 0.6^{e}	9.4 ± 0.6^{def}	8.5 ± 0.5^{f}	5 ± 0.4^{cd}	7.7 ± 0.2^{e}
Line 1	430 ± 45.3^{d}	13.8 ± 0.5^{d}	8.5 ± 0.5^{f}	10 ± 0.5^{ef}	4.4 ±0.4^{cd}	11.2 ± 0.1^{b}
Line 2	813.7 ± 72.2^{bc}	16.8 ± 0.5^{c}	10.5 ± 0.4^{cd}	11 ± 0.5^{de}	5.8 ± 0.3^{bc}	11.6 ± 0.1^{b}
Line 3	898.5 ± 62.5^{b}	17.2 ± 0.5^{bc}	11.4 ± 0.3^{bc}	11.6 ±0.4^{cde}	6.3 ±0.3^{bc}	8.7 ± 0.2^{d}
Line 4	1246.7 ± 70.3^{a}	21.2 ± 0.5^{a}	11.9 ±0.2^{b}	15.6 ± 0.9^{a}	6.7 ±0.2^{b}	8.6 ± 0.2^{d}
Line 5	586.7 ± 58.2^{cd}	16.6 ± 0.6^{c}	10 ± 0.5^{de}	13.7 ± 0.6^{b}	7 ± 0.5^{b}	12.3 ± 0.2^{a}
Line6	1240.8 ± 93.9^{a}	18.5 ± 0.6^{b}	13.3 ± 0.6^{a}	15.7 ± 0.6^{a}	11 ± 0.7^{a}	10 ± 0.2^{c}
Line7	586.3 ± 36.2^{cd}	16.5 ± 0.5^{c}	9.2 ± 0.4^{ef}	12.7 ± 0.5^{bc}	3.1 ± 0.3^{e}	12.3 ± 0.2^{a}
Line8	626.7 ± 44.9^{c}	17.5 ± 0.4^{bc}	9 ± 0.3^{ef}	12.3 ± 0.4^{bcd}	5.2 ± 0.1^{cd}	7.4 ± 0.2^{e}
LSD	171.9	1.5	1.22	1.6	2	0.5
CV%	43.6	17.2	23.1	25.3	19.1	10.6

The data are expressed as means ± standard error of the mean. The means followed by the same letters in the same column are not significantly different at P≤ 0.05 (n=30).

block design and the set-up replicated three times. The normal agriculture and agronomic practices were performed for the plants. Ten fruits were hand picked randomly at colour break stage from 11 months' old papaya tree from the farm with three replications for each hybrid. The fruits were wrapped with newspapers and placed gently in crates in single layers, then transported to the laboratory, sorted, washed and dried at room temperature (25°C±2) for about 30 min. The fruits were then stored at room temperature and relative humidity of 65 to 70% for four days.

Morphological and quality characterization of the fruits

Phenotypic characterization of the new papaya hybrids and the control was determined using papaya descriptors (International Board for Plant Genetic Resources, 1988). The weights of papaya fruits were determined by using an electronic weighing balance (Dahongying, SKU model) and then grouped into small, medium or large based on the fruit's weight, length and diameter. Small fruits consisted of fruits weighing less than 500 g, 15 cm long or less and up to 10 cm in diameter. The medium fruits weighed between 500 and 1000 g and were between 15 and 25 cm long and between 10 and 13 cm in diameter while large fruits consisted of fruits weighing greater than 1000 g or ≤3000 g, >25 cm in length and >13 cm in diameter. The papaya fruits were classified into extra class, class I or class II according to the guidelines of the Codex standard for fresh papaya fruits (Codex Alimentarius, 2007). Data for fruit length, diameter and fruit cavity dimensions were collected using a set of Vernier calipers. Longitudinal sections of the harvested fruits per tree were made and then the fruits lengths were measured from the base of calyx to the tips of fruits using digital Vernier caliper. The diameters of the fruits were measured at the broadest part from the equator. The longitudinal and transversal sections of the harvested fruits per tree were also made for determining the central cavity sizes and shapes. Fruit skin and fresh colour were determined using the Royal Horticultural Society Colour Chart (RHS, 2015). The colours were arranged in four fans with each fan having specific colour group with numbers and letters. Then, a hole was placed on fruits surface or fresh in the presence of natural light and the corresponding colour recorded.

