CHARACTERIZATION OF MORPHOLOGICAL AND QUALITY CHARACTERISTICS OF NEW PAPAYA (*Carica papaya L.*) HYBRIDS DEVELOPED AT JKUAT

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Characterization of Morphological and Quality Characteristics of New Papaya (*Carica papaya L)* Hybrids Developed at JKUAT

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A thesis submitted in partial fulfillment for the Degree of Master of Science in Horticulture in the Jomo Kenyatta University of Agriculture and Technology

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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This thesis has been submitted for examination with our approval as University Supervisors.

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DEDICATION

I dedicate this research thesis in memories of my late father SIBOMANA Ibrahim and my mother in law AKIMANIZANYE Consolée may their souls rest in peace. It is also dedicated to my mother Mukagasana Agnes, my Husband Maniraho Eric and my beloved daughter Ishimwe Rugira Olga.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis Of Variance
DCPIP	Dichlorophenolindophenol
DRI	Dietary Reference Intakes
DV	Daily Value
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Corporate Statistics Database
GDP	Gross Domestic Product
HCD	Horticultural Crop Directorate
IFAD	International Fund for Agricultural Development
NARI	National Agricultural Research Institute
PRSV	Papaya Ringspot Virus
PoU	Prevalence of Undernourishment
TSS	Total Soluble Solids
TTA	Total Titrable Acid
UN	United Nations
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
UV	Ultraviolet
WHO	World Health Organization

ABSTRACT

The issue of accessing high quality nutritious foods such as fruits is a major challenge for many African people. Papaya (*Carica papaya* L.) is among the most grown fruit crops worldwide with high economical and nutritional value. It is grown for a variety of products including juice, wine, jams, candies and dried fruits. Papaya is a very wholesome fruit and an excellent source of vitamins A and C. In Kenya, the papaya industry relies heavily on imported varieties and farmers' selected seeds whose quality is not known. Researchers at Jomo Kenyatta University of Agriculture and Technology (JKUAT) recently developed promising papaya hybrids (lines 1, 2, 3, 4, 5, 6, 7 and 8). However, their morphological and quality characteristics have not been evaluated. Thus the main objective of this study was to evaluate the morphological, nutritional and organoleptic properties of the newly developed JKUAT papaya hybrids fruits. The morphological traits (fruits weight, fruits length, fruits diameter, internal cavity diameter, internal cavity shape, skin colour, flesh colour and stalk end fruit shape), fruits shelf life, physicochemical (pH, total soluble solid, titratable acid and total soluble solid/titratable acid ratio), vitamins (ascorbic acid and β carotene) and organoleptic test were evaluated. The mature fruits of eight newly developed papaya hybrids and their control, Sunrise Solo were evaluated using descriptor for papaya, International Board for plant Genetic Resources (IBPGR), Royal horticulture colour chart, Codex standard for fresh papaya fruits (Codex Stan 183-1993), the standard AOAC methods and the 9- point hedonic scale. The results demonstrated significant differences in fruit size among the newly developed papaya hybrid lines and the control. Line 4 had the longest and heaviest fruits. Fruits from Sunrise Solo, lines 2, 3, 7 and 8 ranged from small (≤ 500g) to medium in size (>500g ≤ 1000g), while those of lines 4 and 6 were large (> 1000g ≤ 3000g). Line 1 had the shortest shelf life of 4 days while Line 7 had the longest shelf life of 11 days.

There was significant difference ($P < 0.05$) in physicochemical and vitamins content among the new papaya hybrids and Sunrise Solo. The total soluble solids (TSS) varied from 7.4 in line 8 to 12.3°Brix in lines 5 and 7. The maximum Vitamin C content of 131.63 mg/100g was recorded in line 6 while the minimum of 51 mg/100g was recorded in line 8. Vitamin A content ranged from 1.69mg/100g to 3.39 mg/100g. Lines 2,7,5,1 and Sunrise Solo were best preferred in the overall acceptability rating as the most liked, thus were promising for fresh consumption compared to line 8 which was the least liked. Hence, most newly developed papaya hybrid lines had quality traits which were comparable to or even superior to Sunrise Solo, which implies that they may be suitable for both local and export markets.

The findings of this study indicate that newly developed papaya hybrid lines have fruits with superior vitamins content than Sunrise Solo. The study suggests that the newly developed papaya hybrid fruits possess excellent levels of ascorbic acid and β-carotene. Therefore, consumer education on the nutritional benefits of papaya consumption could eventually contribute to increased consumption of papaya. The findings of this study will also assist breeders in selecting the best performing papaya hybrids for commercialization and for further quality improvement. All the new papaya hybrid lines should be evaluated in different agro-ecological zones to establish the influences of different ecological conditions on their morphological and quality characteristics.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The world is faced with a lot of challenges including lack of sustainable development and inability to feed its growing population leading to problems such as lack of sufficient food and malnutrition (Godfray *et al*., 2010). The sub-Sahara Africa (SSA) remains the region with the highest prevalence affecting 22.7% of its population in 2016 (FAO, 2017).

The United Nations sustainable development goal calls for an end to 'all forms of malnutrition' by 2030 (UN, 2016). The latest estimate for 2016 indicates that 155 million people under five years across the world are suffering from stunted growth that causes irreversible blindness and death (FAO, 2017). Recent findings of Kenya demography and health survey have also shown that a quarter of all children aged less than five years are stunted because of malnutrition (KNBS, 2015).

Fruits contribute significantly to human nutrition especially in supplying micro- and macronutrients and income generation to farmers (Bhardwaj and Nandal, 2015). Fruits are considered as a commercially important and nutritionally essential food commodity based on its provision of nutrients such as sugars, organic acids, vitamins and minerals, and other non-nutrients constituents including dietary fiber and secondary metabolites with health-beneficial effects (Díaz-Mula, 2011). Papaya (*Carica papaya* L.) belonging to the family Caricaceae and order Brassicales is among the most widely grown fruit crops. Exactly origin of papaya fruits is unknown, probably crop originated from tropical America from where it was distributed to Caribbean and Asian countries, but currently papaya fruits is grown worldwide mainly in the tropics and sub-tropical regions (Morton, 1987).

Papaya fruits have high economical and nutritional value (Imungi and Wabule 1990; Nakasone and Paull 1998; OECD 2005; Ming et al. 2008; Asudi 2010). It is valued for its high nutritive, income and medicinal values (Srivastava and Singh, 2016). It is also an important fruits for export and household income. Papaya is grown for a variety of products including juice, wine, jams, candies and dried fruits. The ripe papaya fruits are eaten fresh as breakfast and dessert fruits, salads and can be processed as juice, jelly, marmalade, candies or as crystallized fruits (Asudi 2010; Saran & Choudhary, 2013). 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, C, the minerals, fibers and papain enzyme (Imungi and Wabule 1990; Nakasone and Paull 1998; Wijaya and Chen 2013). The intake of A small sized papaya fruit of 100g is able to supply more than the Dietary References intake (DRI) of 74-145 mg for Vitamin C (NAS, 1980; Imungi and Wabule, 1990).

The papaya fruit shows a wide variation in many traits including fruits, plant stature and leaf characteristics (Ocampo et al. 2006; Aikpokpodion 2012; Asudi et al. 2010), 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).

Recent evidence also indicates that various commercial varieties such as 'US', 'Redlady', 'Sunrise', 'Sunrise-Solo' and 'Honey dew' from Asia and America, are frequently imported as seeds by some farmers in Kenya (Asudi, 2010). However, majority of other cultivated papaya cultivars have no known names and are either known vernacularly as 'local', 'papayi' or 'apoyo' depending on the region (Asudi *et al.* 2010, 2013).

The varieties such as Kiru, Malindi, PP1, 77, 116, 273, 418,455 and 457 reported in Kenya in the 1990s (Imungi and Wabule, 1990) no longer exist. The decline has been attributed to lack of quality planting materials, genetic erosion due to open pollination, pests and diseases such as ringspot viruses (HCD, 2016; Rimberia *et al.*, 2018). The papaya has been cultivated in Kenya for over 50 years; however the quality of the fruits is still deficient as there are no specific varieties identical for fresh or processing needs to attract major revenue to boost economic development of the country (Rimberia et al., 2011). These challenge of papaya cultivation in Kenya lead to the new hybrid lines under evaluation. Varietal improvement was done by the researchers at JKUAT and the specific interest were to development clean planting materials of high yields and desirable quality fruits in Kenya (Rimberia et al., 2018).

1.2 Problem statement

Papaya fruits have high economical and nutritional value (Imungi & Wabule, 1990). However, global papaya industry is challenged by three major problems including, pest and diseases infestation, post-harvest losses along the marketing chain (Evans *et al*., 2012) and unreliable methods of sex determination among the three sex types (male, female and hermaphrodite) until flowering stage (Rimberia *et al*., 2018).
The papaya ringspot virus (PRSV) is the main disease that drastically reduces fruit yield, fruits size and quality and in some cases results in total loss of production (Tennant *et al*., 2001; Ferreira *et al*., 2002; Evans *et al*.,2012). The disease seriously narrowed the speed of wide papaya production and expansion and the efforts to eliminate this problem led to the development of new cultivars in different countries.

Papaya is produced on small and large scale farms throughout Kenya (Asudi et al., 2010). According to the horticultural validated report, papaya contributed 2.21 billion shillings accounting for 4% of fruits sub-sector; with the area and yield production decreased by 13% and 16 % respectively from 2015-2016 (HCDA, 2016). The most of available papaya varieties were introduced from Hawaii, Philippines, India and Indonesia (Asudi et al., 2013). Since their introductions to Kenya, there were little attempt to develop improved papaya varieties uniquely suited to changing climatic conditions (Rimberia *et al*., 2018).

Most of the available varieties lack quality planting material mainly due to genetic erosion arising from open pollination of papaya (Asudi et al., 2013). In addition, lack of established seed producers in the country means papaya industry relies on imported varieties and farmer's selected seed whose qualities are not known. The available papaya varieties are also challenged by pest and diseases, which compromise the fruit quality.

The most devastating disease is PRSV (Asudi, 2010). The PRSV drastically reduces fruit yield, fruits size and quality and in some cases results in total loss of production (Tennant *et al*., 2001; Ferreira *et al*., 2002; Evans *et al*., 2012). Varieties and landraces of papaya that could potentially be improved for quality and more profitable productivity to suit a variety of locations were reported in Kenya (Asudi et al., 2013). The said challenges have led the researchers at JKUAT to the development of the papaya hybrids which are high yielding, dwarf and tolerant to viral diseases (Rimberia *et al*., 2018). However, the morphology and quality characteristics of the fruits have not been evaluated and documented.

1.3 Justification

The JKUAT research team developed new papaya hybrids from cross pollination between the best performing local germplasms and commercial variety Sunrise solo. However, characterization of the newly developed papaya hybrids morphology and quality diversity has not been done. Fruits morphology and quality data are valuable parameters to be considered in breeding programs.

1.4. Expected output

Fruits morphological data could be considered in trials devoted to adaptation to growing conditions while the nutritional and organoleptic characteristics can be targeted to develop functional food recipes for health, specifically to reduce prevalence of Vitamin C and A.

