AGRONOMIC PERFORMANCE OF NEW JKUAT PAPAYA (*CARICA PAPAYA L.*) HYBRIDS IN DIFFERENT AGRO-ECOLOGICAL ZONES OF KENYA

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Agronomic Performance of New JKUAT Papaya (*Carica Papaya L.*) Hybrids in Different Agro-Ecological Zones of Kenya

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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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DEDICATION

To my dear family at large without whose dedication and sacrifice to educate me, I would not have come this far. I sincerely appreciate the moral support and prayers that you gave during my studies.To my dear wife Lydia Karan, my son Avram Karan and daughter Eleanor Karan, I thank you so much for being there for me. Above all I extend my sincere gratitude to the Almighty God for His hand and peace of mind during my studies. Heavenly Father you made everything possible.

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LIST OF ABBREVIATIONS AND ACRONYMS

TSS	Total soluble solute
NVNM	Non vitamin non mineral
PCR	Polymerase chain reaction
PLYD	Papaya lethal yellowing disease
Pmed	Papaya Meleira RR Sticky Disease
RCBD	Randomized Complete Block Design
PRV	Papaya ringspot virus
DI	Disease incidence
DS	Disease severity
SAD	Standard area diagram

ABSTRACT

There has been low papaya production in Kenya due to poor and low quality seeds that results to low yield accompanied by poor quality. The seeds majorly utilized for propagation are selected by farmers from their previous production and seed that are imported. However, this is not satisfactory since the imported seeds are costly and very few farmers can afford. In addition, most of the selected seeds by farmer have poor adaptability and get infected mostly by papaya viral diseases. The challenges mentioned above showed a gap that therefore necessitated the development of new JKUAT papaya lines. These newly developed lines have been evaluated institutionally and have shown good qualities that can help boost papaya production. This study therefore evaluated the performance of newly developed JKUAT papaya lines (Line 1, Line 5, Line 6 and Line 7) in selected agro-ecological zones of Kenya. The seedlings were raised at JKUAT and latter transplanted after three months to four different study sites; KARLO Mwea and JKUAT(Upper Midlands zones), Nkubu and Mitunguu(Upper Highlands zones). The papaya lines were planted in a randomized complete block design with three replications. Data were collected on their morphological and fruiting characteristics, namely trunk, height, internode length, time to flowering, total number of fruits, flesh thickness, fruit diameter, fruit length, fruit weight and quality parameters. From the result, line 5 in Mwea had the highest number of fruit, followed by line 6 in Mitunguu and then line 5 in Nkubu, while on the other hand, line 1, 7 and solo had the least number of fruits. Fruits from lines 5 and 6 had small to medium size, while those of lines 1, 7 and solo were large in size. Fruit weight was significantly different where the highest was recorded by line 7 in Mitunguu(2kg), followed by line 1 in Mwea(1.85 kg) while the least was recorded by line 5 in JKUAT (1.19 kg) followed by line 5 in Mitunguu (1.35 kg). The papaya lines had a significant differences on flesh thickness where the highest was recorded by line 7 at JKUAT (1.81cm), followed by line 7 at Mitunguu, Nkubu and Mwea (1.80 cm), however on the other hand, the least was recorded by line 5 at JKUAT (1.56 cm), line 5 at Mwea (1.60 cm) and line 5 at Mitunguu (1.60 cm).The results also showed significant differences in height at the first flower emergence. Sunrise solo had the first flower at 92.33 cm at KALRO Mwea while the shortest height at first flower emergence was in Line 6 (69.97 cm) at JKUAT. The total soluble solids (TSS) varied significantly from 14 % in line 5 in Mitunguu to 8.33% in line 7 at Mwea. From the study conducted, all the sites experienced incidences of powdery mildew except JKUAT and among the locations with incidences, there were no significant differences that were noted on both incidences and severity levels. However, there were significant differences that were noted in papaya lines where line 1 at KALRO Mwea had higher incidences and severity (2.4% and 1.25% respectively). The incidence of anthracnose disease was observed at JKUAT only with 2.53% and a severity of 3.34%, while other experimental sites did not show any symptom. Among the lines, lines 6 and 7 did not show symptoms while line 1, 5 and solo sunrise had incidences but they did not have significant differences. The interactions between the locations and papaya lines among the lines with symptoms did not show significant differences, however solo at JKUAT had a higher incidence of 4.58% while line 1 at JKUAT had a higher severity of 6.97%.

Incidence of papaya ringspot virus was noted in all the experimental locations and they showed significant differences with JKUAT having a higher incidence and severity of 6.84% and 10.04% respectively, while on the other hand, Nkubu had the least incidences and severity of 2.05% and 1.92% respectively. Among the papaya lines, line 5 had higher incidences while solo had the lowest levels of 5.98% and 2.67% respectively. There were also significant differences noted on the severity of ringspot virus where line 7 had higher severity levels of 7.92% while the least severity was recorded by solo at 2.84%. In conclusion, different JKUAT papay lines exhibited different agronomic performances both in growth, development and disease resistance where by for the combined traits, line 7 performed highest in fruit weight, fruit diameter and flesh thickness while line 5 was better in total number of fruits and total soluble solids. In addition, lines 5, 6 and 7 were not susceptible to fungal infections in different sites i.e. line 5 free from powdery mildew at KALRO Mwea and Nkubu, line 6 free from powdery mildew at Nkubu and Mitunguu and also free from anthracnose at JKUAT. The study recommends further research to evaluate the performance under other conditions such as heat and water stress .

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Fruit production in Kenya contributes to a lot of income generation and represents an important part of the agricultural industry through earning of foreign exchange and it also contributes to human diet (Prabha and Modgil, 2018). The business of growing fruits like papaya has been shown to be an important part of the economy since it serves various purpose such as supplying the needed food nutrients for most of the citizens (Gunes and Gübbük, 2011). Papaya is among the highly valued, the most cultivated and exploited fruit species in the tropical and subtropical regions across the globe (Prabha and Modgil, 2018). Specifically, papaya is highly ranked in terms of nutritive value which includes vitamins, minerals, proteins, fibers and calories that are well documented (Nwofia and Okwu, 2012). Papaya is a tropical fruit tree, a member of the Caricacea family and in some cases, it is referred to as pawpaw. It originated from tropical regions of America and is currently grown in many tropical countries across the world (Pomper et al., 2010). It is highly consumed in the pharmaceutical and brewing processes. Primarily, many countries produce it for fresh markets either for local markets or for export. India, Brazil, Indonesia, Nigeria and Mexico are among the countries that leads in production of papaya in large volumes (Table 1). In Africa, Nigeria is the leading producer followed by Democratic Republic of Congo (Kaur and Kaur, 2017). Currently, in terms of acreage and volume of production, Kenya is ranked number fifteen. In recent years, the acreage under papaya production has been on the rise as growers embrace the newly introduced varieties in the country. Coastal and Eastern regions are the major producing areas in Kenya, though other regions in the country produce smaller quantities of papaya (Rimberia and Wamocho, 2014).

Most of developing countries such as Kenya have been affected in terms of low production and poor quality due to factors such as adaptation problems and papaya disease infection.

By estimation on production, it is realized that about 30-50% of all the total produce do have poor quality and never reaches the final consumer. Due to the above mentioned challenges there is an increase in the development of new cultivars that can improve production among farmers. The development of the new cultivars depends majorly on the availability of genetic variability which therefore require a favorable response of simultaneous genotype that suits best to most traits of agronomic importance (Cancela et al., 2014). In order to obtain the new pure lines cultivars and also to develop the lines, it may require the use of genetic variability which can be found in segregating papaya generations from time to time. Several studies have been done in papaya crop concerning the segregations of the populations which have a wide genetic variability which have shown traits that when valued show economic importance (Brown et al., 2011). This has therefore led to selection of most of superior genotypes that produces fruits of high quantity and good market quality (Cancela et al., 2014). Often, the marketability of fruits is influenced by consumers' preference but largely the first impression that attracts buyers is the quality judgment such as fruit appearance, fruit shape, individual weight, and color (Saran et al., 2015). To achieve good produce, high producing countries largely use hybrid seeds that results to optimum quality and yield which is highly preferred by both the local and foreign markets. Over the years , there has been papaya varietal improvement and utilization that includes Germplasm selection and improvement done by Capixaba Institute for Research, Technical Assistance and Rural Extension (INCAPER) in Brazil, Agricultural extension and Disease management in Papaya done by Felda Agricultural Services Sdn Bhd in Malysia, Tissue culture and transformation of papaya done by Hawaii Agricultural Research Centre (HARC) in USA, Selection, hybridization and production of high quality papaya fruit for supermarkets and export outlets done by Neofresh (Pty) Ltd. in South Africa and Varietal Development and Evaluation done by Jomo Kenyatta University of Agriculture and Technology in Kenya which led to the development of new JKUAT papaya lines by the JKUAT research team. These JKUAT papaya lines were developed using some of the commercial papaya cultivars and accessions collected locally. The cultivars used had morpho-agronomic traits that were divergent and had good fruit qualities (Asudi et al. 2010). However characteristics of these lines had not been documented and this resulted to evaluation on performances in different selected agro ecological zones of Kenya. Therefore, the objectives of this study were to: 1) Asses the growth and productivity of new JKUAT papaya lines in different selected agro-ecological zones of Kenya; 2) Asses the incidence and severity of papaya ringspot virus, powdery mildew and anthracnose among the new JKUAT papaya lines in different selected agro-ecological zones of Kenya.

Table 1.1: List of Countries by papaya production

Rank.	Country	2018 (Tons)	2017 (Tons)	2016 (Tons)
1	India	5,639,300	5,940,000	5,667,000
2	Brazil	1,603,351	1,058,487	1,296,940
3	Nigeria	850,000	829,563	827,482
4	Indonesia	840,121	875,112	904,284
5	Mexico	836,370	961,768	951,922
6	Dominican Republic	704,786	869,306	863,201
7	DRC	220,483	214,405	215,040
8	Philippines	172,628	167,043	162,481
9	Venezuela	165,102	178,164	175,677
10	Thailand	157,571	178,280	173,269
11.	Colombia	183,732	179,899	177,458
12.	Cuba	176,630	189,086	212,579
13.	Peru	175,988	177,171	169,437
14.	Bangladesh	131,598	134,647	130,371
15	Kenya	131,456	129,089	127,423

Source: FAOSTAT, 2019

1.2 Problem Statement

Commercial production of the papaya fruit crop in Kenya is highly dependent on seeds for propagation. Often, most hybrid seeds used for production are imported while the bulk are farmer selected from the previous crop harvest which are grown from one season to the other. Additionally, the imported seeds are too expensive for ordinary farmers, and on the other hand, seeds selected by farmers from previous produce are inferior in quality which is a common practice and it is hastened by inadequate established seed producers within the country. Most of the varieties grown in Kenya face challenges of poor adaptation to prevailing weather conditions, infestation by pests and diseases and some of the varieties are very tall and the estimated papaya yield losses is up to about 57% (Rimberia and Wamocho, 2014). Often there is inadequate planting materials for the varieties that are available for cultivations as a result of genetic erosion that occurs in plants with open pollination such as papaya (Asudi et al., 2013). This phenomenon leads to a decrease in varietal purity as generation moves from one to another (Kumcha et al., 2008). There has also been a challenge on pest and diseases that infects the available papaya varieties and as a result, it compromise the quality of papaya. In addition, Kenya has varied agro-ecological and agro-climatic conditions that affects the productivity of many crops like papaya (Leghari, 2017). Different regions do receive different amount of rainfall and different temperatures that vary from time to time and also different soil conditions that directly affect the nutrient utilization efficiency in crops. In response to these problems, new papaya lines were developed in JKUAT. These new lines were evaluated at JKUAT farm and showed good quality characteristics (Rimberia et al., 2018; Nishimwe et al., 2019). In relation to this, there was a need for evaluation of the new papaya lines in other selected agro-ecological zones of Kenya to asses their agronomic performances.

1.3 Justification

Kenya is a tropical country with different agro ecological zones that impacts on the growth and production of several crops. Among the fruit crops grown in Kenya, papaya has a high potential to earn the country foreign exchange through exportation and at the same time supplement diet since it is rich in various nutrients that are essential for human health. The crop has a high potential since it matures and produces very fast as compared to other fruit crops. In Kenya, most farmers face serious challenges, especially with pest and diseases and this was a factor that necessitated the development of the new JKUAT papaya lines. The newly developed lines had been evaluated at JKUAT and confirmed to be superior to other varieties in Kenya in terms of quality and diseases resistance (Nishimwe et.al, 2019, Rimberia et al., 2018). The ability to develop and evaluate the performance of new lines in different selected agro ecological zones was of paramount importance for the maximization of productivity potential in different regions. Fruits morphological data and yield could be considered in large scale commercialization of the new varieties to improve papaya production while the disease data on incidences and severity could be key in assessments of disease prone areas and this could specifically reduce loses on production. Evaluations on agronomic performances, yield and disease incidences was more of significance since it impacted on the release of these new varieties in the markets. The assessment of the main devastating papaya diseases were to help provide information on which papaya line could perform well in terms of disease resistance in a given region. Evaluation of these new lines in different regions was also provide essential foundation for future development of other varieties that were to meet the expectation and needs of farmers and consumers. Therefore the objective was to evaluate the agronomic performance of selected JKUAT papaya lines in different agro ecological zones of Kenya.

1.4 Expected output

From the findings on this research, the results on both the morphological characteristics, yield attributes and disease data were key on further exploits on the new varieties. It was beneficial to most growers of the tested locations since they were in a possession of doing their own selection of the varieties based on their preferences and prevailing conditions. Being that it was the first documentation done on the multi-locational trials of these new JKUAT lines, the findings were important to the researchers and developers of these specific lines as it was an achievement and it ascertained their scientific research on breeding of plants.

1.5 Objectives

1.5.1 Main Objective

To evaluate the agronomic performance of selected JKUAT papaya lines in different agro-ecological zones of Kenya.

1.5.2 Specific Objectives

1. To asses growth and productivity of new JKUAT lines in different agro-ecological zones of Kenya.
2. To asses incidence and severity of selected viral diseases and fungal diseases among the new JKUAT papaya lines in different agro-ecological zones of Kenya.

1.6 Null hypothesis

a) H_0: There were no differences in growth and productivity among the new JKUAT lines in different agro-ecological zones of Kenya.

b) H_0: There were no differences in disease incidence and severity among JKUAT papaya lines grown in different agro-ecological zones.

CHAPTER TWO

LITERATURE REVIEW

2.1. Botany of Papaya (Carica papaya)

Carica papaya L. is an herbaceous plant that grows to about 12m high depending on the cultivar. Papaya is a member to the family Caricacea and widely cultivated as food in different countries in the world that are within the tropical and subtropical regions (Pomper et al., 2010). *Carica papaya* is referred to by different names in certain regions across the world. Pawpaw in the UK and Sri Lanka, Tepaya in West and East Malaysia, Papali in India, and Ibepe in the Southwest of Nigeria (Ming et al., 2012). Popularly, the ready ripe fruit is consumed as food while the unripe one is largely used in industries due to its production of latex (rich in enzyme) that is often utilized in a wide range of applications such as industrial consumption , nutritional through diet supplementation, and therapeutically (Saeed et al., 2014). Papaya produces sexually whereby male and female organs are formed on separate plants (dioecious). However, there are also plants that are hermaphrodites (monoecious). Over time, papaya has evolved differently and there are gynodious (female organ on some plants and hermaphrodite organs on others) and also andromonoecious (male organ and hermaphrodite organs on the same plant) and different cultivars have exhibited different morphology (Dhekney et al., 2016).One of the oldest cultivar is solo variety that has been bred to give rise to other varieties such as "Kapoho Solo," "Dwarf Solo," and "Waimanalo". In the modern world, scientist have continually explored advanced plant breeding techniques such as selective, cytogenetically and biotechnological to come up with new cultivars (Ezura and Nishio, 2014). These new cultivars are developed to have superior agronomic traits such as desired fruit characteristics, disease resistance and also to improve yield output (Rimberia et al., 2005). Some have also been bred to improve other papaya products such as secondary metabolites and some proteinases classified under non vitamin non mineral (NVNM) which are supplements in human nutrition (Falana and Nurudeen, 2020). Different cultivars have different characteristics such as shape, colour, size, sugar content and flavor (Aikpokpodion, 2012).

2.1.1 Papaya Morphology

Naturally papaya has a mono-axial stem and does not produce branches but when damaged or macerated, it produces multi stems. The stems when injured produce white milky latex which is itchy when in contact with the skin. The stem is very soft and can be damaged by strong winds or movements by animals. This also pose threats at harvesting since they can be easily damaged (Schweiggert et al., 2012). Leaves are palmnately lobed with the leaf stalks measuring up to 1m long depending on the variety (Brown et al., 2011). These leaves are alternately arranged on the stem as the plant grow. The old leaves senesce and fall leaving the stem clear. At the apex of the plant, there is a cluster of leaves and along the upper part of the stem, there are also other leaves which therefore make up the foliage of the whole plant. The leaves are palmate which show prominent venation (Schweiggert et al., 2012).Papaya plant produce flowers that are of different sex types at maturity. These flowers are trumpet-shaped which are fragrant and have yellow to white colors when fully open. The males appear in long racemes while the females appear in small clusters or sometimes solitary (Buathongjan et al., 2020). It poses characteristics whereby the female flowers are held close against the stem as a single flower or in some cases, they a pear in a cluster of 2-3 flowers. The male flowers are numerous and also small in size (Brown et al., 2011). The fruits vary on sizes depending on the variety and the conditions under which the crop is produced. The fruits are fleshy, a melon-like shape that hang in clusters which are attached to the stem top just below the leaves. Generally, the fruits are green when young and ripen to orange-yellow when mature.

Male papaya – with long racemes

Female papaya- with solitary flowers

Plate 2.1:Different flower types of papaya plants

2.2 Origin and Global Distribution of Carica papaya

Carica papaya originated from Mexico, Central America, the Western sides of India, the Bahamas and Bermuda in 1616 (Ming et al., 2012). In the 15th Century around 1550, Spanish explorers transported papaya seeds to the Caribbean and Philippines regions and later to the kingdom of Naples in around 1626. Later Papaya was introduced to tropical and subtropical regions of the world such as Australia, Hawaii, Sri Lanka and then Africa (Nelson and Jones-Nelson, 2012). In the 1800s it was introduced to Hawaii which up to date remains one of the main producers in the USA (Barragan-Iglesias et al., 2018). In the 1950s, production of *C. papaya* started in Miami and New York and it is believed that it came from areas of Santa Marta (Colombia), Puerto Rico, and then to Cuba by an Italian entrepreneur called Albert Santo. By 1959, in most parts of southern and central Florida, it was grown as one of the food crop in commercial scale (Barragan-Iglesias et al., 2018). Currently in the whole world, Asia as a continent is the highest producer and exporter of papaya (Evans et al., 2012).