Fruit shelf life was evaluated for the fruits at interval of two days from the beginning of ripening until the end of edible life at room temperature (25±2°C) and relative humidity of 65 to 70%. The number of days the fruits lasted at room temperature before softening was recorded. The total soluble solid (TSS) was determined for the fruits using an Atago hand held refractometer (Model RX5000, Tokyo, Japan).

Data analysis

Quantitative data on the fruit weights, diameter and length, internal cavity length and diameter, % brix and shelf life were subjected to a one way analysis of variance using GenStat software 14th edition (VSN International Ltd.) to assess any differences between commercialized hybrid, sunrise solo and the newly developed hybrid lines. Statistical significance was determined at 95% and means separated by the Duncan's Multiple Range test. Qualitative data on fruit colour, shape, texture and ridging on the fruit surfaces were summarized using cross tabulations and processed descriptively using means, frequencies and percentages and chi-square (χ^2) using the Statistical Package for Social Sciences (SPSS) version 18 (SPSS Inc. Chicago, USA) with a statistical significance of 95%.

RESULTS

Morphological characteristics of fruits of the new papaya hybrids

The weights of the fruits varied significantly (Table 1; P < 0.05) between the new papaya hybrid lines and Sunrise solo and ranged from 430 g in Line 1 to 1246.7 g in Line 4. The lightest hybrid line was 110 g lighter than control, Sunrise solo (Table 1). Averagely, papaya hybrid Line 4 also had the longest fruits, while the control, Sunrise solo had the shortest fruits. The mean fruit length varied significantly (Table 1; P< 0.05) between the hybrids and the control. The longest mean fruit diameter of 13.3 cm was recorded in Line 6 while the shortest mean fruit diameter of 8.5 cm was observed in Line 1. The mean fruit internal cavity length varied significantly (Table 1; P <

Figure 1. Morphology of new papaya hybrid lines. **(A)** Sunrise solo with small fruits; **(B)** Line 1 with small fruits; **(C)** Line 2 with small and medium fruits; **(D)** Line 3 medium to large fruits; **(E)** Line 4 with large fruits; (F) Line 5 with small and medium fruits; **(G)** Line 6 with large fruits; **(H)** Line 7 with small and medium fruits; **(I)** Line 8 with small and medium fruits.

0.05) between the new hybrid lines and the control with shortest length in control (8.5 cm) and the longest length in Line 6 (15.7 cm). The mean fruit internal cavity diameter also varied widely and significantly between the hybrids and the control from 3.1 cm in Line 7 to 11 cm in Line 6. Generally, TSS varied significantly from 7.4 to 12.3° Brix in the new papaya lines with lines 5 and 7 having the highest TSS and Line 8 with the lowest TSS (Table 1; $P < 0.05$).

Qualitative characterization of the new papaya hybrids

The shapes of the fruits varied widely and significantly ($\chi 2 = 1137.2$; df = 96, $P < 0.01$) among the new papaya hybrid lines (Figure 1) and the Sunrise solo with 13 different shapes being observed. However, Line 1 had the highest number of varied shapes consisting of 56.7% of fruits with oval shape, followed by round-shaped fruits with 26.7%, elliptic (6.7%), and globular, high round and pear-shaped each with 3.3% fruits. Fruits belonging to Line 2 were divided into five different shapes with 56.7% being turbinate inferior, followed by elongated fruits with 20%, elliptic (16.7%), and club and globular each with 3.3% of fruits. Majority of the fruits (70%) belonging to the Line 3 were oblong-blocky shaped but a few were elongated (13.3%), club-shaped (10%) or rounded (6.7%). Fruits from Sunrise solo had three different shapes with majority (70%) being pear-shaped, a few were oval (16.7%) or round (13.3%) in shape. Fruits belonging to Lines 4, 5, 6, 7 and 8 varied widely but were

divided only into two shapes. Hence, fruits belonging to Line 6 were equally grouped into globular or Oblong-ellipsoid, while 36.7, 73.3 and 46.7% of fruits in Lines 5, 7 and 8, respectively were elongated. Pear-shaped fruits were the majority observed in Line 4 (70%) and Line 5 (63.3%) while 26.7% of fruits in Line 7, 30% of fruits in Line 4 and 53.3% of fruits in Line 8 were elliptic, plum-shaped and blossom-end tapered, respectively.