Characterization of morphological, physicochemical, vitamins and organoleptic properties of newly developed papaya hybrids has a significance impact on development and release of the new hybrids.

Being the first characterization done on these new papaya hybrids, the findings would be beneficial to the breeders who will know how their hybrids performed; this will ascertain their commercialization potential and further improvement. Besides that, documentation on nutritional content will assist the dietician and the whole population in preparing the balanced diets.

The findings will also increase the consumer’s awareness toward papaya fruits intake resulting in healthier and decrease of malnutrition thus, promotes good health and enhance sustainable development.

1.5. Objectives

1.5.1 General objective

The overall objective of the current study was to evaluate the morphological, nutritional and organoleptic properties of the newly developed JKUAT papaya hybrids fruits.

1.5.2 Specific objectives

- To determine morphological characteristics and shelf life of the new JKUAT papaya hybrid fruits
- To determine the physicochemical, vitamins and Organoleptic quality characteristics of the new JKUAT papaya hybrid fruits

1.6 Hypothesis

- The new JKUAT papaya hybrid fruits are not different in their morphological traits and shelf life
- The new JKUAT papaya hybrid fruits are not different in physicochemical, Vitamins and organoleptic quality characteristics

CHAPTER TWO

LITERATURE REVIEW

2.1. Papaya production

2.1.1. Global production

Papayas are important fruits produced in four different regions worldwide. The annual global production from 2006 to 2016 is estimated to range between 9.119 and 13.051 million tons. According to (FAOSTAT, 2018), 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. The dominant papaya producing countries are India, Dominican Republic, Mexico, Costa Rica, Indonesia, Nigeria and Belize.

Table2.1: Worldwide Papaya production in Million tons from 2006 to 2016

Region /Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
World	9.119	9.633	10.074	10.591	10.785	11.296	12.014	12.359	12.699	12.077	13.051
America	4.064	4.165	3.769	3.948	3.905	3.840	3.656	3.864	4.089	4.154	4.322
Africa	1.242	1.246	1.220	1.203	1.231	1.250	1.295	1.312	1.381	1.400	1.370
Oceania	0.014	0.015	0.015	0.014	0.013	0.014	0.013	0.013	0.016	0.017	0.015
Asia	3.799	4.207	5.070	5.426	5.636	6.193	7.050	7.170	7.213	6.506	7.343

Source: FAOSTAT (2018)

2.1.2. Papaya production in Africa

In Africa, papaya is produced in seventeen countries; most of which have shown declining production level between 2015 and 2016 years. The leading papaya producers in the Africa continent are Nigeria and DRC with 836.7 and 215.26 thousand tons respectively in 2016 (Table2.2).

Table2.1: Papaya production in eleven Africa countries (Million Metric tons) from 2006 to 2016

Country/Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Côte d'Ivoire	6.67	9.42	9.69	9.97	11.63	11.05	12.36	13.14	14.13	15.10	15.95
DRC	217.9	219.8	221.8	223.8	225.8	227.8	224.6	215.1	216.9	216.08	215.3
Ethiopia	73.57	57.27	44.00	43.66	40.25	42.57	38.69	31.59	40.44	53.04	50.40
Ghana	3.80	4.10	4.00	4.20	4.50	4.80	5.00	5.35	5.56	5.56	5.56
Guinea-Bissau	1.80	2.20	2.30	2.37	2.48	2.60	2.80	2.85	2.98	3.01	3.12
Kenya	86.00	89.59	88.00	71.25	98.14	101.4	133.5	132.6	125.1	122.63	128.1
Mali	28.27	30.79	31.00	29.55	32.36	33.00	35.00	43.69	59.75	52.47	54.66
Mozambique	41.00	41.50	41.73	42.00	44.00	43.01	45.00	43.27	42.36	42.44	42.50
Nigeria	759.0	765.0	750.0	752.4	750	760	775	800	850	870.9	836.7
Rwanda	6.00	7.00	7.65	5.83	5.86	5.87	6.00	5.41	5.00	4.58	2.92
South Africa	14.30	15.45	15.67	14.14	12.08	13.31	12.71	14.88	14.60	9.97	9.92

Source: FAOSTAT (2018)

2.1.3. Papaya production in Kenya

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. The area under production and yields have also decreased rapidly from 9,346 ha 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 (HCD, 2014). The leading counties in papaya production by value are Machakos, Meru and Makueni accounting for 15 percent, 13 percent and 10 percent respectively (HCD, 2016).

Table2.1: Production area and volume of papaya in selected counties 2012-2016

County	2012		2013		2014		2015		2016	
	Area (Ha)	Volume (MT)	Area (Ha)	Volume (MT)	Area (Ha)	Volume (MT)	Area (Ha)	Volume (MT)	Area (Ha)	Volume (MT)
Bungoma	824	20,269	946	23,438	994	24,725	73	862	60	1,236
Nyeri	2,600	28,600	3,800	41,800	3,995	35,156	-	-	-	-
Tharaka Nithi	735	15,699	732	13,672	682	13,579	1,101	9,370	1,093	9,150
Kwale	491	8,369	532	8,326	1,175	17,579	974	16,368	814	7,862
Makueni	393	11,728	405	8,720	791	9,589	378	5,521	506	7,430
Machakos	-	-	-	-	-	-	1,618	14,182	1,742	15,108
Meru	-	-	-	-	-	-	320	6,982	532	9,944
Kilifi	-	-	-	-	-	-	1,946	37,943	450	22,537
Elgeyo Marakwet	-	-	-	-	-	-	112	3,540	187	4,921
Murang'a	-	-	-	-	-	-	215	3,834	230	2,208
Homa Bay	-	-	-	-	-	-	124	1,473	167	2,054
Migori	-	-	-	-	-	-	320	4,926	240	3,412
West Pokot	-	-	-	-	-	-	262	1,796	266	1,824
Tana River	-	-	-	-	-	-	404	4,340	229	2,740
Kirinyaga	-	-	-	-	-	-	343	1,898	364	2,824
Kisii	-	-	-	-	-	-	89	1,940	90	2,333
Siaya	-	-	-	-	-	-	100	1,538	121	1,104
Others	4,756	65,569	5,266	64,215	5,092	60,202	968	11,268	1,023	10,903
Total	**9,799**	**150,234**	**11,681**	**160,171**	**12,729**	**160,848**	**9,346**	**127,782**	**8,112**	**107,591**

Source : HCDA, 2014 and HCD, 2016 .

The Hyphen (-) indicates where they was no records

2.2. Benefits of papaya

2.2.1. Health and pharmacological benefits

Papaya has a lot of potential to improve the health and wealth of the population. All the nutrients of papaya are effective in protecting the human body against several types of cancers, cardiovascular diseases, strokes and micronutrient deficiencies (Vij & Prashar, 2015). Besides that, the fruit is an excellent source of beta carotene that prevent damage caused by free radicals that may cause some forms of cancer (Aravind *et al*., 2013). The studies indicated that small papaya fruit piece with edible portion of approximately 100g can provide vitamin C ranging between 75-145 mg/100g and beta carotene ranging between 0.4-2.3 mg/100g (Imungi and Wabule, 1990). These value exceeds the dietary reference intakes (DRI) for vitamin C and provide more than 50% of beta carotene of RDA for all ages group (Food and Nutrition Board , Institute of Medicine, 2011).

2.2.2. Socio-economic benefits

Papaya fruit is a source of income for many farmers poor population (Table.2.4). Papaya cultivation provides rapid investment returns due to early maturation, intensive cultivation and high yielding. The papaya is an ideal fruit for growing in kitchen size gardens, home backyards as well as orchards due to its nature as single stemmed tree (Rimberia *et al*., 2014). This motivates both small and large scale farmers to grow the crop. Most papaya varieties in the tropics can be harvested 8-9 months after planting with yields ranging from 60 to 100 T/ha/year for improved varieties (Chan, 2009). Papaya is mostly grown for both fresh consumption and processing of products like; papaya drinks, jams, candies and dried fruit. Unripe papaya fruits and latex from stem which made up of proteolytic enzyme are used in meat tenderizing, cosmetics, pharmaceuticals and chill- proofing beer (Nakasone and Paull, 1998).

Papaya also provides jobs to the farmers, middlemen involved in marketing of papaya products and persons employed in processing industry. Export of papaya and papaya products increase foreign exchange earnings (HCD, 2016).

Table.2.4. Production, volume and values of Kenyan papaya from 2012 to 2016.

Year	Production (Ha)	Volume (MT)	Value (Million KES)
2012	9,799	150,234	3,137
2013	11,681	160,171	3,249
2014	12,729	160,848	3217
2015	9,346	127,782	2,102
2016	8,112	107,591	2,205

SOURCE: (HCDA, 2014; HCD, 2016)

2.3. Main challenges facing papaya industry in Kenya

Kenya's main papaya varieties are of 'Solo' derivative, which are characteristically tall. The economical production life of Solo is only the first 3-4 years, after which the trees become too tall for farmer to carry out agronomic practices like chemical application, scouting of pest, diseases and harvesting (Asudi et al.,2010). Farmers have no choice but to renew the orchards every 3-4 years (Rimberia et al., 2011). This is uneconomical for farmers in terms of time and capital investment.

Further, the recent outbreak of PRSV and fungal diseases cause the retarded growth leading to a significance decrease in yield and quality of fruits (Tennant et al., 2001). Beside this, the bulk (over 99%) of papaya produced in Kenya is consumed locally as fresh fruit and also processed in jam and wine, while small quantities are exported (Rimberia et al.,2011).
The major export destination for the Kenyan papaya is Europe (United Kingdom, France and Germany) and very small quantities go to United Arab Emirates.

The export market is accessed by a few large scale farmers who are able to produce fruits of superior quality based on the national and international requirements of Good Agricultural Practices (Rimberia et al., 2011). The major challenges of papaya fruits production in Kenya are lack of quality planting materials, low productivity, insect pests and diseases and lack of papaya seed producers (HCD, 2016 ; Rimberia et al., 2018). These problems do not only affect yield but also quality of the fruits.

2.4. Papaya description and origin

The papaya, *Carica papaya* L., is a member of the small family Caricaceae (Morton, 1987; De la Cruz Medina *et al*., 2003). Papaya is a soft- wooded, mostly unbranched, herb-like tree crowned with large, palmate-lobed leaves having stout petioles attached directly on the main stem (Ming *et al*., 2008). The tree is large herb growing at the rate of 3 m the first year and reaching over 9 m in height with a hallow green or deep- purple stem becoming 30-40 cm (Morton, 1987; Teixera da Silva *et al*., 2007).

Papaya tree's life span can go up to 5-10 years, therefore, after 2-3 years of cultivation the tree become too tall which complicate the management and harvesting, thus they need to be replanted (Chan, 2009; Asudi *et al*., 2010). Generally the fruits is melon-like, oval to nearly round, somewhat pyriform or elongated club-shaped, 15-50cm long and 10-20cm thick (Morton, 1987; De la Cruz Medina *et al*., 2003).