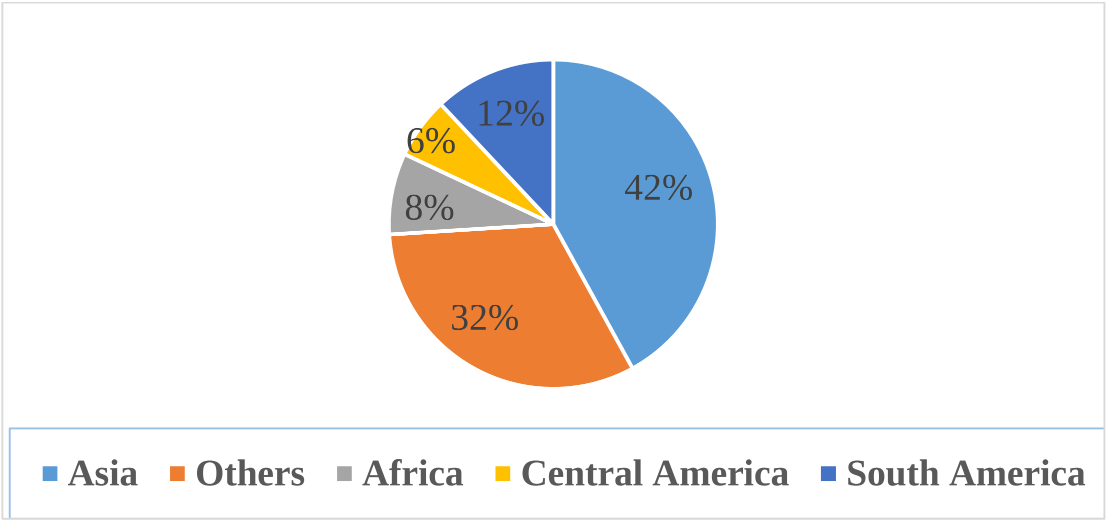


Figure 2.1: Chart showing percentage levels of Carica papaya fruit produced in different geographical regions

2.3 Papaya Production Conditions

Countries that produce papaya in high volumes are found within the tropical and sub-tropical regions. Majorly, the production is high in areas of an altitude of up to 1000m above sea level (Cabrera et al., 2020). They are produced in varied temperatures that range between 25 and 35° C (Bindu and Podikunju, 2017). Preferably, the soil should be well drained with adequate organic matter to improve soil quality. Generally, application of fertilizer should be done around each plant as guided by the fertilizer specification. Papaya is very sensitive to chlorine and therefore chlorine free fertilizers should be used. After transplanting approximately between one to two weeks, application of 28g of high phosphate fertilizer should be used. Soil conditions should have a pH of between 6 and 6.5 for maximum production (Bindu & Podikunju, 2017). Papaya production is affected in regions with poor drainage and high rainfalls since the papaya roots die when continuously drenched for a period of 24 to 48 hours (Bindu and Podikunju, 2017). In cases of low rainfall there should be irrigation as a supplement since overall development, flowering, and fruit set and fruit development essentially depends on optimal water supply. A minimum monthly rainfall of 4 inches (100 mm) and an average relative humidity of 66 percent are suggested as ideal for papaya growth and production (Bindu and Podikunju, 2017). Weeds should be controlled throughout to avoid competition and also to eliminate chances of becoming host to devastating pest and diseases. During the ripening period, dry weather is necessary to get good fruit quality such as total soluble sugars (Soto et al., 2021). Rain is immensely important to agriculture and in situations where there is a limitation in water supply the plants do not develop resulting to low yield with poor quality. In crop production, water is vital and affect both quantity and quality of produce and therefore, rainfall is of fundamental importance for the food industry to flourish (Time and Acevedo, 2020).

2.4 Breeding of Papaya

There are a number of programs in breeding developed in countries globally, however, in developing countries such as Kenya, the programs are still low. Basically breeding strategies can be both traditional and modern technologies that involves observations and selections that are geared towards purposeful manipulation of qualities that enhances the development of new varieties with some characteristics that are desirable which is made possible by modifying the DNA of the seeds and plant cells. Some of the new breeding techniques are reverse breeding, Site-Directed Nucleases, Oligonucleotide Directed Mutagenesis, Agro-infiltration and RNA-dependent DNA methylation. Therefore the objective of breeding is to increase yields, get desired traits, and develop disease resistant and tolerant varieties. The major challenges experienced in breeding is how to improve all the traits that may be of interest without interference. This is always challenging due to correlations that occur in genetic traits due to some genes with pleiotropic effects and the linkages between the genes and the chromosome or a times to population genetic structure. A host of varieties that have been bred in other countries have also been introduced in Kenya and used by many commercial papaya growers. Some of the common varieties introduced and grown in Kenya are solo sunrise and solo sunset developed in Hawaii, Cavite developed in the Philippines, Kiru variety from Tanzania. The literature illustrates that various hybrid varieties used for commercial purposes originated in Asia and America. Despite all these introductions from other countries, there were very limited attempts towards the maintenance of variety distinctness or development of varieties that are suitable for the Kenyan growing conditions (Asudi et al., 2013). Due to open pollination, it further decreases the varietal purity which occurs from one generation to the other. There is also genetic improvement of papaya through haploid, whereby embryo induction was done through anther culture (Rimberia et al., 2005). It further reported that all the plantlets that originated in the process of anther culture were of microspore origin and therefore showed that the technique is vital in the breeding of female papaya.

2.5 Papaya Production in Kenya

Several introduced varieties of papaya in Kenya, are produced and largely sold in markets and consumed as dessert. The major producing areas are Meru, Machakos, Kisii, Embu, and Muranga (Rimberia and Wamocho, 2014). However, in most cases, isolated papaya fruit trees can be seen in most parts of the country grown in homesteads. In most farms, it is not grown as the main stand and many farmers prefer to intercrop it with other crops and mostly planted in the boundaries (Rimberia and Wamocho, 2014). The fruits are harvested throughout the year and sold to local markets while commercial farmers who produce good qualities sell it to export markets. In most instances, the Kenyan papaya is eaten locally as fresh fruit with much demand from grocery stores and town hotels. Commercial farmers sometimes dry the papaya fruit and sell it to the export market as dried fruit mixture (Duangmal and Sritongtae, 2018). In highly commercialized firms, latex is extracted from the unripe fruits and then processed to produce papain. Papain from papaya is proteinase in nature and used in brewing industries and pharmaceutical industries (Benucci et al., 2014). In the coastal regions, people have innovated other ways of utilizing the papain such as removal of spines and string cells that are present in jellyfish and sea urchins.

2.6 Papaya Pests and Diseases

There are a number of pest and diseases that affect papaya production negatively. The common ones are caused by viruses, fungi and nematodes. The major devastating diseases are papaya ringspot virus, powdery mildew and anthracnose. There are also a number pest that affects papaya such as mealybug, Root not nematodes, Aphids(*Myzus persicae)* and Red spider mite.

2.6.1 Papaya Ringspot Virus (PRSV-P)

In the recent past, it is one of the devastating diseases that affect papaya growing fields throughout the world and the main mode of transmission is through the feeding of aphids (*Myzus persicae)* from one plant to the other (Gonsalves, 2010). Among the affected papaya trees, there is a characteristic of banding and mottling in the veins. The leaves appear yellowing which is associated with leaf discoloration and streaks on the petioles that are water soaked. It appears on both the fruits and plant leaves (Pandey, 2017). Affected plants remain stunted in growth due to the hindrance of various physiological processes which later reduces fruit sizes, fruit quality contents and even the physical appearance of the fruits. The disease spreads very fast and has become the limiting factor in papaya production. Its control has been of a problem however, selection of tolerant varieties in combination with other cultural practices such as crop rotation, cross protection with specific mild strains reduces its effects (Pandey, 2017).

2.6.2. Anthracnose (*Glomerella cingulata*)

It is common on plants petioles and fruit itself which is caused by a fungus that produces spores which are orange in color. Often, the symptom is observed in mature fruits where there are water-soaked lesions and form round spots as they enlarge and leaves a sunken spot (Saini et al., 2017). This adversely affects the post-harvest life of the fruits. There are means for control where the harvested fruits are dipped in the warm water of about 45˚C for 15-20 minutes and letter dipped in cold water for 15 minutes. The fruits can also be sprayed with various fungicides such as (Dithane M- 45) W.P. 1:400 and currently, Chitosan is used through stimulation of Defence-Related Enzymes to control the disease (Ali et al., 2012).

2.6.3. Powdery mildew

This is a disease that is caused by the pathogen known as Oidium caricacea. It do thrives in humid areas during the periods of warm days accompanied by cool nights. Their spores germinate rapidly within 10-12 hours provided the right conditions prevail. When the temperatures are about 18- 32^0C, they develop very fast and the pathogen requires a living host for it to complete its life cycle. The immature leaves are the most susceptible but it spreads with time to petioles, pedicels, and peduncles. The affected plants do have water-soaked spots that become powdery patches of mycelium and spores.

2.6.4 Damping-off

This is one of the major diseases caused by fungi (Phytophthora, Fusarium and Aphanomyces) which live in the soil. The disease is more prevalent in conditions experiencing high temperatures accompanied by wet soil with poor drainage. Additionally, it is more severe in poorly aerated soils with high nitrogen levels and a shortage of sun shine duration (Gupta et al., 2016). In most cases, infected seedlings rot at the base of the roots which then wilt, fall and then die (Male and Vawdrey, 2010). In control of this disease, there are measures employed to help in the eradication. The first step is to sterilize the soil with steam of 32.3ºC for 30 minutes to kill or make the soil conditions unfavorable for the pathogen's survival. The soil should also be drenched with effective fungicides to prevent its occurrences (Gupta et al., 2016).

2.6.5 Aphids (*Myzus persicae)*

These are small flying insects that suck the young leaves and results in curled and crinkled leaves especially at the seedling stage. Their eggs are deposited in the buds which have crevices, stems with cracks, and barks of the plant. Generally, tender shoots and under surface of the leaves gets infected leading to curling and crinkling of leaves resulting to stunted growth. In heavy infestation, black sooty mold results due to the development of honeydew. In massive infestation, they transmit viral disease (Dube and Maleka, 2017).

2.6.6 Root not nematodes

They infest the roots of a developing papaya plant and the first stage of larvae development occurs within the egg and as a result the first molt occurs. Thereafter, infestation of roots occur after the larvae hatch from eggs. Depending on the prevailing conditions, the eggs take between 4 to 8 weeks to complete the life cycle. At soil temperatures of about 21° C to 27° C the development take place very fast. Normally, the infected plants show symptoms in patches in the field. The gall is formed in the host root system making the roots to become knobby and knotty. In severe infestation, it reduces the root system and breaks the rootlets hampering the roost proper function of uptake and translocation of nutrients. With time, the plants start to wilt especially during the hot conditions since the nematodes predisposes the affected plants to fungal and bacterial pathogen attacks (Patel and Patel, 2019).

2.6.7 Papaya mealybug

After hatching of the eggs, the nymphs search for feeding sites actively for their development. As they turn to adult, they are covered with a white waxy coating. The affected portions of the plant become chlorotic as it progress and latter change to brown and dry away. With the presence of bugs on the plant, they excrete a product called honey dew resulting moist and shiny appearances of the infested portions. This leads to infection of sooty fungus with black covering (Umeh et al., 2020).

2.6.8 Red spider mite

Spider mites are specialized in using their needle- like mouthparts to extract the cell contents from the leaves. As the sap reduces, the chlorophyll content in the plant leaves gets low. The leaves turn to whitish or covered with yellow speckles. The leaves normally desiccate and drop off in severe infestations. They also produce webbing on the leave surfaces preventing the plant from performing its normal physiological functions (Konopacki and Warabieda, 2018).

Anthracnose

Powdery Mildew

Papaya Ringspot Virus

Damping off

Mealybugs

Aphids

Red spider mite

Root rot nematode

Fruit fly

Plate 2.2: Common pest and diseases that infect Papaya

2.7. Multi-locational effects on Gene and Environment interactions on crop production

Determination of the degree of effects involving the interactions between genotype and environment is critical and it is one of the major areas where a lot of focus is placed by the plant breeders as it determines the performance of a given crop. The multi-locational evaluation of genotype and environment interaction in the research can lead to a novel germplasm that could be suited to be grown in a specific area with a given agro ecological conditions. Agronomic and yield performances of a plant such as papaya is influenced by multiple genes that interacts with different environmental conditions including both biotic and abiotic stress factors that influence crop growth over the season. Additionally, testing and performance trials enable the plant breeders in determination of crop genotype performance coupled with other effects such as natural plant diseases and pest pressures in a given location. Most of the growers attach a value of a crop on both the agronomic performance and the quality achieved by the end users. In this research, the test genotypes were evaluated along with a commercial variety (solo) to serve as a benchmark for the traits that were measured to help in determining the overall potential and value of the test genotype.

2.8. Kenya's agro-ecological zones

Kenya has different Agro-ecological zones that affects crop production. They are land resource mapping unit that defines various climatic conditions, land form and type of soil and land cover. In Kenya, the dry land mass is commonly divided into six agro-ecological zones as the table below indicates. The understanding of agro ecological zones helps in knowing the principles used in designing and managing of sustainable agricultural systems such as production, utilization and the soil fertility. There are various aspects such as physical, chemical and biological that one has to understand in an agro ecological environment of a crop, its land use and the farming system.

Table 2.1: Agro-ecological zones of Kenya

Zone	Approximate Area (km^2)	% Total
I. Agro-Alpine	800	0.1
II. High Potential	53,000	9.3
III. Medium Potential	53,000	9.3
IV. Semi-Arid	48,200	8.5
V. Arid	300,000	52.9
VI. Very arid	112,000	19.8
Rest (waters etc.)	15,600	2.6

2.9. Papaya breeding project at JKUAT

Jomo Kenyatta University of Agriculture and Technology as an institution undertooke a research in commercial and industrial development of papaya. The research was spearheaded by Professor Fredah K. Rimberia Wanzala, Senior lecturer Horticulture Department. These JKUAT papaya lines were developed using some of the commercial papaya cultivars and accessions collected locally. These cultivars have morpho-agronomic traits that are divergent and have good fruit qualities (Asudi et al. 2010). However characteristics of these lines had not been documented and this therefore resulted to evaluation in different agro ecological zones of Kenya. The two specific objectives of JKUAT research were to breed papaya for increased productivity and to produce disease free papaya plantlets of known sex. There were two breeding strategies used; conventional cross breeding and anther culture in vitro and protocols for mass propagation of disease free papaya plantlets of known sex were developed by culturing shoot tip meristems in vitro. From the research, the expected outputs were to produce new high yielding varieties of papaya, disease free papaya planting materials of known sex, personnel trained at technical, Bachelors, Masters and PhD levels. They envisioned that there would be an impact of the outputs on agriculture in Africa where it would contribute to increased production of papaya, contribute to improved livelihoods of papaya farmers and contribute to reduced hunger and malnutrition among papaya farmers

Table 2.2: Previous findings on morphological and quality characteristics of JKUAT papaya lines carried out at JKUAT block A

Hybrids	Fruit weight (g)	Fruit length (cm)	fruit diameter (cm)	Internal cavity length (cm)	Internal cavity diameter (cm)
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

CHAPTER THREE

GROWTH AND PRODUCTIVITY OF NEW JKUAT PAPAYA LINES IN DIFFERENT AGRO-ECOLOGICAL ZONES OF KENYA

Abstract

Papaya is one of the tropical and subtropical fruit crop that is grown around the world. The fruit is rich in nutrients especially vitamin A (2020 IU/l00g). Besides minerals like potassium and magnesium it also possesses vitamin B, folate and pantothenic acid. Studies were conducted in four experimental sites that were in two different agro ecological zones of Kenya between December 2017 and October 2019 to evaluate agronomic performance of selected JKUAT papaya lines. Morphological characteristics were significantly different ($P \leq 0.05$) in the tested papaya lines. Plant height was significantly different across the zones whereby, the highest significant plant height was recorded by solo sunrise and line 7 in KALRO Mwea, while on the other hand, lines 6,1,5 and solo in JKUAT and line 6 in Nkubu were significantly shorter ($P \leq 0.05$)than all other lines in the growing locations. The result also showed significant differences ($P \leq 0.05$) in plant internode length where lines 1 and line 7 in Mwea did not show significant differences but they had a significantly longer ($P \leq 0.05$) internode length than all other lines in the growing regions. The fruits total number sowed significantly differences ($P \leq 0.05$) among the different lines. Lines 5 and 6 in Mwea, lines 5 and solo in Nkubu, line 5 and 6 in Mitunguu and line 5 in JKUAT did not show any significant differences, however, line 5 in Mwea had a significantly ($P \leq 0.05$) higher number of fruits than all other lines in different locations while lines 1,7 and solo in JKUAT and line 1 in Nkubu had a significantly lower number of fruits. The fruit weight varied significantly among the treatments where line 1 and 7 in Mwea did not show significant differences but had a significantly more weight than line 6 and 5 in JKUAT and line 5 in Mitunguu (Table 3.11). The fruit sizes and quality characteristics varied significantly where line 7 and 1 in JKUAT, line 7 in Mitunguu, line 7 in Nkubu and line 7 and 1 in KALRO Mwea did not vary significantly but they had a significantly ($P \leq 0.05$) higher flesh thickness than line 5 in Nkubu, line 5 in Mitunguu,

line 5 in Mwea and line 5 in JKUAT. The total soluble solids showed significant differences where line 5, 1 in Mitunguu and line 5 in Nkubu did not show significant differences, however, line 5 in Mitunguu was significantly different ($P \leq 0.05$) from other lines in different locations(Table 3.11). From the study, the newly developed JKUAT papaya lines were comparable to solo sunrise in various parameters and could be suitable for exploitation in different regions of Kenya both for breeding and commercial fruit production.

3.1 Introduction

Papayas grow in tropical and subtropical climates and they are usually soft in nature with fleshy fruit that make them utilized highly on a wide variety of culinary ways. They have a vibrant color and sweet taste when eaten and they have a wide variety of health benefits which makes them popular fruits among others (Nwofia and Okwu, 2012). There are various health benefits in terms of nutrients found in papaya fruits and it has proven to help in protecting against a number of health conditions (Nwofia and Okwu, 2012). Generally, the vegetative, reproductive and quality responses of any crop varieties are influenced by agro climatic conditions of a particular region. Kenya has a wide variety of agro ecological zones and getting a suitable crop variety for a particular region is key since it will lessen the burden of crop management by farmer to achieve optimum yield. Coastal and Eastern regions are the major papaya producing areas in Kenya, though other regions in the country produce smaller quantities of papaya (Rimberia and Wamocho, 2014). However, these regions have low production due to adaptation challenges and infection by papaya diseases. Due to the above mentioned challenges breeders engage in the development of new cultivars that have better productivity. Several studies that have been done in papaya has therefore led to selection of most of superior genotypes that produces fruits of high quantity and good market quality (Cancela et al., 2014). Countries that produce high volumes do invest heavily on hybrid seeds which have good quality to achieve optimum yield which is highly preferred by both the local and foreign markets. The objective of this study was to determine growth and productivity of new JKUAT papaya hybrids in different agro-ecological zones of Kenya.

3.2 Materials and Methods

The study on growth and productivity of new JKUAT papaya lines in different agro ecological zones was carried out between the months of April 2018 to October 2019. Four JKUAT papaya lines (line 1, line 5, line 6 and line 7) and one commercial variety solo sunrise, was used as a control. The solo sunrise was bought from the Kenya Seed Company while the JKUAT papaya lines were sourced from the seed stock in JKUAT store. The JKUAT lines were soaked in water overnight and placed on a growth chamber after which they were seeded in the seedling trays. The seedlings were raised in a greenhouse at JKUAT until the time of transplanting. At about 30cm in height, they were transplanted at four different experimental sites. The prepared holes were of 60cm deep and 60cm wide at inter and intra raw spacing of 3m.

