ADAPTABILITY, STABILITY AND POST-HARVEST MANAGEMENT OF SELECTED GREEN VEGETABLE PIGEON PEA (*Cajanus Cajan*) GENOTYPES IN EASTERN REGION OF KENYA

OJWANG JUMA DAVID

(BSc, MSc, University of Nairobi)

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This thesis is my own original work and has not been submitted for the award of a degree in any other University.

Signature **Date: 28th November 2023**

Ojwang Juma David

This thesis has been submitted for examination with our approval as University supervisors:

Signed **Date 28th November 2023**

Prof. Richard Ombui Nyankanga,
Department of Plant Science and Crop protection
University of Nairobi,

for **Signed** **Date:** 01/12/2023

PROF. JASPER IMUNGI (Late)
Department of Food Science, Nutrition, and Technology,
University of Nairobi**,**

Signed GangaRao **Date: 29th November 2023**

DR. Dr Ganga Rao, V.P.R, Nadigatla
International Maize and Wheat Improvement Centre (CIMMYT)

DECLARATION OF ORIGINALITY

Name of student: Ojwang Juma David

Registration number: A80/50805/2016

Faculty/School/Institute: Faculty of Agriculture

Department: Plant Science and Crop Protection

Course name: Doctor of Philosophy in Horticulture

Title of the work: Adaptability, Stability and Post-harvest management of Selected green vegetable pigeon peas (*Cajanus Cajan*) in Eastern Region of Kenya

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DEDICATION

This thesis is dedicated to the following very important people in my live:

My father Jaduong Elias Juma Akwiri and Mama, Risper Onim Mikura, the two most influential human being of all times in my life. Your investment in my education has made the person in me today.

To Late Jaduong Bishop Otaya, may you rest in peace! It’s unfortunate you didn’t witness the end! I dedicate this to you posthumously.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS:	Atomic absorption spectrophotometer
AEZ:	Agroecological zone
AMMI:	Additive Main Effects and Multiplicative Interaction
ANOVA:	Analysis of variance
AOAC:	Association of Official Analytical Chemists
APSIM:	Agricultural Production Systems Simulator
ASALs:	Arid and Semi-Arid lands
ASV:	AMMI stability value (ASV) and
CIMMYT:	International Maize and Wheat Improvement Centre
CV:	Coefficient of Variation
DS:	Drought stress
DSI:	Drought Susceptibility Index
DTE:	Drought tolerance efficiency
DTF:	Duration to Flower
DTM:	Duration to Maturity
FAO:	Food and Agriculture Organization of the United Nations
FAOSTAT:	Food and Agriculture Organization Statistics
GEI:	Genotype x environment interaction
GGE:	Genotype main effect (G) plus GEI interaction
GLM:	General linear model
Ha:	Hectares
HI:	Harvest Index
IBPGR:	International Board for Plant Genetic Resources
ICEAP:	ICRISAT East Africa pigeon pea program
ICRISAT:	International Crops Research Institute for the Semi-Arid Tropics
IPCA:	Interaction principal components axis
KALRO:	Kenya Agricultural and Livestock Research organization
KAT:	Katumani
Kg/ha:	Kilograms per Hectares
KIB:	Kiboko
KYM:	Kambi Ya Mawe
LSD:	Least Significant Difference
MZ:	Mozambique
RC:	Rehydration coefficient
RCBD:	Randomized Complete Block design
RH:	Relative Humidity
RWC:	Relative water Content
SC:	Swelling coefficient
TTA:	Total titratable acidity
USA:	United States of America
WHO:	World Health organization
YRR:	Yield reduction rates
YSI:	Yield Stability Index

GENERAL ABSTRACT

Pigeon pea (*Cajanus Cajan*) is an important food security crop grown in the marginal Arid and semi-arid regions of Kenya. Its production and productivity are limited due to moisture stress and poor genotype adaptability to different Agro-ecological zones. The objective of this study was to identify stable, adapted genotypes to different agro-ecological zones and post-harvest management options.