The fruit weight also varies substantially and may range from 0.2kg-12kg depending on the environment and variety (OECD, 2005). The size preferences vary among countries and markets. Export market in USA, Europe and China prefer the small fruits 'Solo' and 'Eksotika' types while the domestic market in Malaysia prefers the medium fruits of the 'Sekaki' variety. Overly large fruits have lost out popularity because of the inconvenience in handling and generally poorer eating quality (Chan, 2009).

Papaya originated from tropical America from where it was distributed to Caribbean and Asian countries, but currently papaya fruits is grown worldwide mainly in the tropics and sub-tropical regions (Morton, 1987; De la Cruz Medina *et al*., 2003; Asudi, 2010).

2.5. Papaya growth and development

Papaya fruit growth and development from pollination to maturation varies with the cultivars, age of bearing trees, time of year of anthesis and the stage selected as an index of fruit maturity (Nakasone and Paull, 1986; Moore, 2014). Papaya starts flowering four months after sowing and produces ripe fruits within 9 months. Once the tree starts flowering, it produces flowers in all seasons, which is a good opportunity for continuous supply of planting material for experiment and continuous fruits yield (Aryal and Ming, 2014).

After fruit set, the fruit undergoes anatomical changes during its development. During the earlier stage of the development, the tissues are predominantly composed of meristematic cells. Later, the outer layer of the epidermal cells increases in size while the sub-epidermal layer remains meristematic (Ram, 2005). In advanced stages, the sub-epidermal cells enlarge and their oval shape creates intercellular spaces. Increase in fruit diameter follows and later, the placenta develops throughout the inner wall of the ovary.

When the fruit reaches maturity, the epidermal cells become small, and 5 to 10 layers of cells with chloroplast develop under it. The pericarp of the fruit is composed of laticifers which develop close to the vascular bundles. The laticifers are ramified throughout the fruit and they secrete latex which contain papain. The fruits rapidly develops owing to rapid cell division and cell elongation (Ram, 2005).

The growth of papaya fruit exhibits a simple sigmoid curve showing increase in dimension, weight and volume. Initial fruit growth is slow, followed by a rapid increase in length, diameter, size, volume and weight. As the fruit matures these growth parameters either level off or decline slightly (Ram, 2005; Puschmann *et al.*, 1997). The fruit has a large cavity containing numerous seeds attached to the inner lining of the ovary wall. It has a smooth, thin skin or pericarp which is green when immature and yellow to orange when ripe.

2.6. Description for papaya fruits

The papaya fruit is melon-like, oval to nearly round, somewhat pyriform, or elongated club-shaped, 15-50cmlong and 10-20cm thick and weighing up to 9kg (Morton, 1987). Semi –wild plants bear small fruits 2.5-15cm in length. The skin is waxy and thin but fairly tough, when the fruit is immature, it is rich in white latex and skin is green and hard (Teixera da Silva et al 2007).

As ripening progresses, papaya fruits develop a light-or deep-yellow-orange coloured skin while the thick wall of succulent flesh becomes aromatic, yellow-orange or various shades of salmon or red. It is then juicy, sweetish and somewhat like a cantaloupe in flavour but some types is quite musky (Morton 1987). Mature fruits contain numerous grey-black ovoid seeds attached to the flesh.

Table2.5. Description of commonly cultivated papaya varieties

Variety	Description	Photo
solo	High quality selection with reddish-orange flesh weighing about 500g, pear shaped	
Cavity special	A semi dwarf type. Fruit is large, oblong and weighs from 3-5kg. It has a star shaped cavity and yellowish orange flesh	
Red Lady	Tolerant to PRSV, fruits are short-oblong on female and long shaped on bisexual plants, weighing about 1.5-2kg	
Sinta	Moderately tolerance to PRSV, fruits weighs about 1.2-2kg and flesh colour is deep yellow. Fruits from female plant are round and oblong from hermaphrodite	

2.7. Maturity Indices

Maturity standards have been evaluated for various fruit, vegetable and floral crops. Harvesting crops at the proper maturity allows handlers to begin their work with the best possible quality produce (Kader and Kitinoja , 2002). Over-maturity or under-maturity affects the quality and the value (Abu-Goukh *et al.*, 2010). Harvesting Fruits too early can reduce the sensory attributes while too later harvesting reduces the shelf life and transportation potential. Various non-destructive indices are used to determine papaya harvest maturity, including the number of days from flowering, fruit size, and external colour (NARI, 2003; Serry, 2011; Ahmad and Siddiqui, 2015).

The standards of maturity for papayas were mainly developed in Hawaii. In this country wholesale and consumer maturity standards for papaya fruit require that in a given lot of fruits, the total soluble solid (TSS) of the edible pulp should average not less than 11.5% (Kader, 2001; Chan and Paull, 2008 ; Serry, 2011; Schweiggert *et al.*, 2012). Papayas fruit are generally picked when they exhibit a slight overall loss of green colour, with some hint of yellow colour at the blossom end. For long distance shipments the fruits are harvested at colour- break stage (Abu-Goukh *et al.*, 2010).

However, each country or specific market has their own requirement. For example, papaya for domestic market in Jamaica is harvested when 25% of the peel colour changes from green to yellow, from apical end while the one for export, 10% of the peel colour development must be achieved and brix of 10% - 14% (Palipane, 2008).

Generally, papaya starts flowering four months after sowing and produces ripe fruits within nine months (Aryal and Ming, 2014). The smaller pear- shaped (Hawaiian) type papaya fruit generally weigh between 350 to 500 gm when mature however, the most obvious index of fruit maturity is external skin colour and this vary according to the variety (NARI, 2003).

2.8. Harvesting practices

Usually the best time of harvesting papaya, is the coolest time in the morning or late evening. Harvesting during the hot afternoons can cause an increase in the fruit temperature which renders it more susceptible to bruising injury (NARI, 2003).

Papaya fruits are picked manually with hand and knives or a specialized cutting blade depending on the size and the age of the tree (De la Cruz Medina *et al*., 2003).There are also some tools that can be used for harvesting of fruit from tall trees. Such kind of specialised tools includes a long pole, a small circular hoop at the top, a small mesh bag attached to the hoop and a horizontal blade above the hoop and bag (De la Cruz Medina *et al*., 2003).

2.9. Postharvest handling

Postharvest handling starts immediately after harvesting the fruits. It involves preparation of fruits for transport including: transportation from the field, pre-cooling, sizing, grading, cleaning, trimming, waxing, among others (Palipane, 2008).

The pre- cooling is referred to the rapid cooling of the fruit immediately after harvest in order to remove field heat, it reduces the heat produced by respiration and water loss, and it decreases the rate of deterioration and limits the growth of decay organisms.

Sorting is also a very critical handling practice that involves grouping of produce in accordance to the uniformity of their size, shape, ripeness and the removal of diseased, insect infected, mechanically damaged and other unmarketable fruits (Palipane, 2008; Stice *et al*., 2009). When the sorting is done, the sizing and grading of fruits for uniformity (small, medium, large, extra-large) is carried out to increase consumer appeal and market demand. It is always advisable to minimize the physical damage. Damage to papaya fruit at the green stage will not show up until the fruit ripens and it can occur from the time of harvest through to final packing (Stice *et al.*, 2009).

The physical damage on the farm usually occurs as result of the harvesting implement, dropping into crates, over –filling of crates and excess movement of fruit during transport. The poor washing, grading and transportation can result in latex staining, punctures, scars and bruises. During ripening, bruised areas will develop into dark soft regions which become affected by secondary diseases such as Anthracnose and Phytophthora (Stice *et al*., 2009).

2.10. Quality provision of papaya fruits

Quality can be viewed as an absence of defects or a degree of excellence. It means different things to different handlers within the distribution chain. Food quality embraces both sensory attributes that are readily perceived by the human senses and hidden attributes such as safety and nutrition that require sophisticated instrumentation to measure (Shewfelt, 1999).

Quality of fresh fruit or vegetable changes as it proceeds from harvest to consumer. The relative importance of different quality attributes changes from handling to purchase to consumption. Quality is then depends on the perspective of the viewer and understanding of the different perspectives of different participants in postharvest distribution is essential in any attempt to improve the quality of a fresh fruit or vegetable to consumer (Shewfelt, 1999).

According to Zhou *et al*., (1994), the quality characteristics of papaya is determined by the size, shape, smooth skin and absence of blemishes. So far, the codex standards for fresh fruits and vegetables (Codex Stan 183-1993) indicates different provisions concerning the quality of papaya fruits (Codex Alimentarius Commission, 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.

2.11. Nutritional and phytochemical properties

Table 2.6. Nutritional and phytochemical properties of papaya fruit pulp

Nutrients	Unit	Value per 100 g
Water	G	88.06
Energy	Kcal	43
Protein	G	0.47
Total lipid (fat)	G	0.26
Carbohydrate	G	10.82
Fiber (total dietary)	G	1.7
Calcium	Mg	20
Magnesium	Mg	21
Phosphorus	Mg	10
Potassium	Mg	182
Vitamin C	Mg	60.9
Vitamin A	IU	950
Folate	µg	37
Glucose	G	4.09
Fructose	G	3.73
Beta carotene	µg	274
Alpha carotene	µg	2
Lycopene	µg	1828
Amino acid (tryptophan)	G	0.008

Source : USAID, 2018

Papaya is a powerhouse of nutrients and it a rich source of three powerful antioxidants namely, vitamins C, A and E; minerals such as magnesium and potassium;vitamin B pantothenic acid; folate and fiber (Aravind *et al.*, 2013; Rahman, 2013;Vij & Prashar, 2015). Phytochemically, the whole plant contains enzymes, lycopene, carotenoids, alkaloids, monoterpenoids and flavonoids (Gunde and Amnerkar, 2016).

Every part of papaya fruit has its specific composition, the root contain Arposide and Myrosin enzyme; the bark contain glucose, fructose, sucrose, galactose and xylitol; leaves contain alkaloids carpain, pseudocarpain, dehydrocarpaine I and II, choline, carposide, vitamins C and E; latex contain proteolytic enzymes, papain and chemopapain; fruit contain protein, fat, carbohydrates, minerals, vitamin C, riboflavin, thiamine, alkaloid and volatile compounds (Krishna *et al*., 2008; Milind and Gurditta, 2011; Boshra & Tajul, 2013; Yogiraj *et al*., 2014).

2.12. Organoleptic properties of papaya fruit

The consumers use the organoleptic properties to judge the eating quality of a commodity. They judge fruits as good quality if they look good, are firm, and offer good flavor and nutritive value. Although consumers by on the basis of appearance and feel their satisfaction, the likelihood to buy that fruit again depends on their perception of good eating quality (Kader and Yahia, 2011).

The papaya's organoleptic properties principally (taste and aroma) involve in almost all cases, volatile compounds (benzylisothiocyanate, terpenes, hydrocarbons, esters, aldehydes, ketones, alcohols and organic acids (Flath and Forrey, 1977; Fuggate *et al*., 2010; de Oliveira and Vitória, 2011; El Hadi *et al*., 2013). There is a significant diversity in aroma compounds of papaya fruit where linalool and Benzaldehyde are the most dominant (Wijaya and Chen, 2013).