3.2.1 Study Sites

The study was conducted in two different agro-ecological zones; Upper Midlands and Upper Highlands. There were four different locations in these two agro-ecological zones namely, KALRO Mwea and JKUAT(Upper Midlands) and Nkubu and Mitunguu irrigation scheme (Upper Highlands). KALRO Mwea a site in Kirinyaga County situated at Latitude of 0.6939 ° S, Longitude of 37.377 ° E, at an elevation of 1159 m above sea level. This site received an average annual temperature of about 21.5 °C, the rainfall was about an average of about 807 mm annually. The second site was JKUAT found in Kiambu County and experienced an average annual temperature of about 19.6 °C and an annual rainfall was about 799 mm. The site lies at a latitude of 1.0891°, Longitude of 37.0105° E, at an elevation of 1416 m above sea level. Mitunguu irrigation scheme was the third site situated in Meru County. It is at a latitude of 0.1089° S and longitude 37.7849 ° E at an elevation of 1020 m above the sea level. This site received about 21.6 °C of temperature annually and an average rainfall of about 1080 mm annually. The fourth site was Nkubu in Meru County. This site is at latitude 0.04626 N, longitudes of 37.65587 and at an altitude of 1388 m above the mean sea level. It had an average annual temperature of about 18.8 °C and annual rainfall of about 1687 mm.

3.2.3 Experimental Design

A Randomized Complete Block Design (RCBD) was used in the lay out of the experiment with three replications. There were 35 plants in each replication, and the treatment comprised 7 plants of each variety that were planted at inter row and intra row spacing of 3m. In each treatment, a random sample of five plants in every replication were taken separately for data collection. The independent factors were locations and treatments while the dependent variables were plant physiological parameters and yield

3.2.4. Planting and orchard management

Transplanting of the seedlings were done within one week in all the experimental sites as follows; Mwea (26-10-2018), JKUAT (28-10-2018), Nkubu (30-10-2018) and Mitunguu (31-10-2018). The holes were prepared and a mixture of compost, manure and top soil were mixed together placed in the planting holes. The plants were taken out of plastic containers carefully without disturbing the roots and placed at the center of the hole. The hole was then refilled while raising the soil around the plant. Immediately after planting, watering was done to every plant. In the times of dry conditions with no rainfall, there was a supplement through irrigation that was done on a weekly basis. One week after transplanting, there was an addition of 40g of triple supper phosphate fertilizer in every hole of papaya. In the months of December, February and April, there was an addition of one bucket of manure added to every hole of papaya plant. There was a regular weeding carried out in all the experimental sites to avoid competitions and also to eliminate chances of pest and disease transmission. The plants were also sprayed against pest and diseases.

Transplanting

Watering

Labelling

Prunning

Plate 3.1: Orchard management practices

3.2.5 Climate and soil conditions of the two selected agro ecological zones

Temperature and Rainfall data were obtained from records of Kenya meteorological stations.

Table 3.1: Rainfall data for the four experimental sites in different agro-ecological zones of Kenya from October 2018 to September 2019

	JKUAT		Mwea		Nkubu		Mitunguu	
	Rainfall (mm)	**Temperature (°C)**	**Rainfall (mm)**	**Temperature (°C)**	**Rainfall (mm)**	**Temperature (°C)**	**Rainfall (mm)**	**Temperature (°C)**
Oct-2018	228	22.7	316	22.7	1140	19.7	540	20.5
Nov-2018	592	22.1	804	22.1	1572	19.1	1092	19.9
Dec-2018	300	21.4	296	21	592	18.7	456	19.6
Jan-2019	156	21.6	204	21.3	192	19.1	152	20.0
Feb-2019	156	22.6	224	22.3	164	19.6	124	20.6
Mar-2019	404	23.0	528	22.9	236	20.1	268	21.0
Apr-2019	752	22.5	1488	22.5	436	19.5	284	20.9
May-2019	408	21.7	1224	21.8	272	18.8	220	19.9
Jun-2019	88	20.5	232	20.4	528	17.6	464	18.3
Jul-2019	44	19.9	188	19.6	192	17.1	144	17.3
Aug-2019	48	20.3	212	20	280	17.5	188	17.7
Sep-2019	56	21.4	160	21.4	244	18.8	240	19.2
AVERAGE	**269.33**	**21.64**	**489.66**	**21.5**	**487.33**	**18.8**	**348**	**19.57**

During the experimental period, there were different environmental conditions experienced in the experimental sites where by they received different amount of rainfall and had different temperature. Averagely, KALRO Mwea had the highest with an average rainfall at 489.66 mm and an average temperature of 21.5^{o}C followed by Nkubu with an average rainfall of 487.33 mm, and average temperature of 18.8^{o}C , then Mitunguu irrigation scheme with an average rainfall of 348 mm and an average temperature of 19.57 ^{o}c and then JKUAT with an average rainfall of 269.33mm and an average temperature of 21.64^{o}C (Table 3.1).

The sample of soil were collected from the 4 experimental sites and analyzed for nitrogen, phosphorus, potassium, pH and electrical conductivity in a laboratory at JKUAT. Phosphorus was determined by Modified Bray No2 Method where a calibration curve of absorbance was plotted against the amount of phosphate in standards. The amount of Phosphate was read in the filtrate from the absorbance and the calibration curve. Available phosphate mg-P_2O_5 kg-1 = C*20/V*0.001*1000*f Where; C =amount of phosphate in the v ml of filtrate (ug-P 2 O 5). V = volume of the sample taken into the volumetric flask (ml), f= moisture correction factor of the soil sample

The nitrogen content was determined through Kjeldahl procedure where the percentage of total nitrogen in soils was calculated by; %N in the soil sample = (a-b) * 0.014* 0.01 * V *100 / * W * al. Where a = volume of the STD 0.01N HCL consumed by the sample, b = volume of the std 0.01N HCL consumed by the blank,v = final volume of the digestion (100ml), w = weight of the sample taken (0.3g),al = aliquots taken for analysis (10ml).

The Potassium content was determined by calculating the concentrations of potassium in the soil sample and calculated by K=C*V*F*100/1000*W

Where;C=(a-b) and a=concentration of K in the sample extract, b=concentration of element in the blank extract, V=volume of extract solution, W=weight of the sample, F=Dilution factor

The pH of the soil was measured using a pH meter that was buffered using two buffer solutions. The electrodes were placed in the buffered solution alternately and pH adjusted.

The electrodes were then washed using distilled water and dipped in the suspension and pH readings taken. The electrical conductivity was measured using an EC meter with conductive electrodes where a digital display was recorded after dipping the electrodes in to the soil solution to measure the soluble salt content in the extract.

Table 3.2: Soil mineral composition from the four experimental sites

Location	Nitrogen (%)	Phosphorus (mg/kg)	Potassium (me/100g)	pH	EC (Ms/cm)
KALRO Mwea	0.52	165.51	8.31	6.83	0.08
JKUAT	0.29	122.00	8.92	6.10	0.19
Nkubu	0.38	118.00	5.91	5.80	0.19
Mitunguu	0.48	130.00	8.23	6.40	0.10

The experimental sites also had different soil composition which could have been influenced by other factors such as water supply, cultivation practices or soil type. KALRO Mwea had the highest nitrogen of 0.51% followed by Mitunguu at 0.47 %, Nkubu 0.39 % and JKUAT 0.28 %. The phosphorus component was also different whereby KALRO Mwea had the highest of 165.5 mg/kg, Mitunguu irrigation scheme (129 mg/kg), then JKUAT (121mg/kg) and Nkubu (119 mg/kg). JKUAT had the highest potassium levels of 8.91 me/100g, followed by KALRO Mwea (8.32 me/100g), Mitunguu irrigation scheme (8.22 me/100g) and Nkubu (5.90 me/100g) (Table 3.2). The highest pH level was recorded at KALRO Mwea (6.82), then Mitunguu irrigation scheme (6.3), JKUAT (6.0) and Nkubu (5.7). The highest electrical conductivity was recorded at Nkubu (0.195 Ms/cm), followed by JKUAT (0.190 Ms/cm), then Mitunguu irrigation scheme (0.102 Ms/cm) and KALRO Mwea (0.079 Ms/cm).

3.2.7 Data collection on morphological characteristics

The data collection on morphological features were carried out once per month beginning on the day of planting going through up to fruit maturation. The Data collection was on height of the plant (cm), both leaf length and width (cm), trunk thickness (cm), total number of nodes, internode length (cm), and height at first flower emergence (cm). The plant height was found by measuring the distance from the ground surface all through to the apex of the shoot using a tape measure. The distance from the ground surface to the last node that differentiated the first flower was used to measure height at flower emergence. Trunk circumference was the perimeter at 20 cm above the ground surface and these were measured by a tape measure .The total number of nodes was determined by counting all the nodes above the ground to the shoot apex. Internode length of each tree was measured from 20 cm above the ground using a tape measure.

Determination of plant height

Determination of leaf length

Determination of internode length

Determination of number of fruits

Determination of fruit weight

Determination of fruit length

Plate 3.2: Different stages of data collection of papaya lines

3.2.8 Fruit yield

The fruits that were mature green to ripe stages and were about 4-5 months old were selected and used for the analysis of yield. Data collection was carried on variables traits such as fruit number, the weight of fruit (kg), diameter (cm), fruit length (cm) and the thickness of flesh (cm). All the fruits were counted and weighed using a weighing balance to determined fruit yield of each line. The mean of ten fruits randomly selected from each tree were used to determine the fruit weight (kg). Longitudinal dissections of the ten fruits randomly selected were made and then fruit lengths (cm) were determined (distal end pole to proximal end pole) by use of a veneer caliper. The thickness (cm) of the fruits flesh were estimated by calculating the mean thickness of the portions from top, middle and bottom of the ten sectioned fruits and done using a veneer caliper. The total soluble solid was measured using a refractometer where a juice was squeezed from the ripe fruit and placed on the refractometer lens and the reading taken. These data were collected for four months, atime in which the fruits were actively on production.

3.2.9 Data Analysis

The data collected on different features on plant morphology, fruit yield and quality of the fruit were subjected to analysis of variance (ANOVA). This was done using GenStat Statistical program, 17th edition (Payne et al. 2011). The difference among the treatments means were tested by a multiple means comparison test (Duncan Multiple Range Test) at a significance level of $p \leq 0.05$. Each value of the mean gotten and standard errors that were presented are the representations of the three replicates of each treatment.

3.3 Results

3.3.1 Plant height of papaya plants in the selected agro -ecological zones of Kenya

There was a significant gradual increase in height in all the experimental sites from the day of transplanting up to 150 days. On the first 30 days after transplanting, there was no significant difference noted among the locations, however, as time progressed, till the 150 days, the result showed significant differences. Plants in KALRO Mwea were significantly taller ($P \leq 0.05$) than plants in Mitunguu, Nkubu and JKUAT. Plants in Mitunguu were also significantly taller than plants in Nkubu and JKUAT, likewise plants in Nkubu were significantly taller than plants in JKUAT (Figure 3.1).

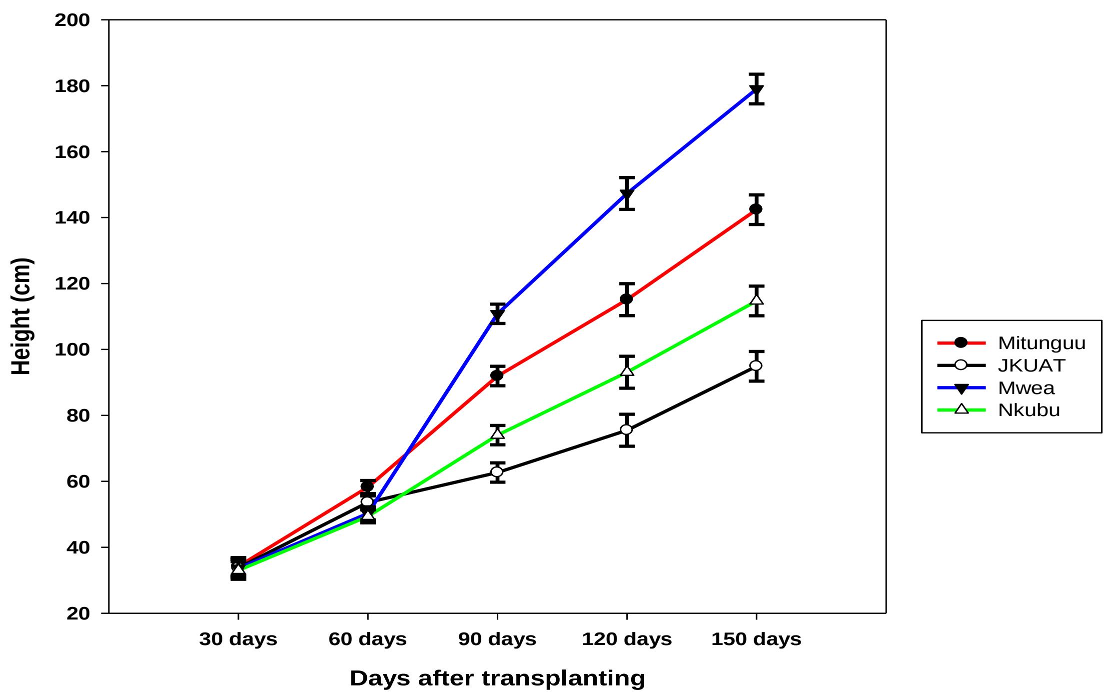


Figure 3.1: Effects of locations on plant height. Points represent means and standards errors of heights of papaya plants taken from three replicates per treatment and measured over a period of 150 days after transplanting

Among the papaya lines, there was a gradual increase in plant height among the papaya lines. In the first 60 days, there were no significant differences in height among the papaya lines, however, from the 90 days to 150 days showed significant differences ($P \leq 0.05$) among the papaya lines. It was noted that solo sunrise was significantly taller than all other papaya lines after 150 days, however, line 7, line 5 and line 1 were not significantly different, but lines 5 and 7 were significantly taller than line 6(Figure 3.2) .

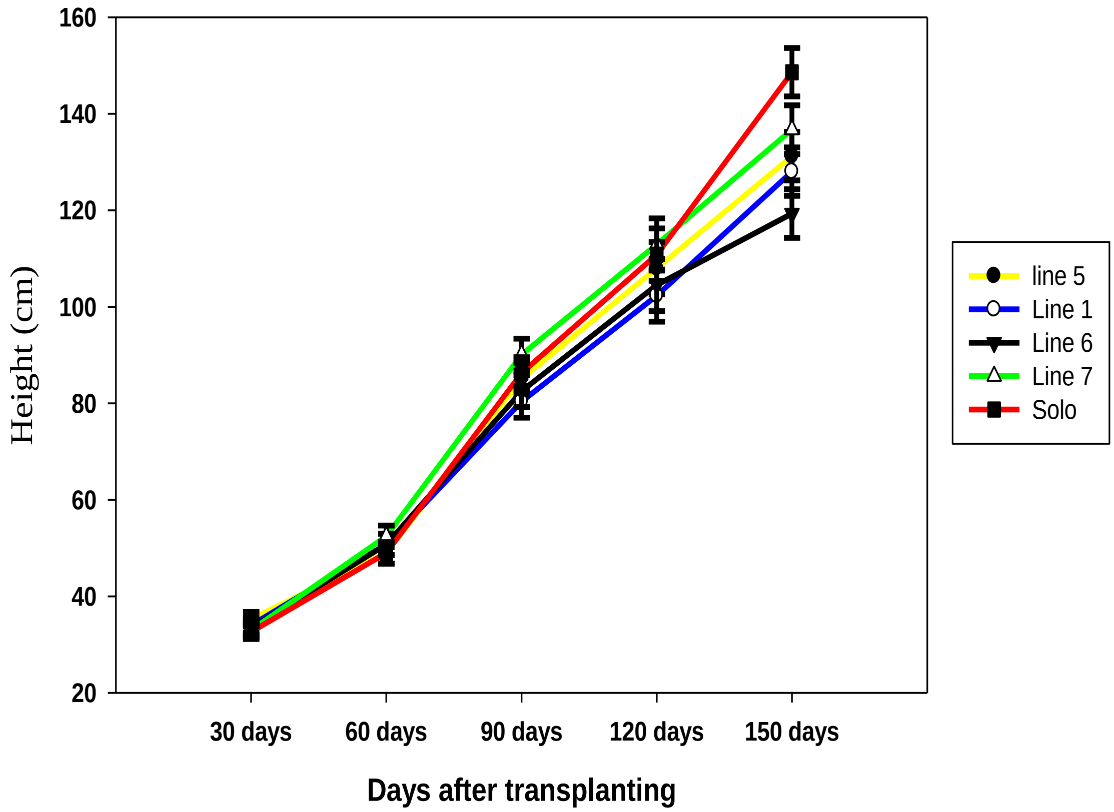


Figure 3.2: Effects of different lines on plant height. Points represent means and standard errors of heights of papaya plants taken from three replicates per treatment and measured over a period of 150 days after transplanting

Table 3.3: Effects of interaction of location and lines on plant heights of papaya plants taken from three replicates per treatment and measured over a period of 150 days after transplanting

Location* Lines	30 Days	60 Days	90 Days	120 Days	150 Days
JKUAT Line 5	37.67±3.67a	45.00±0.58bcdefg	63.67±3.18gh	71.70±2.85i	92.50±2.47hi
Mwea Line 5	36.67±1.20a	55.00±1.00ab	110.33±1.67ab	150.70±4.33a	174.30±2.85b
Nkubu Line 6	36.33±2.33a	55.00±3.06ab	75.67±3.84efg	91.30±5.36fghi	99.00±2.65ghi
Mitunguu Solo	35.67±2.85a	59.33±7.06a	92.67±11.35cd	125.00±20.22bcd	166.30±5.55bc
Mitunguu Line 5	35.00±2.08a	60.67±3.38a	96.00±6.25bcd	118.70±14.83bcde	145.70±15.21cd
Mitunguu Line 7	35.00±3.21a	57.33±2.67ab	96.33±7.84bcd	114.00±9.87cdef	132.70±7.06de
Nkubu Line 1	34.67±2.33a	47.67±2.19bcdef	70.67±2.85fgh	94.70±3.38efghi	115.30±12.91efgh
JKUAT Line 7	34.67±0.88a	44.00±3.00cdefg	66.67±3.18fgh	84.00±6.56hi	109.70±2.19efgh
Mwea Line 6	34.33±1.86a	51.00±2.08abcde	108.00±1.00ab	141.30±3.84ab	172.70±7.69b
Mitunguu Line 1	34.00±2.65a	58.67±1.76a	87.00±2.89cde	106.30±2.19efgh	145.00±5.57cd
Mwea Line 1	33.67±2.73a	55.67±2.96ab	100.00±2.31bc	134.00±3.06abc	165.00±1.53bc
JKUAT Line 1	33.67±0.33a	41.00±1.53efg	63.67±3.53gh	74.30±4.63i	86.70±2.40i
Mwea Solo	32.83±2.95a	52.00±3.00abcd	119.67±0.88a	156.30±3.71a	197.30±10.27a
Nkubu Line 5	31.67±0.33a	43.33±3.38defg	70.33±2.67fgh	91.00±4.58fghi	112.30±6.33efgh
Nkubu Line 7	31.67±1.20a	54.00±6.00abc	81.33±4.63def	99.70±9.82efgh	118.70±11.62efgh
JKUAT Line 6	31.67±2.03a	41.67±2.96efg	58.67±2.96h	74.00±2.65i	83.00±1.53i
JKUAT Solo	31.33±1.45a	37.67±2.19fg	60.67±4.26gh	73.30±5.04i	102.70±2.85fghi
Mitunguu Line 6	31.33±2.33a	55.33±3.33ab	87.67±2.19cde	111.30±3.18cdefg	122.30±4.33ef
Mwea Line 7	30.67±3.17a	54.33±2.96ab	116.00±1.00a	154.00±3.21a	185.70±10.09ab
Nkubu Solo	30.67±0.33a	47.00±1.53bcdefg	72.00±7.00fgh	88.70±8.21ghi	128.00±7.02de
LSD	6.01	9.01	13.33	21.92	20.36
CV%	10.80	10.80	9.50	12.30	9.30