Yield stability and adaptability of green vegetable pigeon pea genotypes, ICEAP 00557, ICEAP 00554, KAT 60/8, KIONZA (Local) and MZ 2/9 was evaluated in a Randomized Complete Block design (RCBD), replicated three times during all seasons. Planting was done at Katumani and Kambi ya Mawe during the main seasons (October 2016) while at Kabete and Kiboko, the genotypes were planted in two seasons, March 2016 and October 2016. Therefore, the genotypes were tested for adaptability and stability in six seasons in total . Combined analysis of variance (ANOVA) revealed highly significant ($P<0.01$) variations in GxE interactions for yield (Kg/ha), 100 Seed mass (g/100 seed), days to flower and maturity ($P<0.05$). AMMI model for grain yield IPCAs, explained 96.5% of the total yield variation. The cultivar MZ 2/9 and KAT 60/8 recorded a lower IPCA1, indicating a wider adaptation and stability. Kambi ya Mawe, Katumani and Kiboko (October planting) had higher IPCA1, indicating greatest interactive environments for adapted genotypes.

The response of green vegetable pigeon pea genotypes ICEAP 00554, ICEAP 00557, MZ 2/9 and KAT 60/8 were evaluated at Kiboko in 2017-18 under open field and at Kabete in 2018-2019 under high tunnel to determine their response to intermittent and terminal moisture stress at vegetative, flowering, and podding phases of growth. There was significant different ($P\leq0.001$) among the moisture regimes for seed weight, number of days to flower, number of pods and seed per pod at both locations. Combined analysis of variance revealed a significant ($P\leq0.01$) interaction between moisture regimes and genotypes for seed weight, days to flower under open field and 100 seed mass, days to flower, harvest index, number of pods and plant height under high tunnel ($P\leq0.001$). Moisture stress at flowering reduced yields, pods per plant and secondary branches under high tunnel by 77%, 72% and 60 % respectively, while under open field, it reduced yield, pod length and harvest index by 43%, 14% and 10%.

The effect of different pre-treatments and storage duration on green vegetable pigeon peas was determined. The pre-treatments included five treatments: Threshed fresh sample stored in a deep freezer at $^{-}18^{0}$C; Threshed fresh sample, dehydrated then stored under room conditions; Threshed fresh sample, blanched then stored in a deep freezer at $^{-}18^{0}$C; Threshed fresh sample, blanched, dehydrated then stores under room condition; and peas stored in pods. Iron (Fe), Zinc (Zn), protein, total sugars, vitamin A and vitamin C concentration was determined before and after the pre-treatment, and subsequently at 0-, 14-, 22- and 60-days of storage. There was significant difference among the pre-treatments ($P<0.001$) and duration of storage ($P<0.001$) for all the nutrients. Significant interaction between pre-treatment and storage duration was also noted ($P<0.001$) among all nutrients profiled. Blanching led to reduction in nutrient concentration, with significant reduction of 43% observed in vitamin C. Blanching of fresh vegetable pigeon peas and keeping them in a deep freezer recorded a mean nutrient loss of 7.7%, after 60 days of storage. Blanching of fresh peas and subsequent dehydration pre-treatment recorded the lowest mean nutrient reduction of 7.4% after 60 days of storage.

Local consumer acceptance for processed and stored green vegetable after 22 days was determined by a team of semi-trained panellists based on 7 – point hedonic scale. There was significant difference ($P<0.05$) among the panelists on appearance, color, odor/smell and seed tenderness, but no significant difference was noted on taste and overall preference ($P>0.05$). The average sensory score among the panelists on physical appearance of samples stored in pods was 6.3, indicating high acceptability, while blanched samples had an average of 6.0 rating on a 7-point hedonic scale. The podded, blanched + oven dried recorded an average of 5.6, 6.6, and 6.1 scores, respectively on seed tenderness.

Future research opportunities need to promote the stable and moisture stress genotypes (MZ 2/9, ICEAP 00557 and KAT 60/8) through participatory on-farm demonstrations for adoption. Development of blanching and dehydration protocol and capacity development of the rural and urban consumers will improve the shelf life, consumer preference and keeping quality of green vegetable pigeon peas for improved livelihoods.