Flavour quality aspects comprise sweetness (types and amount of sugars); sourness or acidity (types and amount of acids); astringency (phenolic compound), and aroma/odor (volatile compound). The utmost need is to develop new fruit genotypes with better flavour, high sugars and moderate to high acids, low phenolic and enough of organoleptical volatiles for good aroma (Kader and Yahia, 2011).

Various factors significantly affects the organoleptic response of humans such as genetic makeup/cultivars, environmental conditions during production, harvesting time (papaya harvested at more advanced maturity phase scores superior user acceptance); postharvest handling and storage (Addai *et al*., 2013; El Hadi *et al*., 2013). Due to high perishability of papaya fruit, the papaya fruit are preserved as fruit jam that may be prepared from papaya fruit only or in combination with other fruits. It has been documented that jam of papaya (*carica papaya L.*) fruit and gooseberry (*Emblica officinalis*) has bright color, a good flavor which is highly admired (Gupta *et al*., 2016).

CHAPTER THREE

EVALUATION OF THE MORPHOLOGICAL CHARACTERISTICS AND SHELF LIFE OF NEW JKUAT PAPAYA HYBRID FRUITS

ABSTRACT

Papaya (*Carica papaya* L.) is among the most grown fruit crops worldwide with high economical and nutritional value. In Kenya, the papaya industry relies heavily on imported varieties and farmers' selected seed whose quality is not known. Researchers at JKUAT have developed papaya hybrids that are tolerant to viral diseases. However, their morphological characteristics and shelf life has not been reported. Therefore, the morphological characteristics and shelf life of mature fruits of eight newly developed papaya hybrids and their control, Sunrise solo were evaluated. Morphological characteristics were determined using papaya descriptors (International Board for plant Genetic Resources 1988). Shelf life was evaluated at interval of two days from the beginning of ripening until the end of edible life at room temperature (25±2 °C). The results were analyzed using GenStat software 14th edition and means separated by least significance difference (LSD) at $P < 0.05$. 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. 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 need for the evaluation and characterization of newly developed papaya hybrid lines in different agro-ecological zones in order to monitor the influences of the environment, pests and diseases.

3.1. 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). Papaya is a large tree-like plant, with a single stem, which grows between 2 and 10 meters tall with spirally arranged leaves confined to the top of the trunk. The tree is also fast growing and prolific and often results in widely separated internodes(Nakasone and Paull 1998; OECD 2005; Teixeira da Silva et al. 2007). The hermaphrodite trees are self-pollinating, whereas 10% male trees are needed when using female for fruits production (Nakasone and Paull 1998; Aryal and Ming 2014). Fruit production occurs between 10th and 14th month from germination, taking about 4 months to develop and is influenced by pollinator efficiency or abundance (Teixeira da Silva et al. 2007).

Papaya fruits range from 10 –50 cm in length and the shapes may vary according to the varieties (Storey 1969). Papaya fruits are melon-like, oval to nearly round, somewhat pyriform, or elongated club-shaped and possess a central seed cavity. The fruit weight also vary substantially and may range from 0.2 – 12 kg (OECD, 2005) 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). Ayele et al. (2017) evaluated hermaphrodite papaya varieties developed through continuous controlled pollination in Ethiopia and found average fruit weight of between 329 and 769 g in the first year of harvesting and a maximum average of 1107 g in the second year of harvesting. Das (2013) evaluated eight varieties including Coorg honey dew, Pusa delicious, Pusa dwarf, Pusa Nanha, Surya, RCTP-1, 'Washington' and one local gynodioecious variety in northern India and found an average weight of 0.85 – 2 kg.

In Kenya, fruit weights of between 0.23 and 1.3 kg have been reported (Imungi and Wabule 1990). Papaya fruit production in Kenya relies on imported varieties and farmers' selected seeds (Asudi 2010; Horticultural 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, JKUAT research team 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 characteristic of the fruits of the newly developed papaya hybrid lines.

3.2. Material and Methods

3.2.1. Study area

The study was carried out at the JKUAT main campus situated in Juja (1º5′ 29″ S, 37º 0′39″ E and 1521.3 meters above sea level), 36 kilometers northeast of Nairobi, Kenya.

3.2.2. Source of papaya fruits

Eight papaya hybrid lines that bred by researchers at JKUAT and the control ('Sunrise solo') were used in experiment. The papaya hybrids were developed as result of selection of papaya seeds collected all over Kenya by Asudi et al. (2010). Line 1 was developed from a cross between a local papaya from Manyani (MAN 1) and Sunrise solo. Line 2 was from a cross of local papaya from Voi (VOI 4) and local papaya from Kilifi (ST2). Line 3 was bred from a cross between a local papaya from Voi (VOI 5) and a local papaya collected from JKUAT farm (BLOCK A). Line 4 was developed as a result of a cross between VOI 5 and Sunrise solo, Line 5 between a local papaya from Mombasa (MT/M7) and (VOI 4), Line 6 between a local papaya from Voi (KIBBELEPTIC) and Sunrise solo, Line 7 between (VOI 4) and (BLOCK A) and Line 8 from a cross between a local papaya from Manyani (MAN 2) and Sunrise Solo.

3.2.3. Experimental design

The newly developed papaya hybrids and Sunrise solo were planted together in an open field in a complete randomized 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 minutes. The fruits were then were characterized.

3.2.4. Morphological 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 500g, 15 cm long or less and up to 10 cm in diameter. The medium fruits weighed between 500 and 1000g and were between 15 to 25 cm long and between 10 and 13 cm in diameter while large fruits consisted of fruits weighing greater than 1000g or ≤3000g, >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 Commission 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 fruit surface or flesh 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 (colour break) until the end of edible life at room temperature (25±2°C) and relative humidity of 65-70%. The number of days the fruits lasted at room temperature before over ripe (softening) was recorded.

3.2.5. Data analysis

Quantitative data on the fruit weights, diameter and length, internal cavity length and diameter 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% level of confidence and means separated by least significance difference (LSD). 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% level of confidence.

3.3. Results

3.3.1. Morphological characteristics of fruits of the new papaya hybrids

The weights of the fruits varied significantly (Table 3.1; $P < 0.05$) 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 3.1). Averagely, papaya hybrid Line 4 also had the longest fruits (21.2cm), while the control, Sunrise solo had the shortest fruits (12.3cm). The mean fruit length varied significantly (Table 3.1; $P < 0.05$) 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 3.1; $P < 0.05$) between the new hybrid lines and the control with shortest length recorded 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.

Table 3.1: The morphological and quality characteristics of Sunrise Solo and new papaya hybrids

Hybrids	Fruit weight (g)	Fruit length (cm)	fruit diameter (cm)	Internal cavity length (cm)	Internal cavity diameter (cm)
Sunrise solo	544 ±56.3	12.3± 0.6	9.4± 0.6	8.5± 0.5	5± 0.4
Line 1	430 ± 45.3	13.8± 0.5	8.5± 0.5	10± 0.5	4.4±0.4
Line 2	813.7± 72.2	16.8± 0.5	10.5± 0.4	11± 0.5	5.8± 0.3
Line 3	898.5± 62.5	17.2± 0.5	11.4± 0.3	11.6±0.4	6.3±0.3
Line 4	1246.7± 70.3	21.2± 0.5	11.9±0.2	15.6± 0.9	6.7±0.2
Line 5	586.7± 58.2	16.6± 0.6	10± 0.5	13.7± 0.6	7± 0.5
Line6	1240.8± 93.9	18.5± 0.6	13.3± 0.6	15.7± 0.6	11± 0.7
Line7	586.3± 36.2	16.5± 0.5	9.2± 0.4	12.7± 0.5	3.1± 0.3
Line8	626.7± 44.9	17.5± 0.4	9± 0.3	12.3± 0.4	5.2± 0.1
LSD	171.9	1.5	1.22	1.6	2
CV%	43.6	17.2	23.1	25.3	19.1

The data are expressed as means ± standard error of the mean.

3.3.2. 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 (Fig.3.1) 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 Line 5, Line 7 and Line 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.

Figure 3.1. Morphology of new papaya hybrid lines: Sunrise solo with small fruits (A); Line 1 with small fruits (B); Line 2 with small and medium fruits (C); Line 3 medium to large fruits (D) Line 4 with large fruits (E); Line 5 with small and medium fruits (F); Line 6 with large fruits (G); Line 7 with small and medium fruits (H) and Line 8 with small and medium fruits (I).

The skin texture of ripened fruits in most hybrids (50.7%) was intermediate or smooth (40.7) with few hybrids namely Lines 4, line 7 and line 8 having rough skin texture (Table 3.2). The texture of ripened fruits varied significantly (χ^2 = 126.7; df = 16, P < 0.01) in all the papaya hybrids (Table 3.2).

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 Line 6 and Lines 1, 2 and 8 respectively (Table 3.2).

The majority of all fruits had slightly star –shaped (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%).

Significant variation in skin colour was observed (χ^2 = 768.7; df = 32; P < 0.01) (Table 3.2) 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 (Fig. 3.2) 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 developed papaya hybrids and the Sunrise solo (Table 3.2).

The study also found significant 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%).

Table 3.1. Qualitative description of the new papaya hybrids

Descriptor	Papaya hybrids									Mean	χ^2
	Control	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Line 7	Line 8	N 270	
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	126.7***
Intermediate	73.3	40.0	23.3	60.0	33.3	40.0	50.0	63.3	73.3	50.7	
Rough	–	–	–	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	115.3***
Intermediate	40.0	16.7	20.0	46.7	33.3	23.3	53.3	43.3	43.3	35.6	
Deep	10.0	–	–	50.0	6.7	30.0	46.7	3.3	–	16.3	
Shape of central cavity											
Irregular	–	–	–	–	–	–	–	6.7	–	0.7	63.9***
Angular	–	–	6.7	–	–	–	–	20.0	53.3	3.0	
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	768.7***
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	
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	768.7***
Vivid orange yellow	–	–	–	–	–	–	96.7	3.3	–	11.1	
Vivid yellowish pink	–	–	93.3	–	–	–	–	–	–	10.4	
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	183.4***
Flattened	40.0	23.3	20.0	50.0	23.3	26.7	30.0	16.7	23.3	28.1	
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**