Means in the same column followed different letter(s) are significantly different at ($P \leq 0.05$)

From the interactions of the lines and the location, 30 days after transplanting, there were no significant differences noted, however, after 60 days to 150 days, there were significant differences that were noted. At full maturity, solo sunrise and line 7 in KALRO Mwea were similar but they were significantly taller ($P \leq 0.05$) than other lines in the growing locations. Similarly, line 7 in Mwea, line 5 in Mwea, line 6 in Mwea, solo in Mitunguu and line 1 in Mwea did not show significant differences but they were significantly taller than line 6 in JKUAT, line 1 in JKUAT, line 5 in JKUAT, line 6 in Nkubu, solo in JKUAT, line 7 in JKUAT, line 5 in Nkubu, line 6 in Mitunguu, solo in Nkubu, and line 7, 1 and 5 in Mitunguu. Lines 6,1,5, solo all in JKUAT and line 6 in Nkubu were significantly shorter ($P \leq 0.05$)than all other lines in the growing locations (Table 3.3)

3.3.2 Internode length of papaya plants in selected agro -ecological zones of Kenya

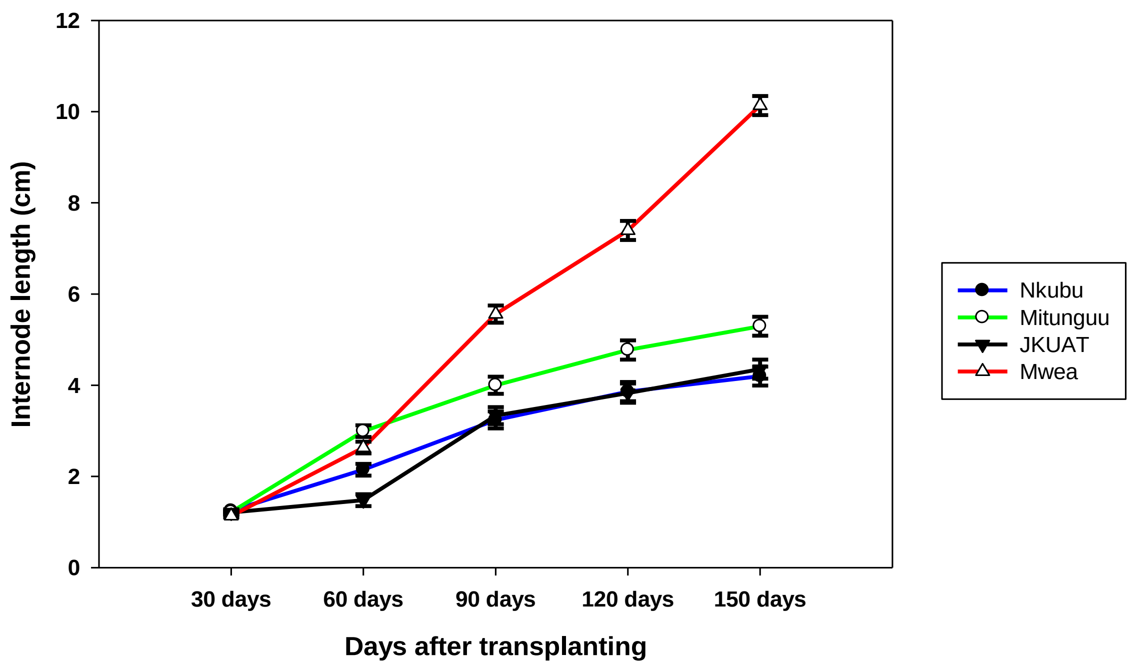


Figure 3.3: Effects of locations on plant internode length. Points represent means and standard errors of heights of papaya plants taken from three replicates per treatment and measured over a period of 150 days after transplanting

Internode length was influenced by changes over time from the time of transplanting to plant maturity as shown across the locations. After 30 days to 150 days after transplanting, there was a significant increase in internode length. Papaya in Mwea had a significantly longer ($P \leq 0.05$) internode length than papaya in Mitunguu, JKUAT and Nkubu. After 150 days, it was noted that papaya in Mitunguu had a significantly ($P \leq 0.05$) longer internode length than plants in JKUAT and Nkubu however, plants in both JKUAT and Nkubu did not show significant differences in internode length (Figure 3.3).

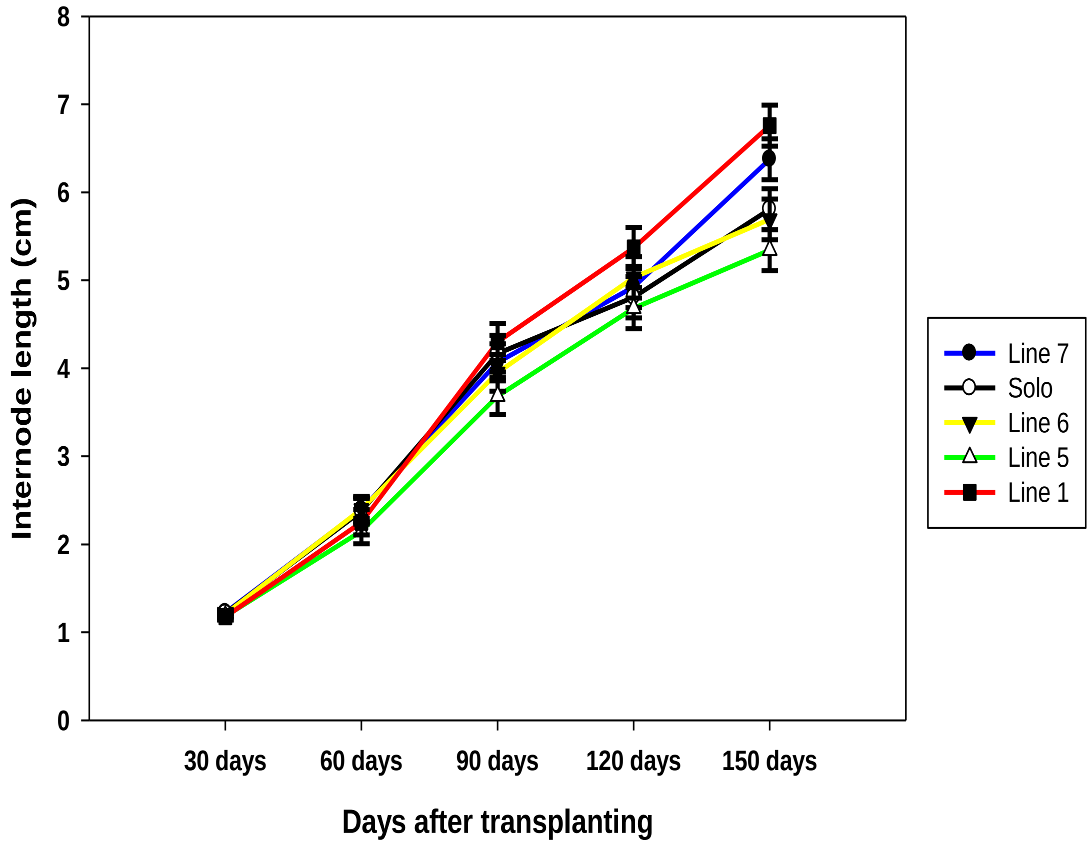


Figure 3.4: Effects of different lines on plant internode length. Points represent means and standard errors of heights of papaya plants taken from three replicates per treatment and measured over a period of 150 days after transplanting

There was a significant increase in internode length among the papaya lines used in the study from the time of transplanting to maturity. From the day of transplanting to the 60 days, there was no significant differences ($P \leq 0.05$) on internode length among the lines, however, after 90 days to 150 days, the papaya lines showed significant differences. At 150 days, line 1 and line 7 had a similar internode length but had a significantly longer length ($P \leq 0.05$) than solo, line 5 and line 6 which were not significantly different from one another (Figure 3.4).

On the interaction of the papaya lines and the locations, it was observed that significant differences ($P \leq 0.05$) existed in the internode length from 30 days to 150 days after transplanting. There was a gradual increase in the internode length with increase in the number of days. At full maturity and 150 days, line 1 and line 7 in Mwea did not show significant differences but they had a significantly longer ($P \leq 0.05$) internode length than all other lines in the growing regions.

Table 3.4: Effects of interaction of location and lines on internode length of papaya plants taken from three replicates per treatment and measured over a period of 150 days after transplanting

Location*Lines	30 Days	60 Days	90 Days	120 Days	150 Days
Nkubu Solo	1.33±0.03a	2.23±0.33bcde	3.06±0.52def	3.73±0.52cd	4.06±0.52fg
Mitunguu Line 7	1.26±0.03ab	3.03±0.13a	3.90±0.06cde	4.63±0.18bc	5.23±0.24cde
Nkubu Line 7	1.26±0.03ab	2.43±0.39abcd	3.63±0.47def	4.13±0.38cd	4.40±0.38defg
JKUAT Line 6	1.26±0.03ab	1.60±0.21efgh	3.50±0.45def	3.83±0.37cd	4.33±0.33efg
JKUAT Line 7	1.23±0.07ab	1.43±0.28gh	3.46±0.17def	3.90±0.06cd	4.53±0.29defg
Mitunguu Line 5	1.23±0.03ab	2.86±0.19ab	3.70±0.12def	4.60±0.06bc	4.96±0.03cdef
Mitunguu Line 6	1.23±0.09ab	2.96±0.09a	3.66±0.17def	4.53±0.07bc	4.90±0.06cdef
Nkubu Line 5	1.23±0.03ab	2.03±0.19cdefg	2.70±0.15f	3.20±0.10d	3.73±0.07g
JKUAT Line 1	1.20±0.12ab	1.53±0.23fgh	3.36±0.26def	4.20±0.21bcd	4.90±0.10cdef
Mitunguu Solo	1.20±0.06ab	3.10±0.26a	4.06±0.27cd	4.83±0.20bc	5.46±0.34cd
Nkubu Line 1	1.20±0.06ab	1.86±0.20defgh	3.63±0.23def	4.26±0.24bcd	4.56±0.34defg
Nkubu Line 6	1.20±0.06ab	2.16±0.19cdef	3.16±0.43def	3.96±0.41cd	4.23±0.38efg
JKUAT Solo	1.20±0.06ab	1.56±0.20fgh	3.40±0.31def	3.80±0.42cd	4.36±0.19efg
Mitunguu Line 1	1.16±0.03ab	3.00±0.06a	4.66±0.20bc	5.26±0.18b	5.90±0.06c
JKUAT Line 5	1.13±0.03b	1.26±0.03h	2.93±0.07ef	3.40±0.25d	3.63±0.27g
Mwea Line 1	1.13±0.03b	2.60±0.21abc	5.53±0.29ab	7.73±0.50a	11.66±0.33a
Mwea Line 5	1.13±0.03b	2.43±0.07abcd	5.40±0.31ab	7.53±0.32a	9.03±0.50b
Mwea Line 6	1.13±0.03b	2.86±0.09ab	5.46±0.26ab	7.80±0.70a	9.30±0.70b
Mwea Line 7	1.13±0.03b	2.66±0.17abc	5.26±0.37ab	7.03±0.03a	11.33±0.17a
Mwea Solo	1.13±0.03b	2.60±0.03abc	6.13±0.32a	6.86±0.41a	9.33±0.44b
LSD	0.14	0.58	0.84	0.95	0.94
CV%	7.40	15.30	12.70	11.60	9.50

Means in the same column followed different letter(s) are significantly different at ($P \leq 0.05$)

Solo, line 5 and 6 in Mwea were similar but they had a significant lower internode length than lines 1 and 7 in in the same location (Mwea). Lines 5 in JKUAT, line 5 in Nkubu, solo in Nkubu, line 6 in Nkubu, line 6 in JKUAT, solo in JKUAT, line 7 in Nkubu, line 7 in JKUAT and line 1 in Nkubu had a significantly lower ($P \leq 0.05$) internode length than line 1 in Mwea, line 7 in Mwea, solo in Mwea, line 5 in Mwea and line 6 in Mwea (Table 3.4)

3.3.3. Stem girth of papaya plants in the selected agro -ecological zones of Kenya

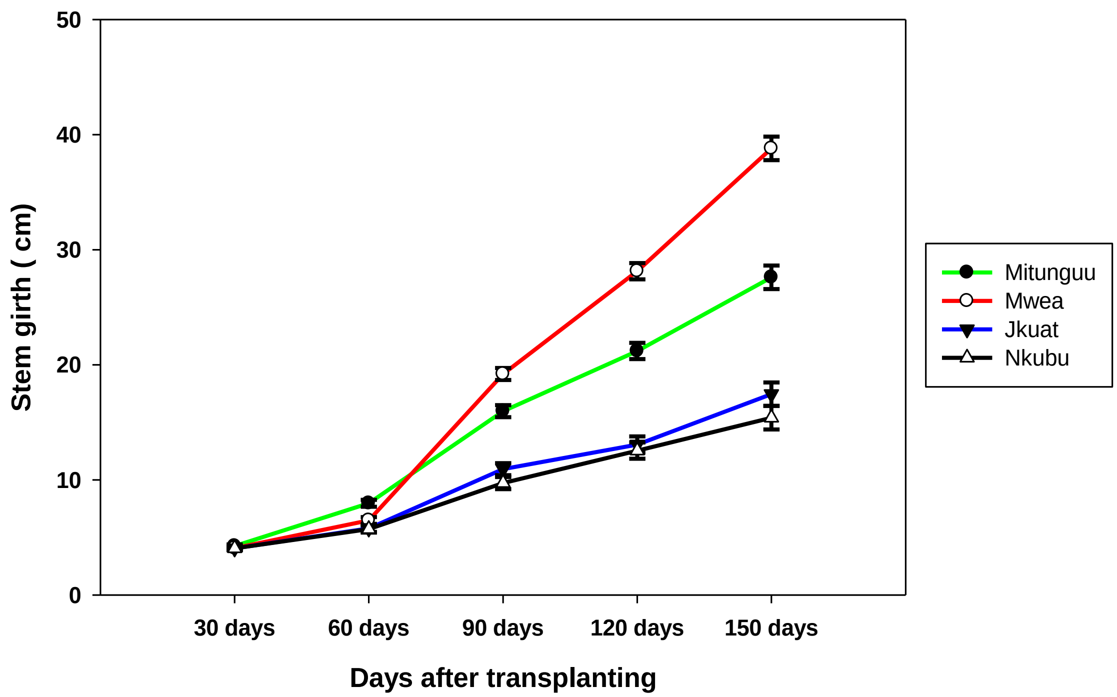


Figure 3.5: Effects of different locations on plant stem girth. Points represent means and standard errors of heights of papaya plants taken from three replicates per treatment and measured over a period of 150 days after transplanting

There was a gradual increase in stem girth from the day of transplanting to maturity, however, 30 days after transplanting, there was no significant difference noted in all the experimental locations. From 60 days to 150 days, there were significant differences noted. After 150 days after transplanting, papaya in Mwea had a significantly larger stem girth ($P \leq 0.05$) than papaya in Mitunguu, JKUAT, and Mitunguu irrigation scheme. Plants in JKUAT and Nkubu had a similar stem girth but they had a significantly smaller ($P \leq 0.05$) stem girth than plants in Mitunguu irrigation scheme (Figure 3.5).

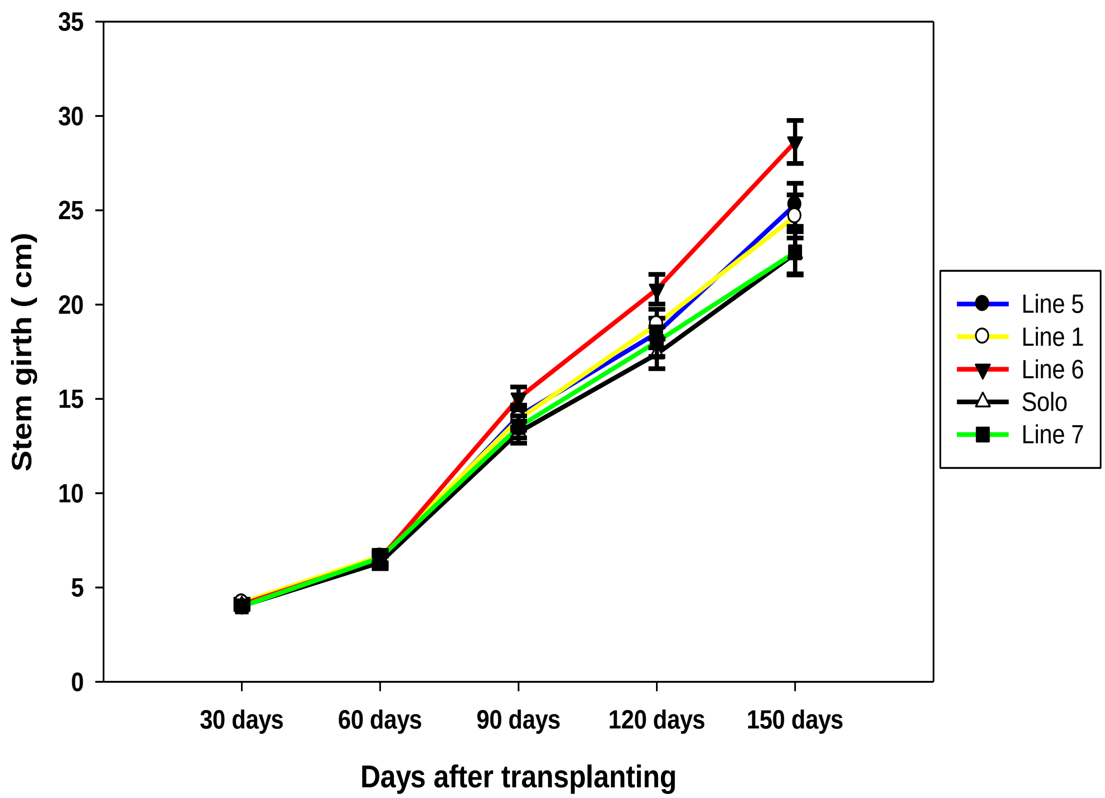


Figure 3.6: Effects of different lines on plant stem girth. Points represent means and standard errors of heights of papaya plants taken from three replicates per treatment and measured over a period of 150 days after transplanting

Among the papaya lines in the different experimental locations, there was a gradual increase in stem girth, however, from transplanting to 60 days, the papaya lines did not show any significant differences but from the 90 days to 150 days, there were significant differences ($P \leq 0.05$). At full maturity, line 6 had a significantly greater stem girth than all other lines used in the study. Line 1, line 7 and solo sunrise were not significantly different but they had a significantly ($P \leq 0.05$) smaller stem girth than line 5(Figure 3.6).

The interactions between the papaya lines and locations showed a gradual increase in girth from transplanting to full maturity, however, 30 days after transplanting, there were no significant differences ($P \leq 0.05$) in the stem girth across all the locations. From the 60 days to 150 days when the papaya were fully mature, there were significant differences that were noted. When the plants had reached 150 days after transplanting, line 6 in Mwea and line 1 in Mwea did not show significant differences but line 6 in Mwea had a significantly ($P \leq 0.05$) bigger stem girth than all other lines in other locations. Likewise, line 1 ,7,solo,5 in Nkubu and line 5,7,solo in JKUAT did not show significant differences but they had a significantly smaller stem girth than lines 5 and 6 in Mitunguu, and line 7, solo, 5,1 and 6 in Mwea (Table 3.5).