Key words: *Moisture stress, Stability, Processing, Drought-tolerance, Consumer preference, pre-treatment and livelihoods.*

CHAPTER ONE: INTRODUCTION

1.1 Background information

Pigeon pea is the third most important legume in Kenya, in terms of area under cultivation, after dry beans (*Phaseolus vulgaries L*) and cowpea (*Vigna unguiculata L.*) (Simtowe *et al.*, 2016). Production is mainly concentrated in Eastern region of Kenya with Kitui, Makueni and Machakos counties (Wambua *et al.*, 2017; Cheboi *et al.*, 2016), contributing 98% of the total production. with minimal production in the Rift (0.8%,) Central region contributing (0.3%) and Coastal region, (0.2%) of the total country production. Omoyo *et al*. (2015) mapped out 24 counties in Kenya as having potential for pigeon pea production, with Mbaazi 1 (ICPL87091), KAT 60/8, and Mbaazi 2 (ICEAP 0040) being the widely grown non-traditional genotypes (Pal *et al*., 2016). pigeon pea serves a variety of purposes, such as food, forage, feed, and meal for animals, piggery and fishery, fuel wood, green manure, barrier crop, rearing of lac insects, and roof thatches (Ohizua et al., 2017; Wangari et al., 2020). The green leaves from plants are also used as animal fodder (Jeevarathinam and Chelladurai, 2020 and Zavinon *et al.*, 2018).

Traditionally, pigeon peas are harvested in the Eastern region of Kenya, when they are immature at green stage of development (Ojwang et al 2016a). Green vegetable pigeon peas fetch better prices, are tasty, palatable, and nutritious, compared to the grain type. Upadhyaya et al., (2013) noted that majority of the consumers prefer peas with good sensory characteristics and longer pods, which is related to increased number of seed within the pods and for ease of threshing. Green coloured pods have a shelf life of 3–5 days post-harvest and can be threshed with ease, compared to the striped or mosaic-coloured pods, which have a short shelf life of 1–2 days post-harvest (Saxena and Mula, 2010).

The crop is drought tolerant legume produced in the dry land's areas of Kenya (Cheboi *et al.*, 2016). The crop has inherent characteristics that makes it perform better under low moisture regimes (Odeny, 2007), due to longer tap roots, which grows faster in the initial phase of vegetative growth, increasing its capacity to survive in low moisture levels and able to produce reasonable yields (Sarkar et al 2018). It provides multiple benefits and is critical food and nutrition security crop for the livelihoods of the population living in marginal, low rainfall zones which constitute 80% of Kenya's land mass (Aruna et al, 2018). The crop products can be consumed as both dry and green peas with potential to generate income through selling in the local and export market (Simtowe et al, 2016). Majority of households are currently using the pods and foliage as animal feeds, while some also use them as source of green manure. Its woody stems are used as fuel and construction material (Kimaro *et al.*, 2020). The crop roots are known to fix nitrogen (Ndimbo et al 2015) and help release the soil bound phosphorus and nitrogen, making them available in soils which are inherently deficit in phosphorus and nitrogen, a characteristic of dry land soils (Varshney et al, 2017).

1.2 Statement of the research problem

Green vegetable pigeon pea has potential in contributing to building resilience among the smallholder farmers in the ASALs against climate change (Géofroy *et al.*, 2020) due to its tolerance to low moisture regimes (Kwena *et al.,* 2015) and multiple harvests in a year. However, recent change in climate, leading to terminal, intermittent and random drought has exposed pigeon peas to extreme weather, associated with increased temperatures and increased moisture stress, causing considerable pigeon pea yield reduction. It is projected that if this situation continues, pigeon peas production and productivity is expected to reduce by about 60%, by 2050 (Kwena, 2015). Planting of poorly adapted genotypes, unreliable rainfall patterns, increase in temperatures, poor post-harvest management and increased pest and disease incidences (Kwena, 2015), has led to significant yield reduction (Cheboi, *et al.,* 2016). On-farm productivity is still below a ton per hectare, compared to research-based yields are estimated at about five tons per heactare (Wambua, 2021). In the recent past, significant investments in pigeon pea research has been put on improvement of grain dry pigeon peas compared to the green vegetable pea type (Dansi *et al*, 2012). There is dearth of research work associated with green vegetable pigeon pea on improved production systems, value addition and post-harvest practices. Detailed literature review on adaptability and stability of specifically green vegetable pigeon pea genotypes produced little information, leading to no policy framework tailored towards green vegetable pigeon pea production in Kenya, due to lack of empirical research evidence compared to the dry grain type. Given its perishability, the greatest challenge among the households producing and marketing green vegetable pigeon peas is to preserve the meagre harvest that can feed them sustainably throughout the year during the seasons of scarcity. Identification of simple and sustainable costeffective post-harvest management technologies that has potential to improve the shelf life of green pigeon peas acceptable to consumers, while at the same time maintain the nutrient content during storage will be important in improving the livelihoods of majority of the population, residing in the Eastern region of Kenya. In the face of climate change, and contribution to the body of green vegetable pigeon pea research, this study has invested in identification and evaluation of potential green vegetable Pigeon pea genotypes that can yield better, under actual moisture stress, adapted and stable to diverse environments and planting seasons, while maintaining their nutrition status, during post-harvest management and storage, preferred by local consumers.