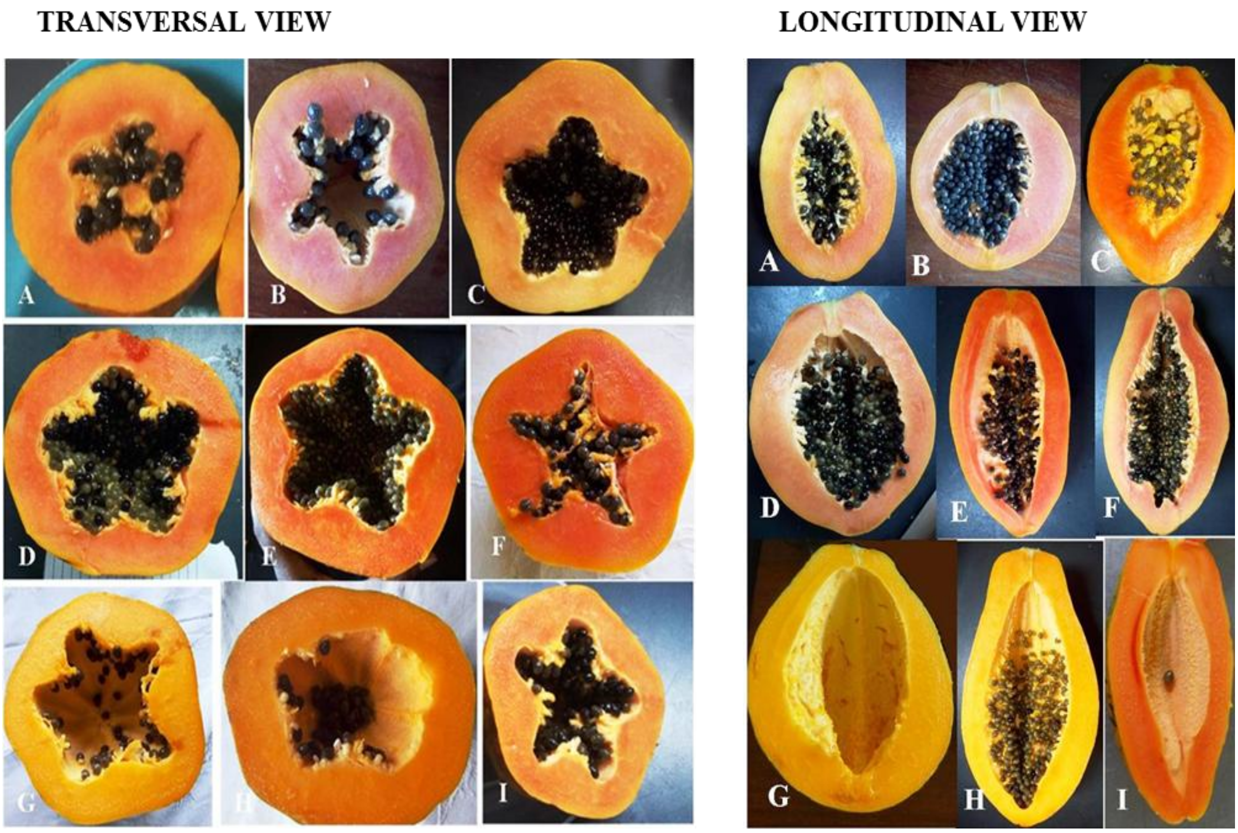

Figure 3.2: Variation in the fruit central cavity shape and flesh colour among new papaya hybrid lines. Sunrise solo with slightly star shaped and vivid reddish orange (A); Line 1 with slightly star shaped and reddish orange flesh colour (B); Line 2 with slightly star shaped and vivid yellowish pink flesh colour (C); Line 3 with slightly star shaped and vivid reddish orange flesh colour (D); Line 4 with slightly star shaped and vivid reddish orange flesh colour (E); Line 5 with star shaped and vivid reddish orange flesh colour (F); Line 6 with slightly star shaped and vivid orange yellow flesh colour (G); Line 7 with angular shaped and strong orange yellow flesh colour (H) and Line 8 with star shaped and vivid reddish orange flesh colour (I).

3.3.3. Classification of new papaya Hybrids based on fruit size and quality

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 Line 8 and Line 3 each with 60% and Line 5 with 40% fruits (Table 3.3). Majority of large fruits were however, recorded in Lines 6 and 4 with 63.3% and 76.7% of large fruits respectively (Table 3.3). 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 fall in Class II (Table 3.3).

Table 3.1. Classification of the new papaya hybrids based on fruits size

	Fruit size classification				CODEX
Hybrids	**Range (g)**	**Small (%)**	**Medium (%)**	**Large (%)**	**classification**
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

3.3.4. The new papaya fruit hybrids storage shelf life

A gradual decline in eating quality among all papaya fruits was observed (Fig. 3.3). 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 11days, while Line 1 had the shortest shelf life of 4 days. Fruit softening and decline in organoleptic quality by 5th day was recorded in Line 1, Line 8 and the control, whereas, Line 7 maintained the quality until the 11th day (Fig.3. 3).

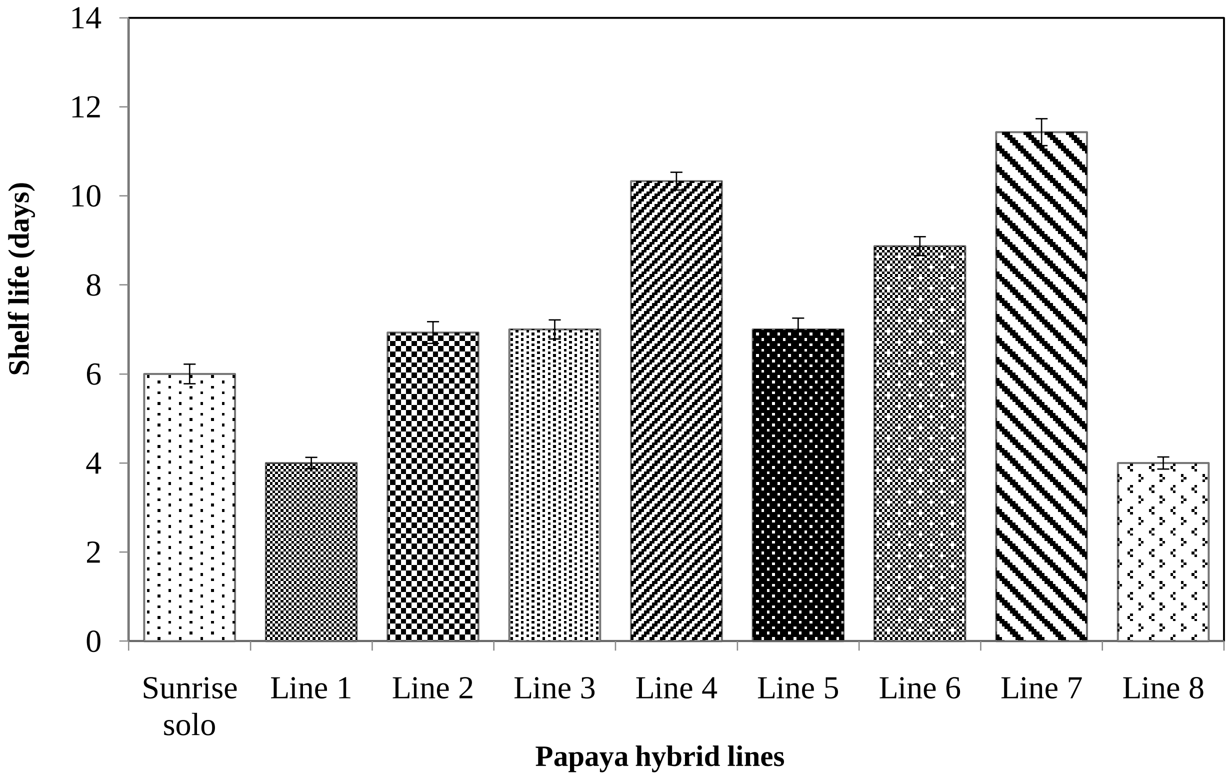

Figure 3.1. The new papaya hybrids fruit shelf life evaluated at interval of two days from the beginning of ripening until the end of edible life at room temperature.

3.4. 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. 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 fruits collected from Voi. This finding was not far from the result that has been reported on Kenyan papaya varieties (small fruits were reported in Kapoho solo variety (230g) and 116 variety(330g); Medium fruits were recorded in Kitare, Kiru, Malindi, Waimanalo and 417 weighing 760g, 770g, 600g, 690g respectively; large fruit were also reported in three varieties including 418 (1100g), 455 (120g) and 457(1300g) (Imungi and Wabule 1990).

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). The researcher 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 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). Consumer acceptance of papaya fruit depends on various properties including fruits size, flesh colour and shape among the others. For instance, in Jamaica pear-shaped fruits with red flesh and mass from 385-533 g are desired for export (Chan and Paull 2008). Although similar fruit attributes are required by both the United Stated (US) and European markets, buyers in the US and the United Kingdom prefer fruits between 274 and 744 g and from 224-535 g respectively (Tennant et al, 2010). In the current study, we found desirable fruits weight with average ranging from 430g -813 g in the Hybrids, which are within the export market limits.

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 Commission 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 behaviour (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. Researcher evaluated the shelf life of newly developed hybrid papaya fruits at room temperature ( ) for 14 days and found an average of 4 – 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. 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.

CHAPTER FOUR

EVALUATION OF PHYSICOCHEMICAL, VITAMINS AND ORGANOLEPTIC QUALITY CHARACTERISTICS OF NEW JKUAT PAPAYA HYBRID FRUIT

ABSTRACT

The issue of accessing high quality nutritious foods such as fruits has become a major challenge for many African people. Papaya (Carica papaya L.) is among the most popular fruits grown in Kenya (contributing 4% of the fruits subsector on Kenyan gross domestic product) and excellent in nutritional content. Researchers at Jomo Kenyatta University of Agriculture and Technology developed promising papaya hybrids whose physicochemical, vitamins content and organoleptic characteristics have not been evaluated. Thus, the aim of this study was to determine the physicochemical, vitamins content and organoleptic quality characteristics of the new JKUAT papaya hybrids and their control, Sunrise Solo. The physicochemical attributes evaluated included; total soluble solids, total Titratable acid, pH and total soluble solid/total Titratable acid ratio. The vitamins evaluated included vitamin C and β-carotene. The organoleptic quality was also evaluated based on appearance, aroma, taste and sweetness. The standard AOAC methods was used to determine physicochemical attributes and vitamins content, 9- point hedonic scale was used on organoleptic evaluation. There was significant difference ($P< 0.05$) in nutritional content of new hybrids papaya fruits and Sunrise solo. The maximum and minimum Vitamin C content of 131.63 mg/100g and 52mg/100g were exhibited by line 6 and 8 respectively. B-carotene content ranged between 1.69 and 3.39 mg/100g as exhibited by line 1 and lines 2 and 8 respectively.

The findings of this study revealed that the nutritional content of the new papaya hybrids is more superior to that of Sunrise Solo while their sensory quality characteristics compared favourably to the one of Sunrise Solo. Based on these findings, lines 1, 2, 5, 6 and 7 are recommended for commercialization in similar ecological zone to that of JKUAT and evaluation in different ecological zones of growth.

4.1. Introduction

The world is faced with a lot of challenges including lack of sustainable development and inability to feed its growing population leading to malnutrition (FAO, 2010). The population has been arising tremendously despite the stagnation in its food production (Godfray et al., 2010). The number of undernourished people in 2016 worldwide increased to an estimated 815 million up from 777 million in 2015.