The skin texture of ripened fruits in most hybrids (50.7%) was intermediate or smooth (40.7) with few hybrids, namely Lines 4, 7 and 8 having rough skin texture (Table 2). The texture of ripened fruits varied significantly (χ^2 =126.7; df =16, P <0.01) in all the papaya hybrids (Table 2). The ridging on fruits' surfaces varied significantly (χ^2 = 115.3; df = 16, P < 0.01) among the new papaya hybrids and the control. Intermediate ridging was common in all the hybrids while superficial and deep ridging types were not observed in Lines 6 and 1, 2 and 8, respectively (Table 2). The majority of all fruits had slightly (56.7%) or star-shaped (39.65%) central cavity. However, the central cavities of a few fruits in Line 7 were irregular (0.7%) and a few fruits in Lines 2 and 7 and majority in Line 8 were angularly shaped (3.0%) (Table 2). Significant variation in skin colour was observed (χ^2 = 768.7; df= 32; P< 0.01) (Table 2) with vivid yellow (38.9%), vivid yellowish green (21.9%) and strong orange yellow (19.3%) being the most dominant in all hybrids fruits. The flesh colour of the fruits (Figure 2) also varied significantly in papaya lines with the control (χ^2 =768.78; df = 32, P < 0.001). Five different flesh colours were found among the newly papaya hybrids and the Sunrise solo (Table 2). The study also found diversity (χ^2 = 183.4; df = 24, P <0.001) in fruit stalk end shape including depressed (30.4%), flattened (28.1%), inflated (16.7%), and pointed (24.8%).

Classification of new papaya hybrids based on fruit size

Among the evaluated new papaya hybrids, Line 1 showed the highest proportion of fruits with small size (70%), followed by Sunrise solo with 50% and Line 5 with 46.7%. The highest proportion of medium sized fruits was recorded in Line 7 with 63.3% fruits, followed by Lines 8 and 3 each with 60% and Line 5 with 40% fruits (Table 3). Majority of large fruits were however recorded in Lines 6 and 4 with 63.3 and 76.7% of large fruits, respectively (Table 2). All the assessed fruits belonging to Lines 5 and 7 were grouped into extra class, fruits belonging to the Sunrise solo, Lines 1, 2, 4 and 6 under class I and those from Lines 3 and 8 felt in Class II (Table 3).

The new papaya fruit hybrids storage characteristics

A gradual decline in eating quality among all papaya fruits was noticed (Figure 3). A distinctness in papaya fruits ripening, shriveling and senescence was recorded between the new papaya hybrid and control. Line 7 had the longest shelf life of 11 days, while Line 1 had the shortest shelf life of 4 days. Fruit softening and decline in organoleptic quality by the 5th day was recorded in Line 1, Line 7 and the control, whereas, Line 7 maintained the quality until the 11th day (Figure 3).

DISCUSSION

From the findings of this current study, the morphological and quality characteristics of papaya fruits showed significant differences with majority of newly developed hybrid lines recording higher fruit weights and size than Sunrise solo. Hence, Lines 1 and 8 had smaller fruits sizes that were comparable to Sunrise solo while Lines 4 and 6 recorded bigger fruits, which could be explained by heritability or dominance of either parental line with Sunrise solo conferring small fruit traits to Lines 1 and 8 while its influence was subdued in Lines 4 and 6. Lines 2, 5 and 7 also produced fruits with similar size characteristics indicating dominance of large fruits collected from Voi.