Table 3.5: Effects of interaction of location and lines on stem girth of papaya plants taken from three replicates per treatment and measured over a period of 150 days after transplanting

Location* Treatments	30 Days	60 Days	90 Days	120 Days	150 Days
Mitunguu Solo	4.43±0.22a	8.00±0.58ab	15.83±1.01d	20.67±1.76f	24.33±1.33e
Mwea Line 5	4.36±0.12a	6.80±0.30abcde	19.33±0.67bc	27.00±0.58bc	37.67±0.33bc
Mitunguu Line 5	4.27±0.12a	7.50±0.76abc	17.00±0.58cd	23.17±0.93def	31.33±2.91d
JKUAT Line 6	4.26±0.17a	5.83±0.42def	11.67±0.67e	13.57±0.47gh	18.50±0.76fg
Mitunguu Line 7	4.26±0.18a	8.50±0.58a	16.00±1.00d	20.00±1.00f	25.00±1.53e
Mwea Line 6	4.26±0.17a	6.33±0.33cdef	22.00±0.58a	32.33±0.88a	43.33±1.45a
Mitunguu Line 1	4.23±0.19a	8.33±0.33a	15.50±0.76d	20.17±0.44f	24.67±1.20e
Mwea Line 1	4.23±0.23a	7.00±0.85abcd	19.67±0.88ab	30.00±0.58ab	41.00±1.53ab
JKUAT Line 1	4.20±0.06a	6.03±0.32cdef	11.50±0.76efg	14.47±1.35gh	20.00±0.58ef
Nkubu Line 5	4.13±0.09a	5.36±0.58ef	10.67±0.93efg	12.33±1.45gh	16.67±2.73fgh
Nkubu Line 1	4.10±0.17a	5.16±0.33f	9.00±0.76efg	11.20±0.91h	13.00±1.00h
Nkubu Solo	4.10±0.06a	5.66±0.17def	8.90±0.80eg	11.43±1.55h	14.00±2.08gh
JKUAT Line 5	4.06±0.07a	5.83±0.42def	9.33±0.33efg	11.47±0.84h	15.50±1.44fgh
Nkubu Line 7	4.06±0.67a	6.00±0.29cdef	9.03±0.74efg	12.40±1.40gh	13.33±1.45gh
Mitunguu Line 6	4.03±1.33a	7.50±0.58abc	15.50±1.04d	22.00±0.58ef	32.67±2.85cd
JKUAT Line 7	3.96±0.19a	5.60±0.26def	11.67±0.67ef	13.73±0.73gh	17.40±1.51fgh
Nkubu Line 6	3.83±0.67a	6.40±0.31cdef	11.00±1.53efg	15.33±2.96g	20.00±2.65ef
JKUAT Solo	3.76±0.24a	5.56±0.43def	10.50±0.76efg	12.10±1.05gh	15.83±1.99fgh
Mwea Solo	3.76±0.48a	6.06±0.43cdef	17.67±0.67bcd	25.33±0.67cde	36.67±1.76bc
Mwea Line 7	3.70±0.46a	6.16±0.17cdef	17.33±0.33bcd	26.00±0.58cd	35.33±0.88cd
LSD	0.68	1.33	2.36	3.19	4.61
CV%	10.10	12.50	10.30	10.30	11.30

Means in the same column followed different letter(s) are significantly different at ($P \leq 0.05$)

3.3.4 The height of papaya lines at first flower emergence, time to first flower, 50% flowering and ripening of papaya lines from two agro ecological zones of Kenya

The height at the first flower emergence showed significant difference where papaya in Mwea were significantly different ($P \leq 0.05$) from all other experimental locations, however, Mitunguu irrigation scheme, JKUAT and Nkubu did not show any significant differences. Time to 50% flowering showed significant differences in the experimental locations where papaya in JKUAT took a significantly ($P \leq 0.05$) longer time than Nkubu, Mwea and Mitunguu. Nkubu took a significantly longer time than Mwea and Mitunguu irrigation scheme however, Mwea and Mitunguu did not show any significant difference (Table 3.6). Time to fruit ripening showed significant differences in the experimental locations where JKUAT took a significantly ($P \leq 0.05$) more days to ripen than Nkubu, Mitunguu and Mwea

Table 3.6: Effects of locations on height (cm) of papaya at first flower emergence, time to first flower(days), time to 50% flowering(days) and time to ripening(days) of papaya plants taken from three replicates per treatment

Location	Height at first flower(cm)	Time to first flower	Time to 50% flowering(days)	Time to fruit ripening (days)
Mwea	85.47±1.59a	155.30±1.08c	161.40±0.99c	308.70 ±0.92c
Mitunguu	79.60±2.28b	156.50±1.01c	159.80±1.06c	308.70±0.98c
JKUAT	76.67±1.76b	168.70±1.14a	178.90±1.14a	328.50±0.86a
Nkubu	76.20±1.54b	163.50±1.09b	171.70±1.27b	320.60±0.87b
LSD	3.73	3.15	1.76	2.72
CV%	6.40	2.60	1.40	1.20

Means in the same column followed different letter(s) are significantly different at ($P \leq 0.05$)

Mitunguu and Mwea did not vary significantly, however they took a significant fewer number of days than Nkubu (Table 3.6).Time to first flower varied significantly among the experimental locations where JKUAT had a significantly ($P \leq 0.05$) higher number of days than Nkubu, Mwea and Mitunguu, however, Mwea and Mitunguu did not show any significant differences in number of days to the first flower between themselves (Table 3.6) .

Among the papaya lines used for the study, height at first flower emergence showed significant differences where solo had a significantly higher height than all other lines under the study. Line5, line 7 and line 6 did not vary significantly however, they had a significant ($P \leq 0.05$) higher height at first flower emergence than line 1 (Table 3.7). Time to 50% flowering showed some significant differences where line 1 and line 6 were similar but they took a significantly longer time than line 7, line 5 and solo sunrise.

Table 3.7: Effects of different lines on height (cm) of papaya at first flower emergence, time to first flower(days), time to 50% flowering(days) and time to ripening(days) of papaya plants taken from three replicates per treatment

Papaya Lines	Height at first flower(cm)	Time to first flower(days)	Time to 50% flowering(days)	Time to fruit ripening (days)
Solo	85.42±1.86a	160.70±1.92ab	168.00±2.45b	317.90±2.74a
Line 5	80.92±2.31b	160.10±1.86ab	164.20±2.27c	314.10±2.70b
Line 7	78.58±1.49bc	159.20±2.07b	164.30±2.39c	315.80±2.66ab
Line 6	76.75±2.19bc	161.30±2.14ab	172.40±2.68a	317.10±2.62ab
Line 1	75.75±2.44c	163.70±1.92a	170.80±2.57a	318.40±2.74a
LSD	4.17	3.52	1.96	3.04
CV%	6.40	1.20	1.40	2.60

Means in the same column followed different letter(s) are significantly different at ($P \leq 0.05$)

Line 5 and line 7 also took a significantly longer time to 50% flower than solo sunrise.

Time to fruit ripening varied significantly among the papaya lines and line 7 took a significant ($P \leq 0.05$) shorter time to ripen than line 1, however, line 1, 7, 5 and solo sunrise did not vary significantly. Likewise line 6, 7, and 5 and solo did not show any significant differences (Table 3.7). In relation to time to show the first flower, a significant difference was noted among the papaya lines where line 1 and solo sunrise were similar but they significantly ($P \leq 0.05$) took a longer time to show the first flower than line 5, however, lines 6,7 and 5 did not show any significant different .Significant differences were noted on the interaction of lines and growing locations. In height at first flower emergence, solo in Mwea, line 5 in Mitunguu, line 1 in Mwea and line 6 in Mwea did not vary significantly, however, solo in Mwea was significantly taller than other lines in other growing locations. Similarly, line 5 in Mitunguu, line 1 in Mwea, line 6 in Mwea, solo in JKUAT, solo in Mitunguu, solo in Nkubu, and line 7 in JKUAT did not vary significantly but they produced the first flower at a significantly ($P \leq 0.05$) higher height than line 7 in Mitunguu, line 1 in Mitunguu, line 6 in Nkubu, line 1 in JKUAT, line 1 in Nkubu and line 6 in JKUAT (Table 3.8). In relation to 50% flowering, there were significant differences that were noted, where line 6 in JKUAT and line 1 in JKUAT did not show any significant differences, however, line 6 in JKUAT achieved 50% flowering at a significantly ($P \leq 0.05$) longer time than other lines in different locations. On the other hand line 7 in Mitunguu achieved 50% flowering at a significantly shorter period of time than all other lines in all the locations. Lines 5 and 7 in Nkubu, line 1 and 6 in Mitunguu and line 6 in Mwea did not show significant differences however, line 5 and 7 in Nkubu were significantly different from line 1,5,7 and solo in Mwea and solo in Mitunguu(Table 3.8).

Table 3.8: Effects of interaction of location and lines on height of papaya at first flower emergence, time to first flower emergence, time to 50% flowering and time to ripening of papaya plants taken from three replicates per treatment

Location *Lines	Height at first flower(cm)	Time to 50% flowering(days)	Time to fruit ripening (days)	Time to first flower
Mwea Solo	92.33±1.86a	160.00±0.58g	309.30±1.20f	154.30±1.33ef
Mitunguu Line5	90.00±6.46ab	155.70±0.33h	305.00±2.65f	157.00±3.06
Mwea Line 1	88.33±0.88abc	162.30±0.88g	310.00±0.88f	157.70±1.67
Mwea Line 6	87.00±1.67abcd	163.70±0.67fg	309.70±3.18f	155.70±2.96
JKUAT Solo	83.33±3.76bcde	179.70±0.88bc	330.30±0.88a	169.00±2.00
Mitunguu Solo	83.00±2.65bcde	161.00±0.58g	309.30±1.20f	156.00±0.58
Nkubu Solo	83.00±4.51bcde	171.30±0.88e	322.30±1.45bcde	163.30±2.40
JKUAT Line 7	82.33±2.33bcde	175.00±0.58de	327.30±1.45abc	166.70±1.76
Mwea Line 7	80.67±3.48cdef	160.30±3.67g	306.70±2.03f	153.30±3.33
Mwea Line 5	79.00±2.65defg	160.70±3.84g	308.00±1.00f	155.70±3.33
Mitunguu Line6	78.67±2.40defg	164.30±0.67fg	309.30±2.33f	156.70±1.86
Nkubu Line 7	78.00±2.00efgh	167.00±0.58f	320.30±1.45de	162.30±1.86
Nkubu Line 5	77.67±2.19efgh	167.00±2.08f	317.30±3.18e	161.00±3.00
JKUAT Line 5	77.00±3.00efgh	173.70±1.86de	326.00±2.52abcd	166.70±3.18
Mitunguu Line7	73.33±2.19fgh	155.00±0.58h	308.70±2.03f	154.30±3.84
Mitunguu Line1	73.00±4.73fgh	163.00±1.53fg	311.00±2.52f	158.30±1.86
Nkubu Line 6	71.67±1.76gh	177.70±2.19cd	321.00±1.53cde	164.00±3.61
JKUAT Line 1	71.00±1.00gh	182.30±0.33ab	330.70±1.76a	172.00±1.53
Nkubu Line 1	70.67±0.67gh	175.30±0.33de	322.00±1.53bcde	166.70±1.20
JKUAT Line 6	69.67±0.88h	184.00±1.00a	328.30±2.40ab	169.00±4.04
LSD	8.35	3.93	6.08	7.05
CV%	6.40	1.40	1.20	2.60

Means in the same column followed different letter(s) are significantly different at ($P \leq 0.05$)

Time to fruit ripening was significantly different in different lines in different locations where line 1, solo, 6,7 and 5 in JKUAT took a significantly ($P \leq 0.05$) more time to ripen than line 6,7,5 in Nkubu, line 1,6,solo,7,5 in Mitunguu and line 1,6,solo,5,7 in Mwea. Line 5,7,6,1 and solo in Nkubu were similar but they took a significant less time to ripen than line 5,7,6,1 and solo in Mwea. (Table 3.8). The number of days to show the first flower also showed significant differences among the lines in different growing locations where lines 1, 6, 5, 7, solo in JKUAT and line 1, 6, 7, 5, solo in Nkubu did not vary significantly, however, line 1 in JKUAT took a significant ($P \leq 0.05$) more number of days to show the first flower than all other remaining lines in the study locations. Likewise, lines 7, solo,6,5,1 in Mwea, lines 7,solo,6,5,1 in Mitunguu and line 5 in Nkubu did not vary significantly but they took a significantly less number of days to show the first flower than line 1 in JKUAT(Table 3.8)

3.3.5 Yield of the papaya lines in the two selected agro ecological zones of Kenya

From the study, the result showed that the number of fruits per tree did not show any significant differences in all the locations (Table 3.9), however, Mwea had the highest while the least number of fruits was recorded in JKUAT. The fruit Wight showed significant difference where Mwea was significantly different ($P \leq 0.05$) from Mitunguu irrigation scheme and JKUAT, however, Nkubu and JKUAT did not show any significant differences. From all the 4 experimental locaions, flesh thickness did not vary significantly while on fruit length, there was a significant different where KALRO Mwea was significantly different ($P \leq 0.05$) from all other sites however, Mitunguu, Nkubu and JKUAT did not significantly vary from one another. Fruit diameter also showed significant differences where Mwea was significantly different from JKUAT but it was similar to Mitunguu and Nkubu. Likewise, JKUAT, Nkubu and Mitunguu did not show any significant difference. Total soluble solids showed that there was significant differences in all the locations and the highest was recorded in Mitunguu irrigation scheme while on the other hand the least total soluble solids was recorded in KALRO Mwea (Table 3.9).

Table 3.9: Effects of location on number of fruits, fruit weight, flesh thickness, fruit length, fruit diameter and total soluble solids of papaya plants taken from three replicates per treatment

Location	Number of fruits	Fruit Weight(kg)	Flesh Thickness(cm)	Fruit Length(cm)	Fruit Diameter(cm)	Brix(%)
Mwea	117.20±4.28a	1.79±0.05a	1.70±0.02a	18.01±0.17a	10.93±0.42a	9.57±0.43d
Mitunguu	114.60±2.50a	1.62±0.06b	1.69±0.02a	17.03±0.20b	10.45±0.40ab	12.13±0.39a
Nkubu	112.60±3.18a	1.65±0.04ab	1.70±0.02a	17.01±0.45b	10.61±0.46ab	11.07±0.42b
JKUAT	97.90±4.23a	1.52±0.08b	1.68±0.02a	16.75±0.20b	9.97±0.39b	10.33±0.30c
LSD	ns	0.15	ns	0.52	0.76	0.65
CV%	8.20	12.70	2.80	4.20	9.90	8.20

Means in the same column followed different letter(s) are significantly different at ($P \leq 0.05$)

Among the lines, there was a significant differences in fruit number per tree among all the lines whereby the highest number was recorded by line 5 while on the other hand, the least number of fruits was recorded by line 7. Line 1 and 7 did not vary significantly ($P \leq 0.05$) but they had a significantly fewer number of fruits than line 5, 6 and solo (Table 3.10). Fruit weight showed significant differences among some lines whereby line 7 and line 1 were similar in weight but were significantly difference from line 5 and line 6. Solo sunrise was similar to line 6 and line 1 but it was significantly different ($P \leq 0.05$) from line 7 and line 5(Table 3.10). There was a significant difference noted in flesh thickness among the lines whereby line 1 and solo sunrise were similar in flesh thickness but were significantly different from line 7, line 6 and line 5 and the highest flesh thickness was recorded by line 7 while the least was recorded by line 5. Fruit length showed some significant differences whereby line 1 was significantly different ($P \leq 0.05$) from all other lines however, solo sunrise and line 6 were similar but were significantly different from line 7, while line 7 and line 5 were not significantly different from one another. On fruit diameter, line 7 was significantly different from all other lines while line 6, line 5, line 1 and solo sunrise did not vary significantly (Table 3.10).

Table 3.10: Effects of lines of number of fruits, fruit weight, flesh thickness, fruit length, fruit diameter and total soluble solids of papaya plants taken from three replicates per treatment

Lines	Number of Fruits	Fruit Weight(kg)	Flesh Thickness(cm)	Fruit Length(cm)	Fruit Diameter(cm)	Brix(%)
Line 5	126.10±2.68a	1.40±0.09d	1.60±0.01d	16.70±0.21cd	10.08±0.19b	12.17±0.63a
Line 6	118.10±3.04b	1.56±0.07cd	1.65±0.01c	17.15±0.19bc	10.15±0.37b	9.62±0.27c
Solo	110.00±3.56c	1.64±0.05bc	1.70±0.02b	17.41±0.24b	9.86±0.13b	11.17±0.32b
Line 7	102.20±3.95d	1.87±0.05a	1.80±0.02a	16.28±0.44d	12.88±0.37a	9.42±0.29c
Line 1	96.40±3.62d	1.75±0.04ab	1.72±0.02b	18.46±0.19a	9.49±0.43b	11.50±0.44ab
LSD	7.50	0.17	0.03	0.59	0.85	0.73
CV%	8.20	12.70	2.80	4.20	9.90	8.20

Means in the same column followed different letter(s) are significantly different at ($P \leq 0.05$)

There was a significant difference noted on total soluble solids noted among the papaya lines whereby line 5 and line 1 were similar but were significantly different ($P \leq 0.05$) from line 6 and line 7. Solo sunrise and line 1 were similar but they were significantly different from line 5, line 6 and line 7 (Table 3.10).

The interaction between the growing locations and the lines grown showed significant differences in the total number of fruits where lines 5, 6, in Mwea, lines 5 and solo in Nkubu, line 5, 6 in Mitunguu and line 5 in JKUAT did not show any significant differences, however, line 5 in Mwea had a significantly ($P \leq 0.05$) higher number of fruits than all other lines in different locations. On the other hand, lines 1,7,solo in JKUAT and line 1 in Nkubu did not show significant differences among themselves, however, they had a significantly fewer number of fruits than lines 6, solo and 5 in Nkubu, line 5 in JKUAT, line 5,6 in Mitunguu and line 6 and 5 in Mwea (Table 3.11). In relation to fruit weight, a significant difference was noted among some lines in different locations, where solo, line 6, line 5 in JKUAT, line 5 and 6 in Mitunguu and line 5 in Nkubu did not show significant differences from one another, however, they had a significantly ($P \leq 0.05$) lower weight than line 7 in Mwea. Line 1 and 7 in Mwea were similar but had a significantly more weight than line 6 and 5 in JKUAT and line 5 in Mitunguu. (Table 3.11).

Flesh thickness showed significant differences where line 7 and 1 in JKUAT, line 7 in Mitunguu, line 7 in Nkubu and line 7 and 1 in KALRO Mwea did not vary significantly but they had a significantly ($P \leq 0.05$) higher flesh thickness than line 5 in Nkubu, line 5 in Mitunguu, line 5 in Mwea and line 5 in JKUAT. Line 6 and solo in JKUAT, line 6,1 and solo in Nkubu, line 6,1 and solo in Mitunguu, line 6 and solo in Mwea did not vary significantly but they had a significantly ($P \leq 0.05$) smaller flesh thickness than line 7 in JKUAT and line 7 in Mitunguu(Table 3.11).