Recent findings of Kenya demography and health survey have shown that one quarter of children less than five years are stunted because of malnutrition (KNBS and ICF, 2015). The issue of accessing high quality nutritious foods such as fruits has become a major challenge for many African peoples where the sub-Sahara Africa diets consist mainly of cereal and staple crops (Fanzo, 2012). Fresh fruits play a very significant role in human nutrition, especially as sources of vitamins, minerals and dietary fibre (Kader & Yahia, 2011).

Papaya (Carica papaya L.) is one of the tropical fruits with important antioxidant properties and also in great demand in international market (Laura et al.,2010). It is among the most popular fruit grown in Kenya. The recent ranking of fruits contribution to the Kenyan GDP, Papaya was ranked as the 6^{th} fruit of importance contributing 4% of the fruits subsector (HCD, 2016).

Regardless income generation from papaya fruits, Rahman (2013) reported various benefits of papaya including, protection against heart diseases, promotes digestive health, anti-inflammatory effects, immune support, protection against macular degeneration, protection against rheumatoid arthritis, wound healing property and many industrial applications.

Researchers at Jomo Kenyatta University of Agriculture and Technology (JKUAT) developed new papaya hybrids from selection and cross pollination of different germplasms collected all over the country and Sunrise solo. However, their nutritional content and organoleptic quality characteristics have not been evaluated in order to ensure their potential for commercialization. Thus the aim of this study was to determine physicochemical, vitamins and organoleptic quality characteristics of the new JKUAT papaya hybrid lines.

4.2. Material and methods

4.2.1. Papaya fruits used for this study

Eight new papaya hybrids, namely Line 1, Line 2, Line 3, Line 4, Line 5, Line 6, Line 7, Line 8 and Sunrise solo fruits were used for this study. The fruits were harvested from JKUAT research farm situated in Juja (1º5′ 29″ S, 37º 0′39″ E and 1521.3 meters above sea level), 36 kilometers northeast of Nairobi, Kenya.

4.2.2 Experimental design

Papaya fruits from 8 newly developed papaya hybrid and Sunrise Solo were harvested from female papaya trees that were about 11month old at JKUAT farm. The harvesting was done on weekly basis due to the availability of the fruit at colour break stage and the papaya fruits were collected and evaluated between December, 2017 and February, 2018. The Sunrise solo is among the most commercially available variety grown in Kenya and it was used as one of the parental line during the development of these new papaya hybrids. The fruits were harvested early in the morning and delivered to the JKUAT postharvest laboratory.

The fruits were washed dried and stored at room temperature for complete ripening. The ripening took 4days then the analysis was performed after. Ten fruits from each hybrids line and Sunrise Solo constituted the sample.

4.2.3 Chemical reagents

Phenolphthalein indicator, sodium hydroxide, standard ascorbic acid, Dichlorophenol indophenols (DCPIP), Trichloroacetic acid (TCA), acetone, Petroleum Spirit, Anhydrous sodium sulphate (Na_2SO4) and Silica gel of analytical grade were purchased from Lab link Supplies Nairobi, Kenya

4.2.4. Physicochemical properties and vitamin determination

4.2.4.1. Total Soluble Solid content (TSS)

Total soluble solid content were determined as described by (Mitcham *et al*., 1996). The (% brix) was determined for using an Atago hand refractometer (Model RX5000, Atago CO.LTD, Tokyo, Japan). Briefly, a drop of homogenized papaya fruit juice was placed on cleaned prism of refractometer's prism, which had been calibrated and the lid closed. The TSS content was then read on a scale of the refractometer when held close to the eye. Between each reading, the refractometer was cleaned with distilled water and wiped with tissue paper.

4.2 pH

This was measured with a pH-meter (Hanna, HI 2211 pH/ORP meter) at ambient temperatures. The standardization of pH-meter with pH buffer solutions of 4.0 was done, the electrode was rinsed by distilled water and then standardized using the alkaline buffer solution of 9.18. Then the pH of the papaya fruits was measured.

4.2.4.3 Total Titratable Acidity content (TTA)

The papaya fruits were homogenized using mortar and pestle to extract the juice, 10 ml of clear juice of papaya fruits diluted by deionized water was added with 0.3 ml of phenolphthalein indicator. The titration of 0.1N sodium hydroxide to a permanent pink colour were conducted and the results were expressed as a percentage of citric acid which is the main organic acid in papaya fruits as previously described by (Mitcham *et al.*, 1996).

4.2.4.4 Ascorbic Acid (Vitamin C) content

This was determined by using 2, 6-dichlorophenol indophenols titration methods as described by (AOAC, 1996). Five grams of papaya fruit pulp was diluted with 10% Trichloacetic acid (TCA) in volumetric flask up to 100ml. Ten (10) ml of diluted solution was titrated with 2, 6-Dichlophenolindophenol up to the pink colour. Percentage of ascorbic acid was calculated using the following formula.

$$\boldsymbol{Ascorbic\ acid}\left(\frac{\boldsymbol{mg}}{\boldsymbol{100g}}\right) = (\boldsymbol{A}-\boldsymbol{B}) \times \boldsymbol{C} \times \left(\frac{\boldsymbol{100}}{\boldsymbol{S}}\right) \times (\boldsymbol{100/10}) \qquad \textbf{(1)}$$

Where **A**= Volume in ml of indophenol solution used in the sample

B= Volume in ml of indophenol solution used for blank

C= Mass in mg of ascorbic acid equivalent to 1ml of standard indophenol solution.

S= Weight of the sample taken (g)

100/10= the total extraction volume/Volume of titrated sample

4.2.4.4. β –carotene content

Determination of β-carotene was done using UV-VIS Spectrophotometer. Exactly 5g of the sample was ground using mortar and pestle and gradual extraction was done with Cold Acetone up to 50 ml. After transferring the extract into 50 ml volumetric flask using a glass funnel plugged with a small cotton wool, the sample was filtered and the residue was washed with cold acetone until devoid of colour. The partitioning with petroleum spirit was then performed after which sample was measured at 450 nm UV-Vis-spectrophotometer.

4.2.5 Sensory evaluation

Sensory evaluation of the full ripe fruits samples under study was done using the 9- point hedonic scale (Lawless & Heymann, 2010). The papaya pulp was separated from the skin and the seeds by knife and spoon, sliced and served to a panel of 30 members comprising staff and students of JKUAT, belonging to the department of Horticulture and food security (Fig 4.2). Appearance, aroma, taste and sweetness were evaluated using a 9-hedonic point ,where (1= Dislike extremely; 2 = Dislike it very much. 3 = Dislike moderately; 4 = Dislike it; 5 = Neither like it nor dislike it. 6 = Like it; 7 = Like it moderately; 8 = Like it very much; 9 = Like it extremely).

Figure 2.1 A panel of 30 members comprising staff and students of JKUAT, belonging to the department of Horticulture and Food Security carrying out organoleptic test of new papaya hybrid fruits

4.3 Statistical Analysis

All data were recorded in excel then subjected to a one-way analysis of variance using GenStat software 14^{th} edition to assess any differences between commercialized hybrid (Sunrise Solo) and the newly developed hybrid lines. Statistical significance was determined at 95% level of confidence and means separated by the least significant difference test (LSD).

4.4. Result

4.4.1 Physicochemical properties and vitamin content

The results of physicochemical properties and vitamins content of different papaya hybrid lines and Sunrise Solo are displayed in Table 4.1.

4.4.1.1. Total soluble solids content (ºBrix)

There was much variation of total soluble solids among the hybrids lines and Sunrise Solo. Lines 5 and 7 recorded the highest TSS of 12.3 ° Brix. The lowest was 7.4°Brix recorded in lines 8.

4.4.1.2. Total Titrable Acidity Content (%)

Among all evaluated papaya fruits, line 2 had the lowest TTA of 0.07%, while the highest (0.09%) was recorded in line 8.

4.4.1.3. TSS/TTA ratio

The maximum TSS/TTA ratio was recorded in line 2(163.6) while the minimum (53.7) was recorded in line 8.

4.4.1.4. pH

The pH values of the new papaya hybrid lines and Sunrise Solo varied from 5.3 to 5.6. Line 6 and 8 were most acid while line 2 was the least acid.

4.4.1.5 Ascorbic acid (Vitamin C)

The significant difference ($P<0.05$) among the vitamin C value of new papaya hybrid lines and Sunrise Solo was observed. The maximum vitamin C of 131.6 mg/100g was recorded in line 6 while the least of 51 mg/100g was recorded in line 8.

4.4.1.6.β carotene

The new papaya hybrid lines and Sunrise Solo varied significantly ($P<0.05$) in their beta carotene content (Table 4.1). The maximum was 3.39 mg/100g exhibited by lines 2 and 8, while the lowest recorded was 1.69 mg/100g exhibited by line 1.

Table 4.1. Physicochemical properties and vitamins content of new papaya hybrid lines and Sunrise Solo

Treatment	TSS (°brix)	pH	TTA (%)	TSS/TTA ratio	Vitamin C (mg/100g)	β-carotene (mg/100g)
Sunrise solo	7.7 ± 0.2	5.5	0.15 ± 0.01	65.3 ± 5.3	63.3 ± 6.59	2.91
Line 1	11.2 ± 0.1	5.5	0.18 ± 0.01	65.2 ± 2.5	63.03 ± 7.24	1.69
Line 2	11.6 ±0.1	5.6	0.07 ± 0.01	163.6 ± 6.6	76.6 ± 0.74	3.39
Line 3	8.7 ± 0.2	5.5	0.16 ± 0.01	66.9 ± 7.1	100.53 ± 3.87	2.3
Line 4	8.6 ± 0.2	5.4	0.09 ± 0.01	111.3 ± 6.4	79.37 ± 4.55	2.02±0.57
Line 5	12.3 ± 0.2	5.5	0.15 ± 0.01	84.3 ± 2.4	70.73 ± 6.93	2.99
Line 6	10 ± 0.2	5.3	0.16 ± 0.01	64.2 ± 2.6	131.63 ± 8.47	2.98±0.08
Line 7	12.3 ± 0.2	5.4	0.15 ± 0.01	85.9 ± 4.2	71.57 ± 1.63	2.9
Line 8	7.4 ± 0.2	5.3	0.19 ± 0.01	53.7 ± 6.2	51 ± 3.9	3.39
LSD	0.5	0.1	0.02	13.6	16.1	0.6
CV%	10.6	3.5	29.4	31.6	11.8	12

The data are expressed as means ± standard error

4.4.2. Organoleptic quality characteristics of the new papaya hybrids ripe fruits

The organoleptic of the investigated papaya hybrid lines shown significance difference ($P\leq 0.05$) between the new papaya hybrid lines and Sunrise Solo. The results obtained are indicated on Table 4.2, where appearance, aroma, taste and sweetness were respectively presented. Based on appearance, line 1 and line 2 were liked very much. Line 7 was liked very much in regard to its aroma characteristic; while line 2 was liked moderately based on the taste. Among the all evaluated papaya hybrids, line 2 was very much liked based on its sweetness.