Fruit size, shape, smooth skin and absence of blemishes, skin and flesh colour are the major characteristics that determine the market price and export grades for fruits (Barrett et al., 2010; Zhou et al., 2014). Fruit colour gives the first impression of the fruits to the consumers and is an indicator of freshness and flavour quality. Hence, an attractive product can stimulate the desire of purchasing while an inappropriate colour indicates loss of freshness or lack of ripeness (Okoth et al., 2013; Barrett et al., 2010). In papaya, most female plants produce large round-shaped fruits of good quality with a large seed cavity while hermaphrodite plants produce small to medium elongated fruits of good quality but with a smaller seed cavity (Villegas, 1997; Nakasone and Paull, 1998). Researchers observed a significant variation and number in the shapes of the fruits among the newly developed papaya hybrid lines and Sunrise solo, while the fruit skin colour varied from vivid greenish yellow to vivid yellow. The fruit flesh colour also varied from vivid yellow pink to vivid reddish orange. Therefore, the present study corroborates previous findings of variations in papaya fruit shapes and colour in Mexico, Venezuela, Kenya and Nigeria (Ocampo et al., 2006; Asudi et al., 2010; Aikpokpodion, 2012).

The colour of papaya fruit flesh is determined largely by the presence of carotenoid pigments. Red and yellow are the two major papaya fruit flesh colours and are controlled by a single genetic locus with yellow being dominant over red (Storey, 1969). Besides, the yellow-fleshed fruit contains β-carotene while the red-fleshed papaya fruit has high levels of lycopene and the conversion of lycopene to β-carotene is catalyzed by

Table 2. Qualitative description of the new papaya hybrids.

Descriptor	Papaya hybrids									Mean N = 270	χ^2
	Control	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Line 7	Line 8		
Fruit skin texture when riped (%)											
Smooth	26.7	60.0	76.7	6.7	66.7	60.0	10.0	33.3	26.7	40.7	
Intermediate	73.3	40.0	23.3	60.0	33.3	40.0	50.0	63.3	73.3	50.7	126.7***
Large	-	-	-	33.3	-	-	40.0	3.3	-	8.5	
Ridging on fruit surface											
Superficial	50.0	83.3	80.0	3.3	60.0	46.7	-	53.3	56.7	48.1	
Intermediate	40.0	16.7	20.0	46.7	33.3	23.3	53.3	43.3	43.3	35.6	115.3***
Deep	10.0	-	-	50.0	6.7	30.0	46.7	3.3	-	16.3	
Shape of central cavity											
Irregular	-	-	-	-	-	-	-	6.7	-	0.7	
Angular	-	-	6.7	-	-	-	-	20.0	53.3	3.0	63.9***
Slightly star shaped	53.3	50.0	50.0	53.3	73.3	53.3	73.3	50.0	46.7	56.7	
Star shaped	46.7	50.0	43.3	46.7	26.7	46.7	26.7	23.3		39.6	
Skin colour											
Vivid yellow	56.7	83.8	16.7	33.3	16.7	20.0	6.7	66.7	50.0	38.9	
Strong orange yellow	10.0	3.3	-	50.0	73.3	33.3	3.3	-	-	19.3	
Deep green yellow	13.3	-	6.7	3.3	-	16.7	26.7	-	-	7.4	768.7***
Vivid yellowish green	13.3	13.3	76.7	13.3	-	3.3	13.3	30.0	33.3	21.9	
Deep greenish yellow	6.7	-	-	-	10.0	26.7	50.0	3.3	16.7	12.6	
Fruit flesh colour											
Strong orange yellow	-	-	-	-	-	-	-	96.7	10.0	11.9	
Vivid orange yellow	-	-	-	-	-	-	96.7	3.3	-	11.1	
Vivid yellowish pink	-	-	93.3	-	-	-	-	-	-	10.4	768.7***
Vivid reddish orange	40.0	76.7	6.7	86.7	86.7	70.0	3.3	-	60.0	47.8	
Reddish orange	60.0	23.3	-	13.3	13.3	30.0	-	-	30.0	18.9	
Stalk end fruit shape											
Depressed	40.0	13.3	63.3	30.0	56.7	26.7	33.3	3.3	6.7	30.4	
Flattened	40.0	23.3	20.0	50.0	23.3	26.7	30.0	16.7	23.3	28.1	183.4***
Inflated	16.7	63.3	-	10.0	10.0	10.0	33.3	-	6.7	16.7	
Pointed	3.3	-	16.7	10.0	10.0	36.7	3.3	80.0	63.3	24.8	