1.3 Justification of the research

Green vegetable pigeon pea is consumed by over 80% of the households in the Eastern region of Kenya. In the past two decades, concerted efforts through research institutions have been able to identify high yielding and adapted pigeon pea genotypes for both green vegetable and dry grain production in the Eastern region of Kenya (Ojwang *et al* 2016a). They further evaluated these genotypes for specific green vegetable pigeon pea production, under rainfed and supplementary irrigation, accepted and preferred by local consumers in Makueni County. Market analysis by Simtowe *et al*., (2016) indicated high demand both in the rural, urban and export markets. Due to its inherent perishability, green vegetable pigeon peas are sold immediately after harvest, attracting lower prices due to glut in the market, due to lack of post-harvest and value addition options for deferred sale. Post-harvest practices have potential to increase the shelf life, enabling the producers to sale at a premium price and use for household consumption during the months of scarcity. Majority of the households especially in the rural areas store the harvested peas in pods for 3-5 days before consumption or delivery to the market, as part of post-harvest management. In the urban areas due access to power supply, majority of green vegetable pigeon pea consumers have invested in cold chains such as refrigerators to keep the product longer. There is therefore need for a better understanding of the adaptability of green vegetable pigeon pea genotypes, their response to terminal and intermittent drought and potential post-harvest options for increased shelf life, with potential to improved livelihoods in the Eastern region of Kenya.

1.4 Research objectives

1.4.1 Broad research objective

The broad objective of this study was to identify stable green vegetable pigeon pea genotypes, adapted to wider production zones in Kenya and post-harvest management options that will contribute towards improved incomes, nutrition among the households in the Eastern region of Kenya.

1.4.2 Specific objectives

(i) To determine the adaptability and stability of selected green vegetable pigeon pea genotypes under different seasons within the main agro-ecological zones in Kenya.
(ii) To assess the response of green vegetable pigeon pea genotypes to moisture stress under various environments.
(iii) To assess the influence of processing, storage on chemical characteristics of selected vegetable pigeon pea genotypes in the Eastern region of Kenya.
(iv) To assess the consumer preference and acceptability of processed and stored green vegetable pigeon peas in the Eastern region of Kenya.

1.4.3 Research hypothesis

(i) Vegetable pigeon pea genotypes are unstable and not adapted to different planting seasons within the agro-ecological zones of the Eastern region of Kenya.
(ii) Vegetable pigeon pea genotypes respond differently to moisture stress under under various environments.
(iii) Processing and storage do not influence the shelf-life, physio-chemical characteristics of vegetable pigeon peas.
(iv) Consumer preference and acceptability are not influenced by processed and storage of green vegetable pigeon peas.