Table 4.1. Organoleptic quality characteristic of the new papaya hybrids fruits

Treatment	Appearance	Aroma	Taste	Sweetness
Sunrise solo	7 ± 0.16	6.63 ±0.1	6.48± 0.18	6.55 ± 0.18
Line 1	8.28 ± 0.1	7.83 ± 0.14	6.43 ± 0.14	6.38 ± 0.14
Line 2	8.02 ±0.13	7.63 ± 0.15	7.92± 0.14	8.17 ± 0.13
Line 3	7.83 ± 014	7.38 ± 0.17	7.23 ± 0.2	7.28 ± 0.22
Line 4	7.9 ± 0.16	6.95 ± 0.19	7.03 ± 0.2	7.13 ± 0.17
Line 5	7.85 ± 0.12	7.57 ± 0.1	7.42 ± 0.13	7.55 ± 0.12
Line 6	6.75 ± 0.12	5.98 ±0,12	6.68± 0.13	6.75 ± 0.15
Line 7	7.68 ± 0.13	8.2 ± 0.09	7.38 ±0.14	7.72 ± 0.13
Line 8	6.75 ± 0.18	6.42 ± 0.17	5.78 ± 0.2	5.88 ± 0.2
LSD	0.39	0.4	0.45	0.45
CV%	14.3	15.7	18.2	17.9

4.5 Discussion

From the findings of the current study, the physicochemical, vitamins and organoleptic quality characteristics of the new papaya hybrids fruits showed superior characteristics (higher TSS, ascorbic acid and Beta carotene) compared to the Sunrise Solo which is the commercial variety in Kenya.

4.5.1. Physicochemical and vitamin content

4.5.1.1 Total soluble solid (TSS)

The consumer acceptance of papaya fruit depends on various physicochemical traits (Schweiggert et al., 2012). For instance, TSS of > 11.5°Brix are a minimum grade requirement for Hawaiian papayas (Chan and Paull, 2008). In this study the highest TSS values of 12.3°Brix were recorded. The results indicated that the new papaya hybrid lines with high TSS content can be used as dessert without any additive, and the hybrids with low TSS content can be used in the processing industry with sugar addition where necessary. The range of TSS obtained is greater compared to the range of 10.5 – 11.5°Brix and 5.4- 9.6°Brix reported by previous researchers (Martin *et al.*, 2011). The results are in range with the findings of Fuggate *et al.*, (2010); Schweiggert *et al.*, (2012) 8-11.7°Brix and 8.8- 13.5 °Brix respectively. The wide variation in TSS content indicated that Lines 2, 5, and 7 have high sugar content that is more than the minimum of 11.5°Brix required for papaya fruits.

4.5.1.2. pH

The value of the new papaya hybrids fruits pulp's pH obtained in this study ranged between 5.3 and 5.6 and were comparable to (5.3-5.5; 5.1-5.5 and 4.9-5.4) reported by previous researchers respectively (Emilie *et al.,* 2005 ; Imungi & Wabule, 1990; Schweiggert *et al.*, 2012).

pH plays an important role in flavour promotion and preservation of fruit pulp (Okoth *et al*., 2013). Low acid food products are characterized by pH value greater than 4.6 and less than 7. The low acid products including minimum processed papaya can be challenged by microorganism growth and multiplication, as well as bacteria's spore germination which result into spoilage (Bockelmann and Von, 1998). Based on the findings of this study, both new papaya hybrid lines and Sunrise Solo fell into low acid class and careful handling and treatment should be adopted in order to reduce microorganism growth and spoilage.

4.5.1.3. Total Titratable Acid

Acidity in fruits is an important factor in determining maturity; it gives the total or potential acidity, rather than indicating the number of free protons in any particular sample. It is measure of all aggregate acids and sum of all volatile and fixed acids. The findings on Titratable acid in the present study ranged between 0.07 and 0.19. This range is not far from the range of 0.07 to 0.14 reported by O.N. de Jesus, J.P.X. de Freitas, 2013 and 0.09 to 0.019 obtained by Schweiggert et al., 2012 on papaya fruits. The fruits acidity is determined by the type of organic acids it contains, the most predominant organic acid in papaya is citric acid. Citric acid accumulates during the second stage of development and during maturation it generally decreases (Monselise, 1986). The reduction of the acidity associated to postharvest ripening has been attributed to the fact that organic acids are substrates for respiratory metabolism in detached products (H. M. Díaz-Mula, 2011). Thus the acidity in all evaluated papaya fruits was very low.

4.5.1.4. Total Soluble Solids/ Total Titratable Acid ratio

The ratio of TSS/TTA gives information on sugar/acid ratio balance in fruits. The high values above 100 observed in some hybrids lines were due to the typically low TTA levels and normal levels of TSS (Imungi and Wabule, 1990). The TSS/TTA ratio can be influenced by fruit variety and stage of ripeness. Since all evaluated hybrids were collected at the same stage of ripening, the significance difference observed in sugar/acid ratio could be due to varietal difference. The high value of TSS/TTA ratio in papaya fruits have been noted by previous researchers (Imungi and Wabule, 1990; Schweiggert *et al*., 2012).

4.5.1.5 Ascorbic acid

The findings on ascorbic acid in this study were comparable to those reported for papayas grown elsewhere such as 79-145mg/ 100g and 33-118mg/100g (Imungi & Wabule, 1990 ; Bello and Enidiok, 2017) respectively.

However, the levels of vitamin C observed in this study were greater than the range of 45.95-73.2mg/100 and 24.9-72.9 mg/100g reported by (Manu e*t al*., 2016; Schweiggert *et al*., 2012).

Vitamin C functions physiologically as a water-soluble antioxidant by virtue of its high reducing power. To provide antioxidant protection, the recommended dietary allowance (RDA) for adults for vitamin C is at 75mg/day for female and 90mg/day for male (Institute of Medicine, 2000). So far The DRA is defined as the average dietary intake level that is sufficient to meet the nutrient requirement of nearly (97-98%) health individuals in a particular life stage and gender group (Food and nutrition Board, 2000). Based on the findings of this study, we can conclude that new papaya hybrids can contribute to more than the DRA in vitamin C content.

4.5.1.6 Beta carotene

The values of beta carotene obtained in the study were greater than the range of 0.4- 2.3 mg/100g reported by (Imungi & Wabule, 1990) while working on Kenyan papaya varieties. Consumption of papaya fruit is recommended for preventing vitamin A deficiency, a cause of childhood blindness in tropical and subtropical countries (Aikpokpodion, 2012). The new papaya hybrids are promising in reducing the prevalence of Vitamin A.

4.5.2. Sensory quality characteristics of the new papaya hybrids ripe fruits

Results on organoleptic test showed that all evaluated papaya fruits were liked. Although both new papaya hybrid lines and Sunrise Solo were liked, based on appearance line 1 was the most liked; based on aroma line 7 was the most liked while line 2 was the most liked based on its taste and sweetness.

The consumers buy fruits based on appearance and feel their satisfaction. Likelihood frequency of buying the fruits again depends on their perception of good eating quality (Kader,2000). The fruits produce a range of volatile compound that make up their characteristic aroma and contributes to their flavour. Many of factors affect volatiles composition include the genetic makeup, degree of maturity, environmental conditions, postharvest handling and storage (El Hadi *et al.*, 2013). Since all papaya fruits were grown in the same environmental conditions and harvested at the same maturity stage, the difference observed among them can be attributed to the varietal genetic makeup.

4.6 Conclusion

This study showed that newly developed papaya hybrids fruits had superior content and Sensory quality characteristics. These findings will assist the breeders in selection of best performing papaya hybrids for commercialization and further improvement based on not only high yielding or resistance to biotic and abiotics condition, but also on nutritional and sensory potential. This study revealed that the nutritional content of the new papaya hybrids exceeded the one of Sunrise Solo while their sensory quality characteristics compared favorably to the one of Sunrise Solo. Based on these findings, lines 1, 2, 5, 6, 7 are recommended for commercialization. The result of this study could contribute to increased fruits consumption, resulting in healthier and decreased micronutrient deficiency prevalence and gradual reduction of diseases resulting from lack of diversified diets.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

Conclusion

Papaya provides cheap source of vitamins and minerals in the diet of people. It was reported that consumer demand for papaya fruits is increasing, as knowledge spreads of its high content of Provitamin A and C (Cano, 1998). In the present study, the morphological and quality characteristics of the new papaya hybrids developed by JKUAT researchers and their control (Sunrise Solo) were evaluated using the selected morphological traits, nutritional value and organoleptic quality attributes. From the findings, the newly developed hybrids performed better than the control in most the evaluated traits. The newly developed papaya hybrids compare favorably with the Kenyan varieties reported by (Imungi & Wabule, 1990).

The study of plant material with desired traits by means of the morphological characterization is an essential step for effective utilization of crop germplasms (Santos *et al*., 2012). In addition, the nutritional and organoleptic quality determination plays a big role in any product development and marketing (DZung *et al*., 2003).

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. The newly developed hybrids fell into extra class, class I and class II based on quality provision of papaya fruits. Thus, it can be concluded that the newly developed hybrids are suitable for both local and export market. The nutritional content of the new papaya hybrids fruits was superior to the one of Sunrise Solo as recorded in lines 6,3,2,7,5 and 4 while that of lines 1 and 4 was comparable to the one of Sunrise Solo. Due to the higher level of ascorbic acid and beta carotene content observed in the new papaya hybrids, they might represent prospective sources of these essential compounds.

Fruits morphological data could be considered in trials devoted to adaptation to growing conditions and breeding program. The findings of this study will assist the breeders in selection of most performing papaya hybrids for commercialization and further improvement. The knowledge about nutritional and organoleptic quality provides useful information to different actors in papaya value chain which can be used to address malnourishment and lack of diversified diets. Therefore the information on nutritional value of the new papaya hybrids observed in the current study would help the consumers to select the best papaya hybrid lines that can supply Dietary References intake of nutrient and good eating quality. The findings of this study will contribute also to increased papaya consumption, resulting in reduction in undernourishment and vitamin A and C deficiency in the population.

Recommendations

- Based on the international quality requirements for papaya fruits, lines 1, 2, 5 and 7 had TSS of more than 11°brix, shelf life of more than 7 days, ascorbic acid content of more than 60mg/100g which are the minimum quality requirements. Additionally, the fruits of these 4 lines were small to medium in size and were classified in extra class and class I. Therefore they are recommended for both local and export markets.
- Line 6 had TSS of 10°brix, 131.63mg/100g of ascorbic acid content and large fruits size, therefore its fruits are recommended for processing and local markets.
- All the new lines should be evaluated in different agro-ecological zones to establish the influences of different ecological conditions on their quality characteristics.
- The study suggests that the newly developed papaya hybrid fruits possess excellent level of ascorbic acid and β carotene. Therefore, consumer education on the nutritional benefits of papaya consumption could eventually contribute to increased consumption of papaya.