***Statistically significant (Chi-square analysis) at $P < 0.01$.

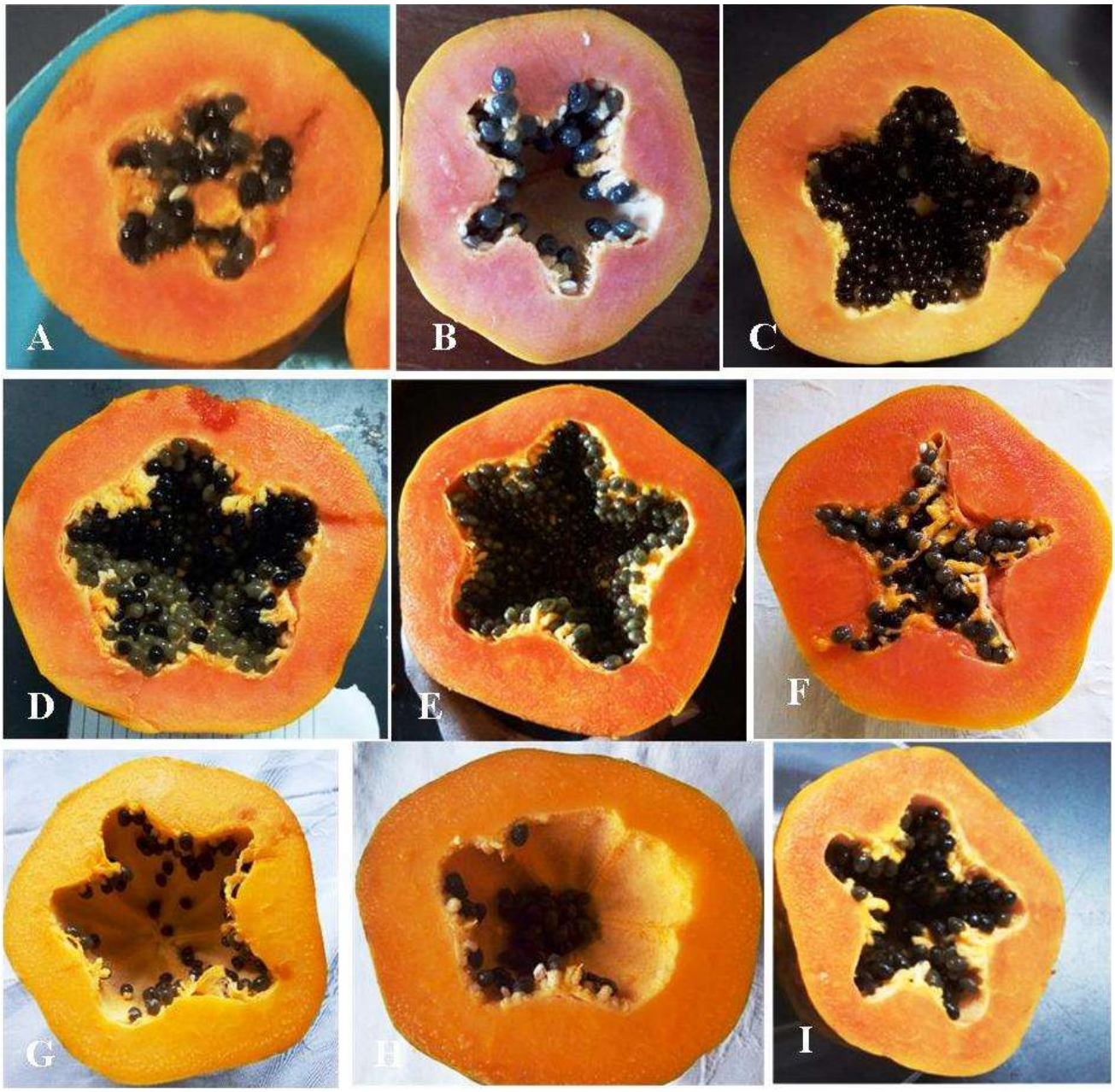

Figure 2. Variations in the fruit central cavity shape and flesh colour among new papaya hybrid lines. **(A)** Sunrise solo with slightly star shaped and vivid reddish orange; **(B)** Line 1 with slightly star shaped and reddish orange flesh colour; **(C)** Line 2 with slightly star shaped and vivid yellowish pink flesh colour; **(D)** Line 3 with slightly star shaped and vivid reddish orange flesh colour; (E) Line 4 with slightly star shaped and vivid reddish orange flesh colour; **(F)** Line 5 with star shaped and vivid reddish orange flesh colour; **(G)** Line 6 with slightly star shaped and vivid orange yellow flesh colour; **(H)** Line 7 with angular shaped and strong orange yellow flesh colour; **(I)** Line 8 with star shaped and vivid reddish orange flesh colour.

lycopene β-cyclase. The carotenoid profile and organization in the cell also differ in yellow and red-fleshed papaya varieties (Yamamoto, 1964; Chandrika et al., 2003; Devitt et al., 2010). Therefore, different