CHAPTER TWO: LITERATURE REVIEW

2.1 Origin, taxonomy, and classification

Pigeon pea was introduced into Kenya from Asia during the construction of the railway line in Kenya in the 19th century, from where it moved to East Africa and then to America (Khanum *et al*, 2015). The crop is classified in number of ways based on the growth habit, duration to maturity and stage of harvesting (Latha et al, 2008). Traditionally also, locals have classified pigeon pea types based on growth patterns and number of seeds in a pod. KIONZA for example came from seven seeded podded local genotype, MUKUNE, is a tall, drooping high yielding type, while MAUTA, has fatty (MAUTA) pods. Research institutions have also classified pigeon pea based on growth pattern, such as determinate, characterized by pods clustering on the plant canopy, with plant growth stopping at flowering, making pod production more uniform. The non-determinate types have their pods borne along the branches. Based on duration to maturity, they are categorized as short duration, as they mature within 100 to120 days. Locally, such genotypes are called Kakuvi in local Kikamba dialect, meaning short. Those that mature within 150 to 200 days are medium duration, also called Kati-kati and those that takes 220 days to mature, being long duration (Jones *et al.*,2002) also called Ndaasa or Katoli in local dialect. Majority of the producers have adopted genotypes that matures between 100 - 200 days (Ojwang, et al 2016), harvested while green between the months of March to July, and when they are dry as grains, in the months of August for both household consumption and local markets.

2.2 Global pigeon pea production

Globally, pigeon pea is ranked the fifth as the most important legume crop, after beans, cowpeas, green grams, and soya beans with high production in Asia, East Africa, Central, southern Caribbean, and west indies (Seleman et al, 2016). Globally, in 2021, pigeon pea was grown in 5.6 million hectares, indicating a 13% increase compared to 10 years ago in 2012. Productivity (Kg/ha) has also improved by 22%, from 706 Kg/ha to 862 Kg/ha while production has improved by 39%, from 3.97 tons in 2012 to 5.48 tons in 2021 (FAOSTAT, 2023). In East Africa region, the area under pigeon peas has reduced by 21%, from 775,631 Ha in 2012 to 610,558 Ha in 2021, while yield productivity has improved by 55%, from 816 Kg/ha in 2012 to 1,264 Kg/ha in 2021. There has also been improvement in production over the past 10 years by 22%, from 632,773 tons to 771,727 tons in 2021 (Table 1).

Table 1: Area (ha), Productivity (Kg/ha) and production (tons) of pigeon peas in selected countries in East Africa (2012 -2021)

	Kenya			**Uganda**			**Tanzania**		
Year	**Hectares**	**Kg/ha**	**Tons**	**Hectares**	**Kg/ha**	**Tons**	**Hectares**	**Kg/ha**	**Tons**
2012	276,136	607	167,623	33,000	406	206,057	257,292	801	13,382
2013	256,396	646	165,636	33,459	400	247,387	287,182	861	13,384
2014	276,124	994	274,523	33,483	400	248,000	250,508	990	13,393
2015	143,491	1,500	215,237	33,516	400	261,889	253,086	1,035	13,407
2016	164,668	912	150,216	35,116	372	253,553	252,578	1,004	13,069
2017	144,218	507	73,183	39,449	340	286,905	290,322	988	13,411
2018	108,326	791	85,684	42,184	325	101,422	87,189	1,163	13,720
2019	136,388	789	107,549	50,310	301	90,088	87,425	1,031	15,130
2020	133,525	926	123,627	43,228	391	190,000	179,189	1,060	16,890
2021	126,617	822	104,010	44,394	391	196,382	177,351	1,107	17,346
Change	**-54.15**	**35.34**	**-37.95**	**34.53**	**-3.65**	**-4.70**	**-31.07**	**38.26**	**29.62**

Reference: ***https://www.fao.org/faostat/en/#data****: Sourced on 4th Feb 2023*

In Asia, pigeon pea was grown in 5.67 million ha in 2021 compared to 4.70 Ha in 2012, representing 21% increase over the past 10 years. Productivity (Kg/ha) has tremendously increased in Asia, by 1098%, from 684 Kg/ha to 8,192 Kg/ha in 2021. Production has also improved by 45%, from 3.2 Tons in 2012 to 4.65 tons in 2021. In Kenya, the country reported a decrease in area under pigeon peas, from 276,136 Ha in 2012 to 126,617 in 2021, representing a 54% reduction. Reduction in area under pigeon peas was also reported in Tanzania, by 31% from 257,292 Ha to 177,351 Ha. Uganda reported an increase of 34%, from 33,000 Ha to 44,393 Ha in 2021. Both Kenya and Tanzania reported an increase in productivity (Kg/Ha) by 35% and 38% respectively, while Uganda reported a reduction of 4% (FAOSTAT, 2023).