Fruit length varied significantly in different lines in different locations where line 1,5,7, solo in Mwea, line 1 and solo in Nkubu, line 1 in Mitunguu and line 1 in JKUAT did not show any significant differences , however, they had a significantly ($P \leq 0.05$) higher fruit length than lines 7 and 5 in JKUAT and line 7 in Nkubu. Likewise line 7 in Nkubu had a significantly smaller fruit length than all other lines in different locations (Table 3.11).

In fruit diameter, line 1 and 6 in JKUAT and line 1 in Mitunguu did not vary significantly in fruit diameter, however, they had a significantly ($P \leq 0.05$) smaller diameter than line 6, 7 in Nkubu, line 7 in Mwea, line 7 in Mitunguu and line 7 in JKUAT. Line 5 and solo in JKUAT, line 1, 5,6 and solo in Mwea, line 6,5, and solo in Mitunguu, line 5,1,6 and solo in Nkubu did not show significant differences but they had a significantly ($P \leq 0.05$) lower diameter than line 7 in Mwea and line 7 in Mitunguu (Table 3.11)

There were significant differences noted in total soluble solids among the lines in different growing locations where line 5, 1 in Mitunguu and line 5 in Nkubu did not show significant differences, however, line 5 in Mitunguu was significantly different ($P \leq 0.05$) from other lines in different locations. Line 1 and solo in Mitunguu, line 5 in JKUAT and line 1 in Mwea did not show significant differences however, they had a significantly ($P \leq 0.05$) higher total soluble solids than line 1,7,6 in JKUAT, line 5,6,7 and solo in Mwea and line 6 and 7 in Nkubu(Table 3.11)

Table 3.11: Effects of lines of number of fruits, fruit weight, flesh thickness, fruit length, fruit diameter and total soluble solids of papaya plants taken from three replicates per treatment

Location. Treatment	Number of Fruits	Fruit Weight(kg)	Flesh Thickness(cm)	Fruit Length(cm)	Fruit Diameter(cm)	Brix(%)
Mwea Line 5	134.30±5.36a	1.62±0.09abcd	1.60±0.12gh	17.77±0.57abcde	10.33±1.57def	9.33±0.88ghi
Mwea Line 6	128.00±4.73ab	1.67±0.18abcd	1.67±0.24efg	17.37±0.20bcdefg	10.43±0.04def	8.50±0.29i
Nkubu Line 5	127.70±1.20ab	1.44±0.12bcde	1.63±0.09fgh	16.57±0.56efg	9.90±0.03def	13.67±0.67ab
Mitunguu Line5	125.00±2.89abc	1.35±0.18de	1.60±0.07gh	16.47±0.18efg	10.23±0.01def	14.00±0.56a
Mitunguu Line6	121.00±4.58abcd	1.48±0.19bcde	1.66±0.27efg	16.73±0.15defg	9.70±0.03def	10.67±0.33defgh
Nkubu Solo	118.00±3.21abcde	1.61±0.09abcd	1.71±0.60def	17.80±0.21abcde	9.80±0.03def	11.33±0.33def
JKUAT Line 5	117.30±6.77abcde	1.19±0.25e	1.56±0.35h	16.00±0.15g	9.83±0.03def	11.67±0.33cde
Nkubu Line 6	115.00±5.51bcde	1.66±0.03abcd	1.65±0.68efgh	17.57±1.25bcdef	11.33±0.03cde	9.67±0.33fghi
Mitunguu Solo	114.30±1.76bcdef	1.67±0.09abcd	1.68±0.09efg	17.03±0.15cdefg	9.90±0.06def	12.33±0.33bcd
Mwea Solo	113.70±8.82bcdef	1.79±0.01abc	1.71±0.26def	18.07±0.20abcd	10.37±0.04def	10.00±0.58efghi
Mitunguu Line7	112.00±1.73bcdef	1.84±0.03abc	1.81±0.31ab	16.60±0.32efg	13.27±0.04ab	10.67±0.33defgh
JKUAT Line 6	108.30±4.91cdefg	1.42±0.09cde	1.64±0.09efgh	16.93±0.09cdefg	9.13±0.03f	9.67±0.33fghi
Mwea Line 7	106.30±9.53defg	2.00±0.02a	1.80±0.19abcd	17.77±0.29abcde	13.87±0.06a	8.33±0.33i
Nkubu Line 7	105.00±2.67defg	1.80±0.05abc	1.80±1.18abc	14.50±1.06h	11.60±0.01bcd	9.67±0.33fghi
Mwea Line 1	103.70±7.88defg	1.85±0.05ab	1.72±0.21cdef	19.10±0.15a	9.67±0.04def	11.67±1.20cde
Mitunguu Line1	100.70±1.20efgh	1.77±0.07abc	1.71±0.44def	18.30±0.07abc	9.13±0.45f	13.00±0.58abc
Nkubu Line 1	97.30±5.36fghi	1.74±0.02abcd	1.72±0.58cdef	18.60±1.80ab	10.40±0.02def	11.00±0.00defg
JKUAT Solo	94.00±3.51ghi	1.51±0.17bcde	1.68±0.47efg	16.73±0.19defg	9.37±0.04ef	11.00±0.58defg
JKUAT Line 7	85.70±6.74hi	1.83±0.18abc	1.81±0.15a	16.27±0.29fg	12.77±0.06abc	9.00±0.00hi
JKUAT Line 1	84.00±8.74i	1.65±0.11abcd	1.73±0.35bcde	17.83±0.23abcde	8.77±0.03f	10.33±0.67efgh
LSD	14.99	0.34	0.07	1.18	1.71	1.46
CV%	8.20	12.70	2.80	4.20	9.90	8.20

Means in the same column followed different letter(s) are significantly different at ($P \leq 0.05$)

3.4 Discussion

The plant growth, development and productivity are influenced by various factors which directly affects crop performances in a given area. These may include immediate surrounding environment factors, genetic makeup or their interaction as shown in studies of genetic variability in papaya (Bindu, 2018). The experimental locations in the selected zones recorded different average annual rainfall and different average annual temperature (Table 3.1). Mwea had the highest average rainfall while JKUAT had the least and from the results, the sites that had high average rainfall of above 384 mm had significantly higher yield than sites that had low average rainfall. The result therefore indicated that seasonal amount of rainfall or intraseasonal distribution affected crop production. In cases of low amount of rainfall during the growth season, crop production sufferes leading to low yield.

From the study, line 1,line 6,line 7 and line 5 had significantly shorter height at first flower when compared to solo sunrise a commercial variety that flowered at a sfignificanlty higher height (Table 3.7). Studies done on earliness in flowering and tree height in Papaya showed that shorter plants tend to flower at a much lower height (Lim et al. 2007). From observation, the new JKUAT papaya lines were therefore considered as shorter plants. The study showed that there was significant differences in growth rate from the time of transplanting to the time of first flower emergence across the locations and between the lines (Table 3.8). Different plants have different cell production and cell expansion which mutually interact to grow tissues that feeds back on cellular dynamics and this could have resulted in differences in growth rate. There was also Signiant differences in time to the first fruit among the treatments (papaya lines) and the control (solo sunrise) and that could have been due to genotype-environment (G*E) interactions that could have resulted to implication noted since the interaction will influence how a given line performs agronomically. The time taken from the first flower emergence to 50% flowering showed significance difference. It was noted that the process occurred earlier in some such as line 5 and 7 at Mitunguu while on the other hand, line 1 and 6 at JKUAT took a significant longer time to 50% flowering. The variations that occurred could have been attributed due to different inherited characteristics by the plants and the genetic capability. Similar results were found on studies of genetic regulation performed on flowering time in annual and perennial plants (*Arabidopsis)* which had a similar trend (Khan et al, 2013).Plants can also experience early flowering as an adaptation mechanisms when the prevailing conditions are harsh and not favouring its normal growth cycle. This conditions do happen especially when plants start reproductive stage so as to complete the life cycle (Yan, 2020). The total number fruits produced by the fruits did not show significant differences across the locations (Table 3.9), however, a significant differences were noted between the papaya lines (Table 3.10) where line 5 had a higher number of fruits while line 1 had the fewer number. There was a varied significant differences in the Fruit weight (kg/fruit) among the papaya lines. The weight ranged from 1.19 kg in line 5 at JKUAT to 2 kg in line 7 in KALRO Mwea. As found in this study, the significant differences noted on yield could be attributed to the differences in the genetic makeup of the papaya lines under research. This could be true since all the newly developed JKUAT papaya lines originated from different parents and additionally, the interactions between the environment and the lines could have led to the observed difference. Other studies of estimation of genetic components and heritability for fruits yield and quality characters done on tomato (Solanum Lycopersicum) showed that differences on fruit weight and yield was as a result of differences in genetic make-up (ELnager, 2018). Similar findings were also reported on capsicum pepper lines on their morphological and yield evaluation that was carried out in Ghana in two agro-ecological zones (Nkansah et al 2011). This result can also apply to other plants such as papaya since fruit development process take similar trend. Additionally, the prevailing environmental conditions such as different soil and mineral composition in the two agro ecological zones could have caused variation of yield of the new papaya lines (Table 3.2).Concentration of mineral nutrients that is available in the soil largely affects the development and growth of any crop. For plants to obtain adequate supply of the required nutrients to meet their demands for the basic cellular processes, they face significant challenges due to relative immobility of the nutrients. When the required nutrients are in deficit, it may result to a decrease in the productivity of any given plant and therefore, the different papaya lines used could be having different abilities for absorption .These factors are key attributes and could have led to differences in number of fruit, weight, diameter and flesh size among the papaya lines as shown in table 3.10. The yield attributes could also be different due to different rates in which processes such as photosynthates translocation is different from the source to sink in different plants at different times. There could also be differences in photo respiration processes that took place within the plant as shown by Aliyev (2012) on studies of wheat and soybean genotypes productivity in relation to photosynthesis and photorespiration. Photosynthesis and respiration is highly affected by temperature and light duration and these conditions were different in each location as shown in table 3.1. For expression of genetic characters ,genetic constitution of different lines are some of the key factors that directly affect performance in a particular set of environment such as flesh thickness, weight and fruit diameter. Related findings were shown on the studies of genetic variability, heritability and genetic advance for yield traits in tomato (Solanum Lycopersicum L.)(Bhandari et al, 2017).

There was a significant variation in total soluble solids among the papaya lines .This could be attributed to high photosynthetic efficiency and fast rate of diversion of sugars from source to sink sites. The result was best depicted by line 5 where it showed a high total soluble solids at 12.17%. The results on TSS at JKUAT agrees to the findings reported on evaluation of physicochemical, nutritional and sensory quality characteristics of new papaya hybrids fruits developed in JKUAT (Nishimwe et al. 2018). From the study, we postulate that from all the 4 experimental locations, line 5 was better in total fruit number and total soluble solids, line 7 in fruit weight, flesh thickness, fruit length and fruit diameter.

3.5 Conclusion

Different papaya lines exhibited different traits in different experimental locations. The study showed that JKUAT papaya lines had a performance and yield output that was comparable to solo which is a commercial variety grown in Kenya (Table 4.1). This study revealed that the newly developed JKUAT papaya lines adapted well to prevailing conditions experienced in the four experimental locations. With respect to growth and development, the result revealed that line 6 was the shortest since it had the lowest plant height in all the 4 experimental sites except Mwea .Additionally, line 5 had a better performances on stem girth, time taken to fruit ripening, total number of fruits and highest total soluble solids all the experimental sites except Mwea. Line 7 had most of the combined traits where it took the shortest time to first flower emergence, shortest time to 50% flowering, had the highest fruit weight, fruit diameter and flesh thickness.

3.6 Recommendations

The study recommended exploitation of the newly developed JKUAT papaya lines in tested locations. With the adverse changes in climatic conditions experienced globally, it was recommended that more research should be done to test the performance of these new lines under heat and water stress conditions to assess on their performances.

CHAPTER FOUR

DETERMINATION OF INCIDENCE AND SEVERITY OF SELECTD PAPAYA DISEASES AMONG THE NEW JKUAT PAPAYA LINES IN DIFFERENT AGRO-ECOLOGICAL ZONES OF KENYA

Abstract

The major constraints that affects papaya production in most parts of the world are biotic stresses related to pest and diseases. In Kenya, the main diseases that leads to a reduction in papaya production are anthracnose, ringspot (PRSV) and powdery mildew. The most affected are the local varieties such as Yellow Mountain, red royal and malkia and thus this research was aimed to assess incidence and severity of papaya ringspot virus, anthracnose and powdery mildew among the new JKUAT papaya lines in two different agro-ecological zones of Kenya. From the study conducted, all the sites experienced incidences of powdery mildew except JKUAT and among the locations with incidences, there were significant differences that were noted on both incidences and severity levels. However, there were significant differences that were noted in papaya lines where line 1 had higher incidences and severity (2.4% and 1.25% respectively). On the interactions, it was noted that at KALRO Mwea, all the lines experienced incidences of powdery mildew except line 5. The incidence of anthracnose disease was observed at JKUAT only with 2.53% and a severity of 3.34%, while other experimental locaions did not show any symptom. Among the lines, lines 6 and 7 did not show symptoms while line 1, 5 and solo sunrise had incidences but they did not show significant differences. The interactions between the locations and papaya lines among the lines with symptoms did not show significant differences however solo at JKUAT had a higher incidence of 4.58% while line 1 at JKUAT had a higher severity of 6.97%. Incidence of papaya ringspot virus was noted in all the experimental locations and they showed significant differences with JKUAT having a higher incidence and severity of 6.84% and 10.04% respectively while on the other hand, Nkubu had the least incidences and severity of 2.05% and 1.92% respectively. Among the papaya lines, line 5 had higher incidences while solo had the

lowest levels of 5.98% and 2.67% respectively. There were also significant differences noted on the severity of ringspot virus where line 7 had higher severity of 7.92% while the least severity was recorded by solo at 2.84%. Based on the results, different lines performed differently and showed different traits that could be compared to those of Solo sunrise. Lines 5, 6 and 7 were more resistant to powdery mildew and anthracnose than solo sunrise while on the other hand, line 1 was more susceptible. On papaya ringspot virus, solo sunrise performed better than JKUAT lines at KALRO Mwea and Nkubu.

4.1Introduction

Papaya (*Carica papaya*), is a member of the family Caricacea, a fruit crops that does well in both tropical and sub-tropical regions across the world. Papaya is prone to many diseases which are economically important and can lead to high losses. The most common diseases are Anthracnose, Ring spot virus and Powdery mildew (Ventura et al, .2004). There are several management practices that have been put in place such as rouging out infected plants in the fields, quarantine regulation that enforces restriction to plant movement, use of chemicals (pesticides) against insect transmitters. There is also the use of cross protection but generally, these have not been fully effective in controlling the diseases. Naturally many of the papaya varieties grown have not shown resistant to these diseases. Therefore, the development of papaya variety that are resistant is considered as one the best strategy that can be used for long-term measures of most of the diseases. For example, studies show that most species from a related genus, *Vasconcellea,* that exhibit resistance to Papaya ringspot virus, and therefore, such materials are key and valuable resource which can be exploited towards the development of varieties that are resistant to papaya diseases. Towards the development and improvement of superior plant varieties, crossing of tolerant varieties with susceptible but of high yielding commercial varieties has resulted to better varieties with some tolerance levels and at the same time improve yield under conditions that are infectious (Singh, 2012). More efforts have been made towards the incorporation of genes that are resistance from other genera found in the Caricacea family. These genera include *Vasconcellea cauliflora, V. quercifolia, V. stipulata* and *V. pubescens*. In most of the developing countries, the decline in production of papaya is attributed to varieties that are poor in quality, poor cultural practices, and the existence of inoculums of fungal and bacterial as well as viral diseases (Gonsalves et al., 2000).When the above mentioned challenges are addressed, the production can be enhanced through appropriate disease management coupled with good agricultural practices. This therefore call for a research on assessment of anthracnose, ring spot virus and powdery mildew which will enables those in farming to select the best performing varieties of their choices in the study area . Assessments of Anthracnose, PSV and powdery mildew diseases are therefore one of the considerations that should be utilized to curb the existing problems. This will enable farmers to obtain the desired varieties to produce for which the output of this study was likely to assist and sensitize papaya growers. There is ever increasing demand for papaya to feed the growing human population and at the same time supply the ever-expanding papaya industries both at national and international level. With the increase, it has created a need for the expansion of papaya cultivation in to areas where it has not ever been extensively grown. Through the incidence and severity of plant diseases assessment, researchers are in a position to determine the distribution geographically and status of the disease in the whole region which when further utilized can help to give more priorities in certain research themes to the situations (Bock et al, .2010). This study was to assses incidence and severity of papaya ringspot virus, powdery mildew and anthracnose among the new JKUAT papaya hybrids in different selected agro-ecological zones of Kenya.

4.2 Materials and methods

This study was carried out in four different locations (JKUAT, Mwea, Nkubu, and Mitunguu) that were in two selected agro ecological zones of Kenya (upper highland and upper midland zones). A Randomized Complete Block Design (RCBD) was used in the lay out of the experiment with three replications. There were 35 plants in each replication, and the treatment comprised 7 plants of each variety that were planted at inter row and intra row spacing of 3m. Data collection was carried out from the time of transplanting to full maturity of the plant on a monthly basis.

4.2.1 Assessment and evaluation of disease incidence and severity

A field survey was done systematically in all the blocks of *C. papaya*, powdery mildew, anthracnose and papaya ringspot virus (PRV) diseases were carried out on the farm from May 2018 to September 2019. Papaya plants were evaluated for disease incidence and severity monthly. Jensen's equation (2019) was used to calculate disease incidence (DI) while for the determination of the disease severity (DSI) a rating scale by Viera et al, 2014 was applied. The scale used was; 0 = no symptom, 1 = 1-20 % severity level on infected plants, 2 = 20^{+}-40 %, 3 = 40^{+}-60 %, 4 = 60^{+}-80 % and 5 = 81^{+}-100 %.