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APPENDICES

Appendix I: ANOVA tables

a) ANOVA of new JKUAT papaya hybrids and Sunrise solo fruits weight

Source of variation	D.F.	S.S.	M.S.	v.r.	F pr.
Replication	2	692318.	346159.	3.03	
Treatment	8	21650271.	2706284.	23.68	<.001
Residual	259	29597679.	114277.		
Total	269	51940268.			

b) ANOVA of new JKUAT papaya hybrids and Sunrise solo fruits length

Source of variation	D.F.	S.S.	M.S.	v.r.	F pr.
Replication	2	2.290	1.145	0.14	
Treatment	8	1570.647	196.331	23.61	<.001
Residual	259	2153.616	8.315		
Total	269	3726.552			

c) ANOVA of new JKUAT papaya hybrids and Sunrise solo fruits diameter

Source of variation	D.F.	S.S.	M.S.	v.r.	F pr.
Replication	2	18.716	9.358	1.63	
Treatment	8	587.209	73.401	12.77	<.001
Residual	259	1488.537	5.747		
Total	269	2094.462			

d) ANOVA of new JKUAT papaya hybrids and Sunrise solo fruits cavity length

Source of variation	D.F.	S.S.	M.S.	v.r.	F pr.
Replication	2	35.969	17.984	1.85	
Treatment	8	1396.492	174.562	17.95	<.001
Residual	259	2518.253	9.723		
Total	269	3950.714			

e) ANOVA of new JKUAT papaya hybrids and Sunrise solo fruits cavity diameter

Source of variation	D.F.	S.S.	M.S.	v.r.	F pr.
Replication	2	36.742	18.371	3.99	
Treatment	8	1158.766	144.846	31.44	<.001
Residual	259	1193.105	4.607		
Total	269	2388.613			

f) ANOVA of new JKUAT papaya hybrids and Sunrise solo fruits shelf life

Source of variation	D.F.	S.S.	M.S.	v.r.	F pr.
Replication	2	7.1167	3.5583	4.26	
Treatment	8	1566.9000	195.8625	234.61	<.001
Residual	259	216.2250	0.8348		
Total	269	1790.2417			

g) ANOVA of new JKUAT papaya hybrids and Sunrise solo fruits TSS

Source of variation	D.F.	S.S.	M.S.	v.r.	F pr.
Replication	2	30.515	15.257	13.59	
Treatment	8	910.895	113.862	101.40	<.001
Residual	259	290.817	1.123		
Total	269	1232.227			

h) ANOVA of new JKUAT papaya hybrids and Sunrise solo fruits pH

Source of variation	D.F.	S.S.	M.S.	v.r.	F pr.
Replication	2	0.19199	0.09600	2.67	
Treatment	8	2.32191	0.29024	8.09	<.001
Residual	259	9.29541	0.03589		
Total	269	11.80931			

i) ANOVA of new JKUAT papaya hybrids and Sunrise solo fruits TTA

Source of variation	D.F.	S.S.	M.S.	v.r.	F pr.
Replication	2	0.037820	0.018910	10.78	
Treatment	8	0.349615	0.043702	24.91	<.001
Residual	259	0.454345	0.001754		
Total	269	0.841779			

j) ANOVA of new JKUAT papaya hybrids and Sunrise solo fruits TSS/TTA ratio

Source of variation	D.F.	S.S.	M.S.	v.r.	F pr.
Replication	2	22427.5	11213.8	15.79	
Treatment	8	284263.5	35532.9	50.04	<.001
Residual	259	183897.2	710.0		
Total	269	490588.2			

k) ANOVA of new JKUAT papaya hybrids and Sunrise solo fruit's vitamin C content

Source of variation	D.F.	S.S.	M.S.	v.r.	F pr.
Replication	2	236.73	118.37	1.37	
Treatments	8	13926.55	1740.82	20.19	<.001
Residual	16	1379.29	86.21		
Total	26	15542.57			

l) ANOVA of new JKUAT papaya hybrids and Sunrise solo fruit's vitamin A content

Source of variation	D.F.	S.S.	M.S.	v.r.	F pr.
Replication	2	0.2561	0.1281	1.20	
Treatments	8	8.5729	1.0716	10.02	<.001
Residual	16	1.7106	0.1069		
Total	26	10.5396			

m) ANOVA of new JKUAT papaya hybrids and Sunrise solo fruit's appearance

Source of variation	D.F.	S.S.	M.S.	v.r.	F pr.
Replication	1	0.741	0.741	0.64	
Treatment	8	158.826	19.853	17.05	<.001
Residual	530	617.293	1.165		
Total	539	776.859			

n) ANOVA of new JKUAT papaya hybrids and Sunrise solo fruit's aroma

Source of variation	D.F.	S.S.	M.S.	v.r.	F pr.
Replication	1	1.896	1.896	1.50	
Treatment	8	253.800	31.725	25.12	<.001
Residual	530	669.237	1.263		
Total	539	924.933			

o) ANOVA of new JKUAT papaya hybrids and Sunrise solo fruit's taste

Source of variation	D.F.	S.S.	M.S.	v.r.	F pr.
Replication	1	22.407	22.407	14.06	
Treatment	8	200.426	25.053	15.72	<.001
Residual	530	844.493	1.593		
Total	539	1067.326			

p) ANOVA of new JKUAT papaya hybrids and Sunrise solo fruit's sweetness

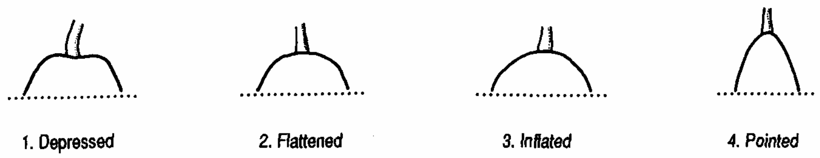
Source of variation	D.F	S.S.	M.S.	v.r.	F pr.	
Replication	1		14.031	14.031	8.87	
Treatment	8		248.787	31.098	19.66	<.001
Residual	529		836.931	1.582		
Total	538		1098.746			

Appendix.II: Descriptors for papaya

6.2.16 Stalk end fruit shape

See Fig. 5

1 Depressed
3 Flattened
5 Inflated
7 Pointed



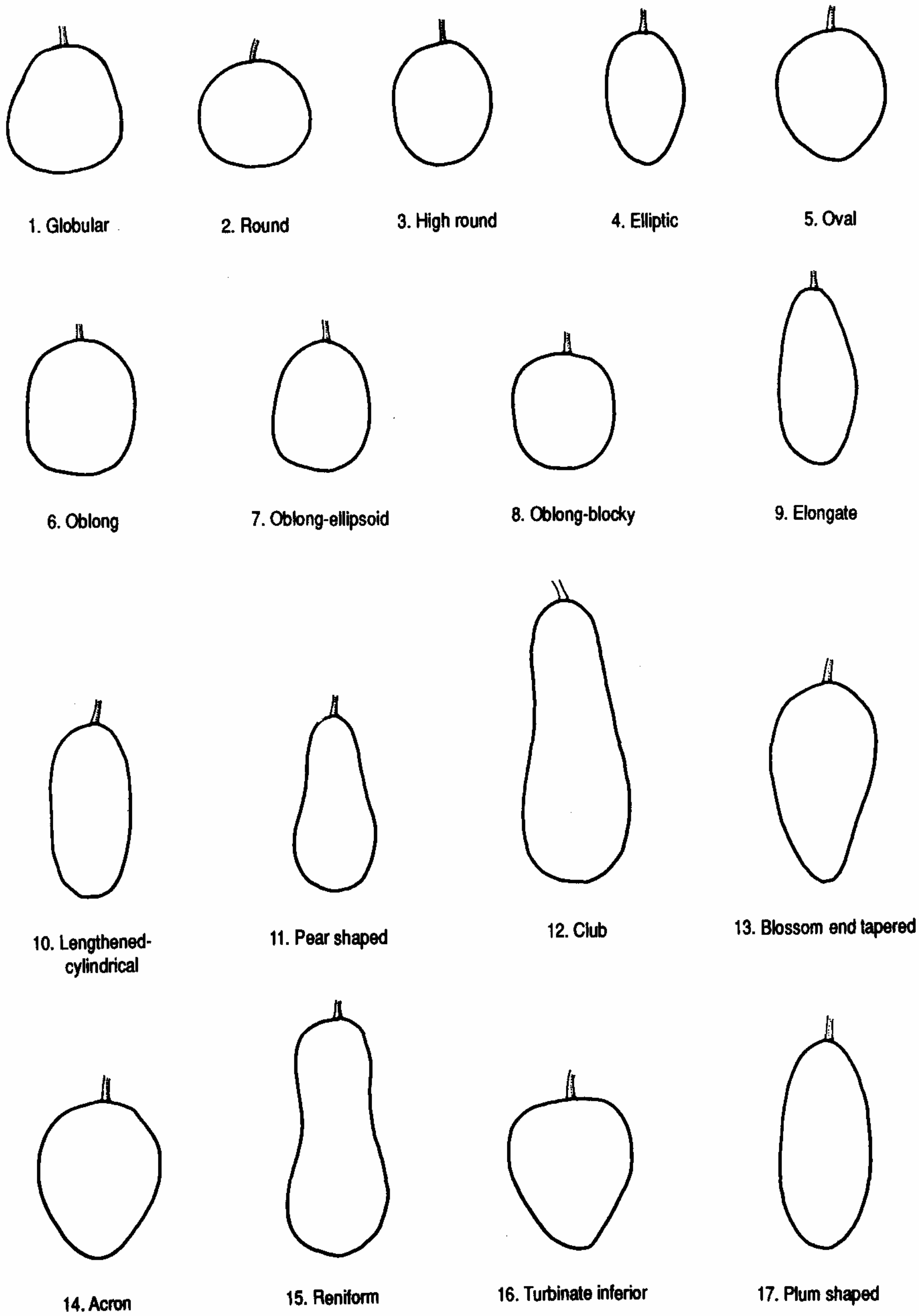


Fig. 2. Fruit shapes

6.2.16 <u>Stalk end fruit shape</u>

See Fig. 5

1 Depressed
3 Flattened
5 Inflated
7 Pointed

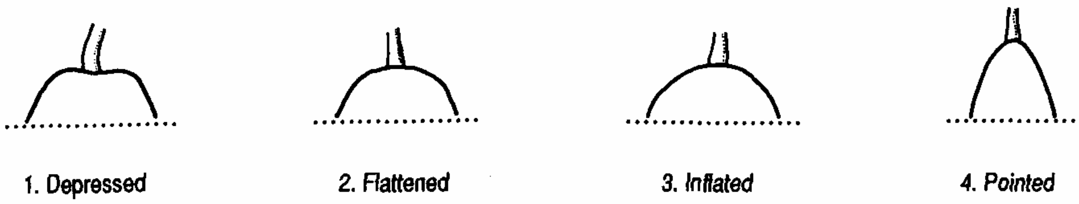


Fig. 5. Stalk-end fruit shape

6.2.17 <u>Size of blossom end scar</u>

3 Small (< 0.5 cm)
5 Intermediate
7 Large (> 1.0 cm)

6.2.18 <u>Fruit skin texture when ripe</u>

3 Smooth
5 Intermediate
7 Rough (ridged)

6.2.19 <u>Ridging on fruit surface</u>

3 Superficial (low depression)
5 Intermediate (moderate depression)
7 Deep (usually 5 distinct ridges)