2.3 Green pigeon pea production and yield variables.

2.3.1 Green vegetable pigeon pea production

Determination of vegetable pigeon pea production and productivity in Kenya is difficult at farm level, as it's mainly eaten at the household. Producers don't keep records of production and therefore, chances of tracking the quantities sold through the markets or consumed has not been successful. In Africa, apart from Kenya, immature green vegetable pigeon peas are consumed in other countries such as Malawi, Zambia, and Tanzania (Ecocrop, 2016). Compared to the dry grain, green, vegetable pigeon peas are more nutritious and fetches better prices. Due to their perishability post threshing, producers prefer selling the green vegetable pigeon pea, in pods especially where they are being transported for longer distance to the market (Shiferaw et al, 2007). In the rural household, majority prefer to keep the peas in pods for not more than five days for consumption and wait to deliver to the market. About 30%–35% of the produced pigeon peas were consumed as cooked green pigeon peas or dry peas (Simtowe et al 2016). While among the urban consumers prefer threshed packed peas, that can be stored in a normal fridge at 4^{o}C or a deep freezer at $^{-}$18^{o}C for longer shelf life, due to connectivity to the electric grid or solar system.

There is scanty information available to support production and productivity potential of available genotypes. Most recent attempt towards achieving this objective was through Ojwan'g et al., (2016), who evaluated potential green vegetable pigeon peas genotypes for irrigated and rain fed production systems. They reported yield productivity of up to of 5,881 Kg per hectares under irrigation at Kiboko and 3,786Kg per hectares under rainfed production systems at Kambi ya Mawe. The yield parity at Kiboko under irrigation and at Kambi Ya Mawe show the potential for higher yields when the production conditions are at optimum, especially when the scanty and poorly distributed rainfall in the region is supplemented with irrigation.

2.3.2 Maturity indices in green vegetable pigeon peas

Traditionally, green vegetable pigeon peas harvesting is mainly done manually by hand picking, enabling selection of mature pods as they mature at different times (Singh et al, 2018). The major challenges when harvesting pigeon peas for the green vegetable peas has been the difference in maturity of the pods even within a branch (Faris and Singh, 1990). This means that selective harvesting must be done to harvest mature pods to achieve higher yields at different time. Mechanical harvesting has also been used especially with short duration genotypes, whose pods mature uniformly and grows at the plant apex, for processing such as for canning and freezing. Generally, whether mechanical or hand picking, the stage at which green vegetable pigeon pea are harvested is important, which determines the yield, quality, and post-harvest management options for the product (Mula and Saxena, 2010). Several methods have been used to determine the time for harvesting green vegetable pigeon peas. Under research situation, determination of the harvesting date based on duration post flowering is usually reliable. This requires investment in time for monitoring and field scouting and better record keeping which is limiting among the local producers. Traditionally, local producers have determined the maturity of the pods based on physical appraisal of the pods and pressing the seeds in the pods to determine (Ojwang, 2015).

2.3.3 Duration to flowering and maturity in vegetable pigeon peas.

Duration to flower and maturity has been used to determine the adaptability of pigeon peas to different agroecological production zones, which vary in temperature, photo periodicity, Soil moisture level that interact with genotypes during growth and development (Kinhoégbè et al, 2020). Locations with lower mean temperatures have been reported to delay flowering and therefore maturity of the early maturing genotypes (Silim and Omanga, 2001), compared to long duration. Early flowering is a major inherent pigeon pea plant characteristic that responds to moisture stress and has been used to identify drought tolerant genotypes, soils, moisture levels has been noted to either accelerate or delay flower initiation or maturity of pigeon peas. In chickpeas, water stress has been reported to accelerate time to maturity compared to those produced under optimal condition (Khoiwal, et al 2017). High moisture levels lengthen flowering and maturity duration, leading to taller plants compared to those planted under low soil moisture level (Ojwang et al 2016a). Early maturity is attributed to hastening phenological phases as a means of drought escape (Jerotich, 2013), as the plants capitalizes on available moisture to accelerate flowering and maturity. Matching green vegetable pigeon pea genotypes to environmental conditions, that will support its growth and development will be important in fitting them to the correct environmental conditions for better adaptability (Muhammad et al 2019).