4.2.2 Percentage of disease incidence

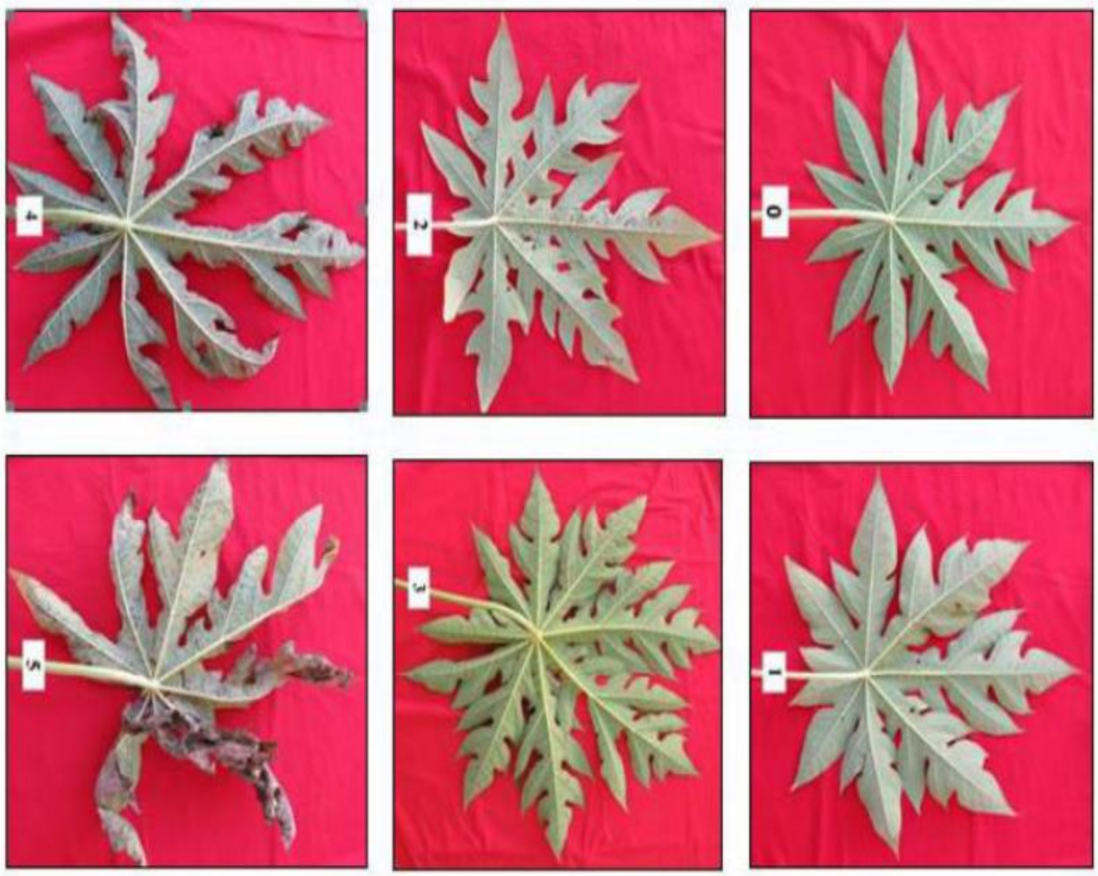
The virus disease incidence was determined by calculating the symptomatic plants from the total plants sampled in each treatment(Gutiérrez et al., 2003).This was calculated by; DI (%) = x/N × 100; where X = Number of infected fruits and N = Total number of fruits in the field,

4.2.3. Methods of visual estimation

Visual estimates of disease severity based on ratio scale of measurement was applied (Bock et al., 2015). The percentage scale that was used ranged from zero to 100%. The rater or the observer gauged the proportion of the organ showing symptoms and that was applied to estimate severity accordingly with the aid of standard area diagrams (Pethybridge & Nelson, 2018).

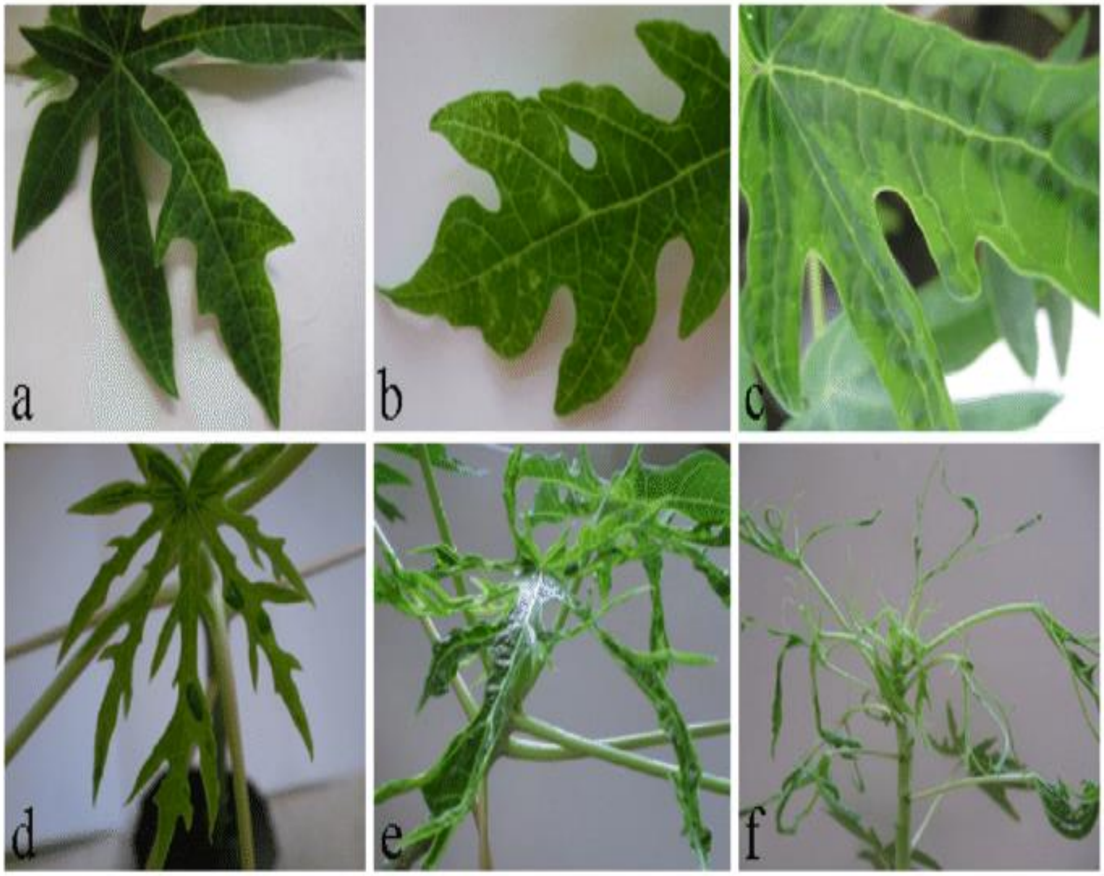
4.2.4. Methods to improve accuracy of estimates by use of Standard area diagrams

Standard area diagrams which is a tool used to improve accuracy of a rater estimates was applied for all the diseases observed (Pethybridge & Nelson, 2018). This was applied to help standardize raters readings and therefore improved inter-rater reliability on individual specimens. On SADs, first, the main category was selected which had a specific % intervals of 10, 15, 20, 25%...95 and 100% (Del Ponte et al., 2022)



0- No symptom, 1-(1 to 10% of leaf infected), 2-(10-25% of leaf infected), 3-(25-50% of leaf infected), 4-(Over 50% of leaf infected), 5(The whole plant leaves defoliation)

Plate 4.1: Standard area diagram for anthracnose severity on papaya



A- No symptom, B-(1 to 10% of leaf infected), C-(10-25% of leaf infected), D-(25-50% of leaf infected), E-(Over 50% of leaf infected), F-(The whole plant leaves defoliation)

Plate 4.2: Standard area diagram for severity of Papaya Ringspot Virus

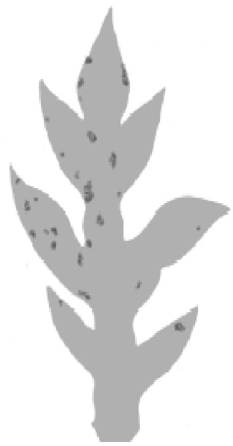
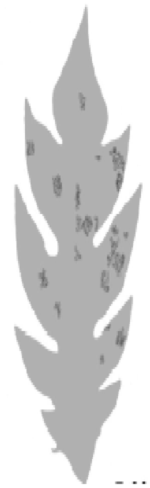
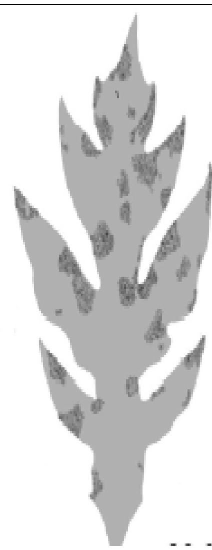
 1-(1-10% of leaf infected)	 2-(10-20% of leaf infected)	 3(20- 30% of leaf infected)
 4(30- 40% of leaf infected)	 5(50% + of leaf infected)	

Plate 4.3: Standard area diagram for severity of Powdery mildew on papaya

4.2.5 Scoring of the disease severity

Table 4.1: Papaya Ring Spot Virus (PRSV)

Scale	Disease Symptom
0	No symptom
1	Mild mottling, mosaic symptoms with observed water-soaking streaks on plant surfaces
2	Severe mottling,mosaic with water-soaking streaks on the plant
3	Whole leaf distortion with water-soaking streaks on the plant surface
4	Shoe like stringing with water-soaking streaks plant surface
5	Defoliation and subsequent death of the plant

Table 4.2: Anthracnose

Scale	Disease Symptom
0	No symptoms of the disease
1	1 to 10% plant leaflet surface covered with lesions
2	10-25% plant leaflet area covered with lesions
3	25-50% plant leaflet area covered with lesions and some chlorosis
4	Over 50% of the plant leaflet area covered with lesions and extensive necrosis
5	The whole plant leaves defoliation

Table 4.3: Powdery mildew

Scale	Disease Symptom
0	No lesion
1	1-10% of plant parts infected with pale yellow leaf spots
2	10- 20% of plant parts infected with pale yellow spots turn to large white blotches
3	20- 30% of plant parts infected with large blotches covering entire leaf, petiole and stem surfaces
4	30- 40% of plant parts infected with the older lesions turning brown and appear shrived
5	50% of plant parts infected resulting to leaf curl and leaf drops

4.2.6. Data analysis

The data on disease incidence and severity were subjected to the analysis of variance (ANOVA) using GenStat software. Whenever there were significant treatment effect, means were compared using Tukey's test. All tests were performed at 5% level of significance.

4.3 Results

4.3.1. Powdery Mildew incidence and severity of papaya plants in the selected agro -ecological zones of Kenya

From the locations, there were significant differences in incidences of powdery mildew, however, plants in Mwea, Nkubu and Mitunguu did not vary significantly among themselves but they had a significantly higher levels of powdery mildew than JKUAT. Severity levels also varied significantly among the locations where Mwea, Nkubu and Mitunguu did not vary significantly but they had a higher severity levels than JKUAT (Table 4.4)

Table 4.4: Effects of location on powdery mildew incidence and severity of papaya plants taken from three replicates per treatment

Locations	Incidence (%)	Severity (%)
Mwea	2.22±0.69a	1.43±0.46a
Nkubu	1.72±0.59a	0.75±0.28ab
Mitunguu	1.21±0.40	0.75±0.23ab
JKUAT	0.00±0.00b	0.00±0.00b
LSD	1.19	0.74
CV%	125.40	136.10

Means in the same column followed by different letter(s) are significantly different at ($P \leq 0.05$)

Among the lines, there were significant differences that were noted whereby line1 and solo were similar but they had a significantly higher incidences than line 5 and line 6. Lines 7, 5 and 6 did not show any significant differences among themselves. Severity levels of powdery mildew among the lines showed significant differences where line 1 and solo did not vary from one another but they had a significantly higher severity levels than line 5 and line 6. On the other hand, line 7, 5 and 6 did not show any significant differences (Table 4.5)

Table 4.5: Effects of lines on powdery mildew incidence and severity of papaya plants taken from three replicates per treatment

Lines	Incidence (%)	Severity (%)
Line 1	2.40a±0.88	1.25a±0.45
Solo	1.89a±0.62	1.09a±0.44
Line 7	1.39ab±0.44	1.01ab±0.35
Line 5	0.38b±0.38	0.16b±0.16
Line 6	0.38b±0.27	0.16b±0.11
LSD	1.33	0.82
CV%	125.40	136.10

Means in the same column followed by different letter(s) are significantly different at ($P \leq 0.05$)

On the interaction of location and lines planted, significant differences were noted in some lines in some locations where line 1 in Mwea had a significantly higher powdery mildew incidences than all other lines in all the locations that did not show any significant differences. Severity levels showed significant differences among the lines in different locations where line 1 in Mwea, solo in Mwea and line 7 in Nkubu did not show any significant difference, however, line 7 in Mwea had a significantly higher severity levels than solo in Nkubu, solo in Mitunguu, line 1 in Nkubu, line 7 and 6 in Mwea, line 5, 1 and 7 in Mitunguu (Table 4.6)

Table 4.6: Effects of Location*Lines on powdery mildew incidence and severity of papaya plants taken from three replicates per treatment

Location * Lines	Incidence (%)	Severity (%)
Mwea Line 1	6.06±1.75a	3.40±0.79a
Nkubu Line 7	3.03±0.87b	1.86±0.91abc
Nkubu Solo	3.03±1.75b	0.95±0.55bc
Mitunguu Solo	2.52±0.32b	1.27±1.01bc
Nkubu Line 1	2.52±1.82b	0.95±0.55bc
Mwea Solo	2.02±1.33b	2.13±1.68ab
Mwea Line 7	1.51±0.88b	0.95±0.55bc
Mitunguu Line 5	1.51±1.52b	0.63±0.64bc
Mwea Line 6	1.51±0.87b	0.63±0.32bc
Mitunguu Line 7	1.01±0.51b	1.22±0.79bc
Mitunguu Line 1	1.01±0.51b	0.63±0.32bc
Mwea Line 5	0.00±0.00b	0.00±0.00c
JKUAT Line 6	0.00±0.00b	0.00±0.00c
JKUAT Line 7	0.00±0.00b	0.00±0.00c
JKUAT Line 1	0.00±0.00b	0.00±0.00c
JKUAT Line 5	0.00±0.00b	0.00±0.00c
JKUAT Solo	0.00±0.00b	0.00±0.00c
Mitunguu Line 6	0.00±0.00b	0.00±0.00c
Nkubu Line 6	0.00±0.00b	0.00±0.00c
Nkubu Line 5	0.00±0.00b	0.00±0.00c
LSD	2.6	1.65
CV%	125.40	136.10

Means in the same column followed by different letter(s) are significantly different at ($P \leq 0.05$)

 Powdery on older leaves	 Powdery on young leaves

Plate 4.4: Patches of Powdery Mildew on the papaya lines

4.3.2. Anthracnose incidence and severity of papaya plants in the selected agro - ecological zones of Kenya

The incidences of anthracnose was experienced only in JKUAT and therefore it was significantly different from Mitunguu, Mwea and Nkubu.

Table 4.7:Effects of location on Anthracnose incidence and severity of papaya plants taken from three replicates per treatment

Locations	Incidence%	Severity%
JKUAT	2.53±1.01a	3.33±1.30a
Mitunguu	0.00±0.00b	0.00±0.00b
Mwea	0.00±0.00b	0.00±0.00b
Nkubu	0.00±0.00b	0.00±0.00b
LSD	1.45	1.78
CV%	311.70	288.80

Means in the same column followed by different letter(s) are significantly different at ($P \leq 0.05$)

Table 4.8: Effects of Lines on Anthracnose incidence and severity of papaya plants taken from three replicates per treatment

Lines	Incidence%	Severity%
Solo	1.14±0.90a	0.98±0.77a
Line 5	1.13±0.90a	1.44±1.10a
Line 1	0.88±0.66a	1.74±1.24a
Line 6	0.00±0.00a	0.00±0.00a
Line 7	0.00±0.00a	0.00±0.00a
LSD	1.63	1.99
CV%	311.70	288.80

Means in the same column followed by different letter(s) are significantly different at ($P \leq 0.05$)

Among the lines, solo, line 5 and line 1 did not vary significantly but they had a significantly higher incidences than line 6 and line 7. Severity levels showed significant differences where solo, line 5 and line 1 did not show any significant differences however, they had a significantly higher levels than line 6 and line 7 (Table 4.8)

In the interactions between the locations and lines, there was significant difference noted where solo in JKUAT and line 5 in JKUAT were not significantly different but they had a significantly higher anthracnose incidence than line 1 in JKUAT which was also significantly difference from all other lines in all the locations. Severity of anthracnose showed significant differences where line 5 and 6 in JKUAT were not significantly different from one another , however, they had a significantly higher severity levels than solo in JKUAT which was also significantly different from all other lines in all the locations.(Table 4.9)

Table 4.9: Effects of Location and Lines on Anthracnose incidence and severity of papaya plants taken from three replicates per treatment

Location *Lines	Incidence%	Severity %
JKUAT Solo	4.57±3.15a	3.93±2.69ab
JKUAT Line 5	4.54±3.15a	5.78±3.75a
JKUAT Line 1	3.53±2.20ab	6.96±3.94a
Mitunguu Solo	0.00±0.00b	0.00±0.00b
Mwea Solo	0.00±0.00b	0.00±0.00b
Nkubu Solo	0.00±0.00b	0.00±0.00b
Mitunguu Line 1	0.00±0.00b	0.00±0.00b
Mwea Line 1	0.00±0.00b	0.00±0.00b
Nkubu Line 1	0.00±0.00b	0.00±0.00b
Mitunguu Line 5	0.00±0.00b	0.00±0.00b
Mitunguu Line 6	0.00±0.00b	0.00±0.00b
Mitunguu Line 7	0.00±0.00b	0.00±0.00b
Mwea Line 5	0.00±0.00b	0.00±0.00b
Mwea Line 6	0.00±0.00b	0.00±0.00b
Mwea Line 7	0.00±0.00b	0.00±0.00b
Nkubu Line 5	0.00±0.00b	0.00±0.00b
Nkubu Line 6	0.00±0.00b	0.00±0.00b
Nkubu Line 7	0.00±0.00b	0.00±0.00b
JKUAT Line 6	0.00±0.00b	0.00±0.00b
JKUAT Line 7	0.00±0.00b	0.00±0.00b
LSD	3.26	3.98
CV%	311.70	288.80

Means in the same column followed by different letter(s) are significantly different at ($P \leq 0.05$)

Anthracnose on fruit

Anthracnose on leaf

Anthracnose on stem

Plate 4.5: Picture of Anthracnose on JKUAT papaya lines

4.3.3. Papaya Ringspot Virus incidence and severity of papaya plants in the selected agro -ecological zones of Kenya

Significant differences were noted in the incidences of papaya ringspot virus across the locations where JKUAT had a significantly higher incidences of ringspot virus than Mitunguu and Nkubu, however, it was not significantly different from Mwea. Mwea, Nkubu and Mitunguu also did not show any significant differences among them.

Table 4.10: Effects of location on Ringspot Virus incidence and severity of papaya plants taken from three replicates per treatment

Location	Incidence (%)	Severity(%)
JKUAT	6.84±0.72a	10.04±1.51a
Mwea	4.61±1.24ab	4.96±1.21b
Mitunguu	4.01±0.94b	4.71±1.17b
Nkubu	2.05±0.46b	1.91±0.63b
LSD	2.54	3.08
CV%	78.40	77.10

Means in the same column followed by different letter(s) are significantly different at (P ≤ 0.05)

There was also significant difference noted on the severity levels of ringspot virus where JKUAT had a significantly higher severity levels than Mwea, Nkubu and Mitunguu, however, Mwea, Nkubu and Mitunguu did not vary significantly. (Table 4.10). Among the papaya lines, there was a significant difference that was noted where line 5 had a significantly higher incidences of ringspot virus than solo, however, line 1, 7, 6 and solo did not vary significantly. Severity cases of ringspot virus also showed significant

Table 4.11: Effects of Lines on Anthracnose incidence and severity of papaya plants taken from three replicates per treatment

Lines	Incidence (%)	Severity(%)
Line 5	5.98±1.71a	6.26±1.61ab
Line 1	5.66±0.89ab	7.09±1.45a
Line 7	4.59±0.87ab	7.92±1.99a
Line 6	2.99±0.84ab	2.91±1.00b
Solo	2.67±0.56b	2.84±0.94b
LSD	2.84	3.44
CV%	78.40	77.10

Means in the same column followed by different letter(s) are significantly different at ($P \leq 0.05$)

differences where line1 and 7 did not vary significantly but they had a significantly higher severity levels than line 6 and solo. Line 1, 7 and 5 also did not vary significantly same to line 5, 6 and solo that did not vary significantly (Table 4.11).