papaya fruit flesh colours observed in the present study could be due to differences in the carotenoids content in the newly developed papaya hybrid lines. The variation in skin colour in mature ripen fruits observed among the new hybrid lines and Sunrise solo could also be related with enzymatic degradation or chlorophyll degradation during ripening (Ding et al., 2007; Zuhair et al., 2013).

Besides morphological traits, consumer acceptance of papaya fruit depends on various physicochemical properties including TSS. For instance, TSS of > 11.5°

Table 3. Classification of the new papaya hybrids based on fruits size.

Hybrid	Range (g)	Fruit size classification			CODEX classification
		Small (%)	Medium (%)	Large (%)	
Sunrise solo	200 - 1625	50.0	43.3	6.7	Class I
Line 1	150 - 1200	70.0	23.3	6.7	Class I
Line 2	650 - 930	33.3	36.7	30.0	Class I
Line 3	260 - 2045	6.7	60.0	33.3	Class II
Line 4	685 - 2435	0.0	23.3	76.7	Class I
Line 5	200 - 1400	46.7	40.0	13.3	Extra class
Line6	470 - 2595	6.7	30.0	63.3	Class I
Line7	255 - 1030	33.3	63.3	3.3	Extra class
Line8	320 - 1500	36.7	60.0	3.3	Class II