2.3.4 Seed mass (g/100 seed) in green vegetable pigeon peas.

Pigeon pea seed mass is an important yield determinant, and it varies widely among genotypes and environments. The seed size defines the consumer preference, and the most preferred seed size in in Kenya are large seeded mainly from medium and late maturing genotypes, compared to the Indian market that require 10–14 g/100 seeds (Varshney et al., 2017), mainly for dehulling. The seed weight and size are mostly determined by environmental conditions and genotypes, and interaction between genotype and environment (GIE). Short duration genotypes record lower seed mass due to shorter growth duration compared to longer duration genotypes. Pigeon peas produced at locations that are characterized by cooler temperatures experience longer seed filling phase, therefore, produce heavier seeds (Manyasa *et al.,* 2008) compared to warm locations. Moisture stress has also influenced seed mass in pigeon peas. Crops produced under moisture stress have recorded low seed mass, which has been associated with detrimental effects of drought on CO_2 assimilation, as the stomata closes, to reduce further moisture loss. Closure of stomata inhibits photosynthesis and movement of photosynthate, to the developing seed, due to reduced transpiration, leading to smaller grain size hence lower yields (Saritha *et al.,* 2012). Therefore, water is an important product during photosynthesis, translocation of the photosynthate and movement of nutrients through the xylem from the soil to the developing seed (Gooding *et al.*, 2003). Moisture levels must be at optimal for better seed development, both in numbers and size, for better yields.

2.3.5 Number of seeds per pod and pod length in green vegetable pigeon pea

The population of seed in a pod has been used as an indicator for yielding ability in pigeon peas and relative occurrence of abortion in legumes, which is dependent on the location, moisture level and season of production (Thagana *et al.,* 2013). Asfaw and Blair (2014) also reported a reduction in seed per pod and seed weight of common bean, under terminal water stress. It has also been used by consumers as a preference for green vegetable pigeon pea genotypes, as more peas indicates more consumable peas on the table. Genotypes producing pods with 5-7 seeds has been reported (Saxena *et al.,* 2010) as the most preferred among the producers, as it indicates more peas at harvest. Evaluation of germplasm at world collection of pigeon pea seed bank have observed accessions with pods having 5 to 7 seeds (Upadhyaya et al., 2007), indicating need for exploration of the germplasm for breeding work, for genotypes with more seed per pod. Local genotypes such as KIONZA, which yields more compared with other such as Mukune and Mauta, has seven seed as the name suggest in local dialect. The genotype is therefore produced by majority of local producers due to its high yielding ability. The length and width of the pods have been reported to be related with weight of the seed when produced under rain fed and supplementary irrigation (Ojwang *et al.,* 2016b). Udensi and Ikpeme, (2012) reported that the longer the pod, the more space it creates for the ovule to grow in pigeon peas, providing more space for expansion, leading to bigger and heavier seeds. Shorter pods reduced such space for seed growth in size and numbers, leading to a smaller number of peas, reduced numbers and with low seed weight, and therefore lower yields.

2.3.6 Final plant height in green vegetable pigeon peas.

The final plant height at harvesting is an important trait for productivity determination (Attia, 2013). Taller plants have more branches creating more podding points in plants, leading to better yields. Plant height has also been used by producers to select genotypes with ease of harvesting. Medium duration genotypes have been preferred by majority of women producers due to ease of harvesting, as they don't bend much especially (when harvesting short duration) or straighten their hands much (when harvesting long duration) during harvesting. Women producers in Makueni indicated that shorter genotypes, what they call, 'Kakuvi, make harvesting difficult as one must bend for longer time, while tall ones, 'Katoli', are a challenge in reaching the pods during harvesting. The plant height is mainly influenced by the duration a genotype takes to maturity, location, and condition in which they are growing (Amri et al 2014). Ojwang et al (2016b) observed that plants grown under supplementary irrigation, at Kiboko research station, recorded an enhanced plant height by 34.4cm compared to those produced under moisture stress at Kambi ya Mawe, due to improved soil moisture levels. Similar observation has been made in faba beans by Attia (2013). Intermittent and terminal moisture stress leads to reduction in plant height, caused by decrease in photosynthesis and translocation of photosynthate. Reduction in photosynthesis reduces cell division during cell mitosis, affecting cell elongation, and expansion, leading to reduced plant height under moisture stress (Kalima, 2013). When evaluating crops under water deficit condition, the height of plants can be used as drought tolerance indicators (Amir et al, 2014) in vegetable pigeon peas.