From the interactions of locations and lines, there were significant differences that were noted where line 5 in JKUAT, line 1 in JKUAT, line 7 in JKUAT, Line 5 in JKUAT, and line 6 in JKUAT had a significantly higher incidences of ringspot virus than line 6 in Mitunguu, line 7 in Nkubu, solo in Nkubu and line 6 in Mwea. All the other remaining lines in all the locations did not show any significant differences between them (Table 4.12).

Table 4.12: Effects of Location*Lines on Ringspot Virus incidence and severity of papaya plants taken from three replicates per treatment

Location*Lines	**Incidence (%)**	**Severity (%)**
Mwea Line 5	8.12±5.60a	6.42±3.16bcd
JKUAT Line 1	8.12±2.14ab	10.33±4.21abc
JKUAT Line 7	7.69±1.48abc	16.39±0.92a
JKUAT Line 5	7.69±1.96abc	11.56±3.16ab
JKUAT Line 6	6.83±0.85abc	7.303±1.88cd
Mitunguu Line 5	6.41±3.92abc	6.10±2.89bcd
Mwea Line 1	5.98±1.71abc	7.03±3.15bcd
Mitunguu Line 1	5.55±1.54abc	6.42±2.61bcd
Mitunguu Line 7	4.70±1.13abc	7.62±3.69bcd
Mwea Line 7	4.70±1.13abc	7.03±3.15bcd
JKUAT Solo	3.84±0.74abc	4.60±2.69bcd
Mwea Solo	3.41±1.54abc	3.69±2.28bcd
Nkubu Line 1	2.99±0.85abc	4.59±1.82bcd
Nkubu Line 6	2.99±1.54abc	2.77±1.89cd
Mitunguu Solo	2.13±1.13abc	2.45±1.59cd
Nkubu Line 5	1.70±0.85abc	0.95±1.55d
Mitunguu Line 6	1.28±0.74abc	0.95±0.55d
Nkubu Line 7	1.28±1.28abc	0.63±0.64d
Nkubu Solo	1.28±0.74abc	0.63±0.32d
Mwea Line 6	0.85±0.85c	0.63±0.64d
LSD	5.67	6.89
CV%	78.40	77.10

Means in the same column followed by different letter(s) are significantly different at ($P \leq 0.05$)

The severity levels of ringspot virus showed significant differences where line 7 in JKUAT, line 5 in JKUAT and line 1 in JKUAT did not vary significantly however, they had a significantly higher severity levels of ringspot than line 6, 5, 7 and solo in Nkubu, line 6 and solo in Mitunguu and line 6 in Mwea which were also not different from one another. The other remaining lines did not show significant differences in all the locations. (Table 4.12)

	
Papaya Ringspot Virus on leaves and stems	Papaya Ringspot Virus on fruits

Plate 4.6: Pictures of Ringspot Virus on JKUAT papaya lines

4.4 Discussion

The examined papaya diseases that affect production and leads to heavy losses are powdery mildew, anthracnose and papaya ring spot virus. Powdery mildew is one of the persistent and common threat that causes high loses to both home gardeners and commercial farmers (Braun, 2017). Papaya is host to a dozen species of fungi that cause powdery mildew and the major one is O. caricae-papayae (Tsay et al. 2011). Plants respond differently to certain pathogens but consistently resist certain pathogens. On the other hand, they succumb to others however resistance is usually specific to certain pathogen species or pathogen strains (Mukhtar & van Peer, 2018). From the study, powdery mildew was experienced in Mwea, Nkubu and Mitunguu which could illustrate that they had a conducive environment for pathogen to thrive while in JKUAT, there were no symptoms. From the locations that had symptoms, there were no significant differences among locations however they were significantly different from JKUAT (Table 4.4). Among the papaya lines, there were significant difference noted and the highest incidence and severity was recorded by line 1 (2.40% and 1.25% respectively) while the lowest incidence was recorded by line 5 and 6 both with 0.38% and the lowest severity was recorded by line 7 at 1.01% (Table 4.5). The different papaya lines could be having different levels of resistance, where by line 1 was more susceptible ,on the other hand, the least susceptible were line 6 and 5. The resistance could also be due to different genetic make-up of the papaya lines. The differences in resistance was also noted in other studies carried out on genetic resistance to powdery mildew in strawberry which showed that the powdery mildew resistance was controlled by multiple genes (Liu and Zhang ,2014). The interactions between the locations and papaya lines showed significant differences and it was noted that line 1 in Mwea had higher levels of incidences and severity (6.06 % and 3.41 % respectively) (Table 4.6). This was significantly different from all other lines in other growing locations which could have been due to different environmental conditions. Locations in upper highland zones (Nkubu and Mitunguu Irrigation Scheme) were affected at early stages (2 months) after transplanting while in upper midland zones (KALRO Mwea) it infected later when the plants were mature and these were the periods when the regions received high rains followed by warm days (Table 3.1). The different infestation stages of plant growth is also cited by research done on other crops like oat (Sánchez-Martín et al., 2011). It therefore showed that the disease can affect papaya plants in all growth stages from seedling to maturity. Additionally, the result is similar with previous studies carried out in China on occurrence of powdery mildew caused by Pseudoidium neolycopersici on papaya (Mukhtar & van Peer, 2018). It illustrated that the pathogen thrives best in humid areas with warm days and cool nights. These fungal disease of papaya infects leaves and fruit (Plate 2.2) that lead to premature defoliation and reduced yields. As a result of this, it lower sales due to downgraded fruit and on severe cases, the fruits are not fit to harvest (Mukhtar & van Peer, 2018). The severely infected leaves became necrotic and scorched with time and this was more pronounced at KALRO Mwea in line 1. They later curled and fell off the plant before they fully matured which is also cited in other studies (Lebeda and Mieslerová, 2010). In the mature fruits, the fungus may disappear but there will be gray scars left behind on the surfaces (Vielba-Fernández et al., 2019) .These scars restrict growth of the underlying tissue and as a result, the fruits tend to have deformed shapes that do not fetch good prices and therefore no value in the market.

Anthracnose is a fungal disease of papaya that if not managed can cause significant yield losses. The disease can affect the plants in the field when favorable conditions prevail since it infect leaves and stems when there is high humidity and ample amount of water (Saini et al., 2017). From the observations made, the disease only affected papaya plants in JKUAT while other growing locations did not show symptoms. The papaya in JKUAT that showed symptoms were infected between the months of June and September. During this period, the region received a higher mean rainfall in June and July (Table 3.1). That prevailing conditions could have created ample amount of water and with high humidity that could have created favorable conditions for the disease development.

Among the lines that had symptoms, the highest incidence was recorded by solo sunrise at 1.14% in the month of August followed by line 5 and 1 at 1.13% and 0.88% respectively while line 6 and 7 were not infected. The highest severity was recorded by line 1 at 1.74% while the least was solo at 0.98%.This result showed that solo sunrise is highly susceptible in the presence of anthracnose inoculum than lines 5, 6, 7 and 1. The levels of susceptibility of plants to diseases may vary on different factors such as environmental that may affect development of plant diseases and they also determine whether they become epiphytotic (Granke and Hausbeck, 2010). The most notable are extremes of temperature, relative humidity, soil moisture, soil pH, soil type, and soil fertility. The findings are similar with findings on studies done on Phytophthora Rot of Cucumber fruit (Granke and Hausbeck, 2010). When the conditions are favorable for the disease development, the plant defense responses get suppressed. When this happens, it modulate plant physiology that makes it easier to provide them with nutrients hence accommodate fungal invaders (Granke and Hausbeck, 2010). The interactions between the location and the papaya lines had significant difference among the lines that were affected and the ones that did not show symptoms. Solo in JKUAT had the highest incidence at 4.58% followed by line 5 at JKUAT at 4.54% then line 1 at JKUAT at 3.53%

while other lines in other locations did not show the symptoms. However on the other hand the disease was more severe in line 1 at JKUAT (6.97%) (Table 4.9). The resistance can vary depending on the plant species and the resistance source and also the stage of plant development. Additionally, other experimental locations that did not experience cases of anthracnose such as KALRO Mwea, Nkubu and Mitunguu Irrigation Scheme may not be having prevalence of the disease pathogen. The fungus (Colletotrichum gloeosporioides) is more dangerous and leads to more destructions at the post-harvest stages (Ademe, 2013). However, from the study, the disease was experienced both at vegetative and postharvest stages. As the disease starts, the symptoms are small light-colored spots on the leaves and the fruits. As it progress, the spots become sunken and enlarge having a water soaked appearance. The finding is similar to symptoms shown on studies of morphological, pathological and genetic diversity of Colletotrichum species responsible for anthracnose in papaya (Carica papaya L) (Torres-Calzada et al., 2012).The single spots are generally numerous but merge up to form larger spots from 1- 5 cm in diameter. In leaves, the severe cases results to shrinkage leading to premature fall while as fruit continues to ripen the disease progresses and results to pinkish-orange colored spots which are irregular or circular which letter merge to form larger spots (Rampersad, 2011). The fruits produced from the infected plants did not show symptoms at immature stages, however, at the start of ripening, the symptoms were noted. Studies done on breeding for anthracnose disease resistance in chili showed that in the immature fruits, it doesn't show any symptom since the disease remain latent till the post climacteric stages of the fruit (Ridzuan et al., 2018). The pathogen do resumes growth immediately the fruits begins to ripen and it is at this stage when the symptoms appear on the fruits. The pathogen absorbs the nutrients from the fruit as it continue with its colonization and then forms the spores to complete its life cycle (Maeda et al., 2014).

The incidence and severity of papaya ringspot virus showed significant differences among the locations where the highest incidences and severity were recorded in JKUAT (6.84 % and 10.04 % respectively) while on the other hand the least incidences and severity were recorded in Nkubu (2.05% and 1.92% respectively) (Table 4.10).The differences could have resulted to different environmental conditions that were experienced in the these different locations. This is in line with other research that showed that temperature dramatically affects the host-virus interaction (Mangrauthia et al., 2009). Often, outbreaks of viral diseases are frequently associated with the ambient temperature which is a major component required for host development. The phenotypic expression of symptoms and viral accumulation are found to appear at higher temperatures. The symptoms showed both mosaic and leaf mottling leading to leaf distortions which are similar to findings achieved on studies of assessing different papaya (Carica papaya L.) varieties tolerant responses to ringspot virus (PRSV) infection in conjunction with establishment of symptom severity rating scale for resistance screening (Jayavalli et al., 2015). Among the papaya lines, significant differences were noted where the highest incidence was recorded by line 5 (5.98%) while the highest severity was recorded by line 7 (7.92%). On the other hand, the least incidences and severity was recorded by solo (2.67% and 2.85% respectively) (Table 4.11). The differences in levels could be attributed to different levels of resistance by different lines due to their different genetic make-up. Studies on horticultural characterization and papaya ringspot virus reaction of papaya Pune Selections showed that the genes dictate how plants respond to prevailing surroundings (Sharma & Tripathi, 2019).The affected plants showed a reduced growth rate and subsequently, there was a reduced production par single affected plants. The reduction on both quantity and fruit quality as a result of ring spot virus is also shown in other studies on morphological traits, growth and yield performance, and Papaya ringspot virus strain papaya reaction in Vasconcellea cauliflora in Pune, India (Sharma et al., 2016). The interactions of locations and lines showed significant differences where higher levels of incidences were recorded by line 5 in Mwea and line 1 in JKUAT at 8.12% while the highest severity were recorded in line 7 at JKUAT (16.39%). In most circumstances, there are many environmental conditions that affect plant disease development. Where favorable conditions interacts with a variety that is more susceptible, the plants is more likely to get infected with disease as opposed to plants that are resistant. Some of the environmental conditions that were different in the growing locations were temperature, water availability and soil fertility. Literature shows that the disease is transmitted by many species of aphids (mainly *Myzus persicae* and *Aphis gossypii*) in a non-persistent manner (Sudha et al., 2013).

4.5. Conclusion

Assessments of Anthracnose, PRSV and powdery mildew disease is a key consideration that could be utilized to curb the existing problems. When implemented, it could therefore assist farmers to obtain the desired varieties for which the output is enhanced. Based on the results, all the lines were infected by ringspot virus showing that they were all susceptible. However, some lines showed resistant towards fungal diseases. Line 5 was not infected in both KALRO Mwea and Nkubu, same to line 6 that was not affected by powdery mildew in Nkubu and Mitunguu irrigation scheme. Lines 6 and 7 also showed resistance towards anthracnose and could therefore be utilized to improve production. There is ever increasing demand for food to feed the growing human population and at the same time supply the ever-expanding industries both at national and international level and it is at this point that increased papaya production can help boost the economy. Through the assessment of the incidence and severity of plant diseases, researchers determine the geographic distribution and status of the disease throughout a region which when further utilized, could help to prioritize research themes to the situation.

4.6 Recommendation

The study recommended more research to be done in other agro-ecological zones of Kenya to assess on their resistance or susceptibility to the diseases. Additionally, there could be a study to assess the tolerance levels of the new JKUAT lines against the papaya diseases. The study also recommended exploitation of varieties that showed resistance to specific disease.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

From the findings of this study, the newly developed JKUAT papaya lines could be used by farmers to improve on their productions. The lines showed superiority in different agronomic traits of which some were key factors considered by both the producer and consumer. In relation to performance achieved, the study revealed that with the prevailing conditions in two different agro ecological zones in Kenya, the newly developed JKUAT papaya lines had adapted well. However, the zones had different soil nutrient levels, different amount of rainfall and temperature and this could have affected the performance leading to significance differences noted in both morphological and quality characteristics in the tested papaya lines**.** With respect to growth and development, the result revealed that line 6 had the lowest plant height in all the sites except Mwea which is an advantage in production since it also makes the subsequent operations easier. The results also indicated that line 5 had a better performances on stem girth which is an indication of plant strength and necessary if is high yielding plant. Line 5 had the highest total number of fruits in all the experimental sites which is a key indicator of high yield and in addition had the highest total soluble solids all the experimental sites except Mwea. Line 5 also had a better performance in time taken to fruit ripening which was evident in all experimental sites except Mwea showing that it is an early maturity line. The study also reviled that line 7 had most of the combined traits where it took the shortest time to first flower emergence, shortest time to 50% flowering, had the highest fruit weight, fruit diameter and flesh thickness. On disease resistance and susceptibility, it was noted that all the lines were infected by viral disease (papaya ringspot) while on the other hand, lines 5, 6 and 7 were not susceptible to fungal infections in different sites i.e. line 5 free from powdery mildew at KALRO Mwea and Nkubu, line 6 free from powdery mildew at Nkubu and Mitunguu and also free from anthracnose at JKUAT. Line 7 was also free from anthracnose at JKUAT. The developed JKUAT lines could be recommended for further cultivation by farmers in these areas where the test was carried out and also other areas that experiences similar environmental conditions especially those lines that showed most of the combined preferred traits such as line 5(high in fruit number, total soluble solids, high stem girth, shortest time to ripening and less susceptible to powdery mildew) and line 7(high in weight, flesh thickness, diameter and resistance to anthracnose). Further, more research was necessary to be carried out under other conditions such as heat and water stress conditions to evaluate the performance of the newly developed papaya line.

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APPENDICES

Appendix I: ANOVA of papaya height at first flower emergence

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	3	817.92	272.64	10.67	<.001
Treatment	4	713.73	178.43	6.98	<.001
Location*Treatment	12	1046.00	87.17	3.41	0.002
Total	59	3608.98			

Appendix II: ANOVA of time taken to first flower emergence of papaya plants.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	3	1762.85	587.62	32.29	<.001
Treatment	4	138.40	34.60	1.90	0.130
Location*Treatment	12	31.07	2.59	0.14	1.000
Total	59	2744.98			

Appendix III: ANOVA of time taken to 50% flowering of papaya plants

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	3	3656.583	1218.861	214.83	<.001
Treatment	4	654.767	163.692	28.85	<.001
Location*Treatment	12	113.500	9.458	1.67	0.114
Total	59	4720.850			

Appendix IV: ANOVA of time taken to fruit ripening of papaya plants

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	3	4248.33	1416.11	104.50	<.001
Treatment	4	145.27	36.32	2.68	0.046
Location*Treatment	12	31.67	2.64	0.19	0.998
Total	59	4949.93			

Appendix V: ANOVA of number of fruits of papaya plants

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	3	3385.40	1128.47	13.71	<.001
Treatment	4	6803.73	1700.93	20.67	<.001
Location*Treatment	12	610.27	50.86	0.62	0.813
Total	59	14444.73			

Appendix VI: ANOVA of fruit weight of papaya plants

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	3	0.53487	0.17829	4.09	0.013
Treatment	4	1.54177	0.38544	8.84	<.001
Location*Treatment	12	0.15292	0.01274	0.29	0.987
Total	59	4.02197			

Appendix VII: ANOVA of fruit length of papaya plants

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	3	13.9267	4.6422	9.08	<.001
Treatment	4	32.6350	8.1588	15.97	<.001
Location*Treatment	12	15.0317	1.2526	2.45	0.018
Total	59	81.5200			

Appendix VIII: ANOVA of fruit diameter of papaya plants

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	3	7.185	2.395	2.22	0.102
Treatment	4	88.461	22.115	20.50	<.001
Location*Treatment	12	15.875	1.323	1.23	0.302
Total	59	154.674			

Appendix IX: ANOVA of fruit flesh thickness of papaya plants

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	3	0.002232	0.000744	0.34	0.797
Treatment	4	0.285723	0.071431	32.55	<.001
Location*Treatment	12	0.009143	0.000762	0.35	0.974
Total	59	0.466965			

Appendix X: ANOVA of fruit brix content of papaya plants

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	3	53.7792	17.9264	22.75	<.001
Treatment	4	69.4000	17.3500	22.02	<.001
Location*Treatment	12	23.8667	1.9889	2.52	0.015
Total	59	180.2125			

Appendix XI: ANOVA of powdery mildew incidence of papaya plants

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	3	40.850	13.617	5.21	0.004
Treatment	4	39.221	9.805	3.75	0.011
Location*Treatment	12	63.021	5.252	2.01	0.051
Total	59	247.156			

Appendix XII: ANOVA of powdery mildew severity of papaya plants

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	3	15.3034	5.1011	5.11	0.005
Treatment	4	13.5793	3.3948	3.40	0.018
Location*Treatment	12	18.9843	1.5820	1.59	0.138
Total	59	87.1770			

Appendix XIII: ANOVA of Anthracnose incidence of papaya plants

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	3	72.077	24.026	6.18	0.002
Treatment	4	16.544	4.136	1.06	0.388
Location*Treatment	12	49.632	4.136	1.06	0.416
Total	59	286.411			

Appendix XIV: ANOVA of Anthracnose severity of papaya plants

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	3	125.455	41.818	7.19	<.001
Treatment	4	31.378	7.844	1.35	0.270
Location*Treatment	12	94.134	7.844	1.35	0.233
Total	59	472.074			

Appendix XV: ANOVA of Ring Spot Virus incidence of papaya plants

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	3	174.74	58.25	4.93	0.005
Treatment	4	109.31	27.33	2.31	0.075
Location*Treatment	12	83.99	7.00	0.59	0.834
Total	59	832.64			

Appendix XVI: ANOVA of Ring Spot Virus severity of papaya plants

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Location	3	514.66	171.55	9.86	<.001
Treatment	4	271.72	67.93	3.90	0.009
Location*Treatment	12	194.59	16.22	0.93	0.527
Total	59	1666.92			

Appendix XVII: Publication

Karan, N., Githiri, M., & Rimberia, F. K. (2021). Agronomic performance of new Jkuat papaya in different agro-ecological zones of kenya. *African Journal of Agricultural Research*, *17*(5), 750-757.