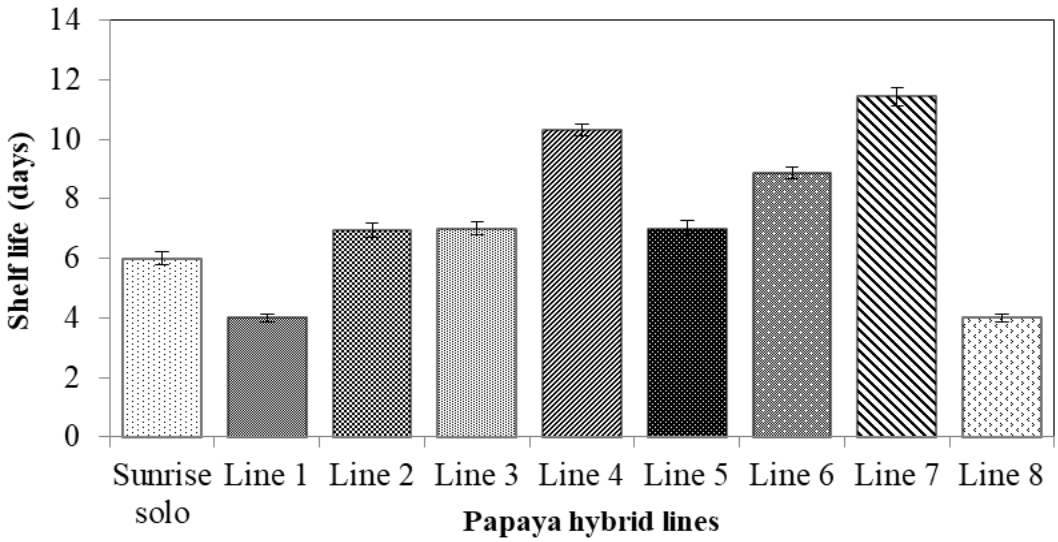

Figure 3. The new papaya hybrids fruit storage characteristics evaluated at interval of two days from the beginning of ripening until the end of edible life at room temperature.

Brix are a minimum grade requirement for traded Hawaiian papayas (Chan and Paull, 2008) while in Jamaica pear-shaped fruits with red flesh, TSS of ≥12° Brix and mass from 385 to 533 g are desired for export. Although similar fruit attributes are required by both the United States (US) and European markets, buyers in the US and the United Kingdom prefer fruits between 274 and 744 g and from 224 to 535 g, respectively (Tennant et al., 2010). In the current study, researcher found desirable TSS ranging from 11.2 to 12.3° Brix in Hybrid Lines 1, 2, 5 and 7 with average weights of 430 to 813 g, which are within the export market limits. However, Hybrid Lines 3, 4 and 6 had large fruits with ≤10° Brix and may be suited for domestic market or local processing industries. However, low °Brix values found in Sunrise solo and Line 8 could have been due to environmental conditions.

The new papaya hybrids fruits were also classified into Extra class, Class I and Class II. The codex standards for fresh fruits and vegetables (Codex Stan 183-1993) indicates different provisions concerning the quality of papaya fruits (Codex Alimentarius, 2007). The Extra class indicates superior quality fruits free of defects; Class I indicates fruits with slight defects in shape or skin due to mechanical, sun spots and/or latex burns with no effect on the fruit's pulp, general appearance and quality of the produce, while Class II includes fruits which satisfy the minimum requirements with defects that may allow them to retain their essential characteristics regarding keeping and presentation qualities. Therefore, this information will assist different actors in papaya value chain to make appropriate decision about the new papaya hybrid lines.

Papaya fruit shows rapid softening and yellowing and has a short-term shelf life due to its climacteric behavior (Archbold and Pomper, 2003; Fernandes et al., 2006).

The storage of papaya fruit at low temperature extends its commercial shelf life, while storage in an inappropriately low temperature results in skin scald, hard lumps in the pulp around the vascular bundles, water soaking of flesh, increased susceptibility to postharvest pathogens and abnormal ripening (Almeida et al., 2005). Therefore, storage conditions in tropics for fresh products are important and essential for quality and shelf life of fruits. In many places of traditional markets and streets in Indonesia in uncontrolled environments, papaya fruits are exposed to high temperatures of up to 30°C, thereby reducing their shelf life (Mohammad et al., 2015). This situation is also common in Kenya where most poor farmers cannot afford such controlled environments to lengthen fruit shelf life. Researchers evaluated the shelf life of newly developed hybrid papaya fruits at room temperature for 14 days and found an average of 4 to 11 days with Line 7 recording the longest shelf life, which could be because of delayed physiological change such as little water loss. This is especially useful for storage, long distance transportation, export and marketing plan for the fruits. Evaluation of morphological and quality characteristics of the fruits of the newly developed papaya hybrid lines has highlighted fruits with small and medium sizes and desirable shapes and TSS that could be suitable for both export and local markets and compared favourably with Sunrise solo, which is an imported papaya variety in Kenya. However, characterization and assessment of distinctness, uniformity and stability of the most performing fruits in different agro-ecological zones is needed in order to monitor the influences of the environment, pests and diseases. There is also need to study the shelf life of newly developed papaya fruits under different temperature conditions or develop new technologies for longer storage to curb postharvest losses.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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