2.3.7 Green vegetable pigeon pea branching.

Branches in pigeon peas provides the podding points and therefore positively associated with higher yields. Genotypes with less branches have fewer podding points, leading to lower yields. This suggests that tall and spreading plant types have an advantage in field peas, as they create more opportunities for pod production, leading to high yields. Ojwang et al (2016a) observed a positive relationship between the number of primary and secondary branches to yield, though not significant. Genetic makeup, duration to maturity and locations have been reported to influence branching in plants (Kimaro *et al.*, 2021). The degree of branching varies genotypically in faba bean germplasm, and its expression is also influenced by growing conditions (Hughes et al, 2020). Khan et al, (2012) observed that the variation in number of branches per plant among the bean varieties can be attributed to the differences in their genetic makeup. Understanding the inheritance of branching could be useful for the development of more competitive genotypes for use as green vegetable production.

2.3.8 Green vegetable pods per plant

Pods in green vegetable pigeon peas has been associated with yield and other yield variables as reported by Ojwang et al (2016a), who recorded a positive relationship between yield, seed mass and number of pods in a plant. This shows the significant importance of pods per plant as a yield determinant in green vegetable pigeon peas. The growing conditions and location have been reported to affect pod production in pigeon peas. Production of pigeon peas under moisture stress has potential to reduce pods population, which may be associated with reduced fertilization, flowering, and pod initiation (Ambachew *et al.,* 2015). Ambachew *et al*., (2015) observed that introduction of intermittent drought at podding phase of development has been associated with reduction in pods numbers by 36%, while introduction at flowering reduced by 72% in beans. Low moisture levels reduced translocation of photosynthate towards the developing flowers, leading to reduced flower population and therefore number of pods developed due to increased cases of flower and pod abortion (Emam et al, 2010), during plant development.

2.4 Climate change in pigeon pea production system

Variability in climate, especially rainfall and temperature are currently influencing year to year crop production, which is likely to alter pigeon peas cropping patterns and yields in the near future (Niang *et al*., 2014). Recent yields evaluations have indicated that the pigeon peas productivity has remained low at farm level at 200 to 500 kg ha ^{1}, far lower than its potential yield of about 5,000 Kg/ha (Ojwang et al 2016a), as result of climate change. Christensen et al (2007) predicted that in Kenya and the rest of East Africa, temperatures and rainfall are expected to increase by about 2°C and 11%, respectively, by 2050 due to climate change. Based on this then, Beebe et al, (2014) have projected that due to these changes, area under beans production will reduce. Thus, if not checked, climate change will undermine agricultural productivity and expose millions of people to hunger and poverty, especially in semi-arid areas where temperatures are already high and rainfall low and unreliable (Ochieng et al, 2016). This will create a dangerous effect on global food security leading to several biotic and abiotic stresses (Admasu et al, 2019). Kwena et al (2020) used Agricultural Production Systems Simulator (APSIM) model to assess the impact of both increase in temperature and rainfall on pigeon pea yield at Katumani research station in Machakos. They observed that pigeon pea production will be negatively affected by climate change going forward due to its susceptibility to high temperatures and water logging, emphasizing the need to development genotypes that are tolerant and matched to the correct ecological condition as part of adaptation to climate change.

2.4.1 Variability in temperature on pigeon peas growth and development

Pigeon peas grows well in an optimal temperature range of 18^{o}C-38^{o}C (Saxena *et al.*, 2010). Ojwang *et al* (2016b) reported that temperature have significant effect on growth and development of vegetable pigeon pea genotypes, with greatest effect being observed at flowering phase. Temperatures ranging 26^{o}C to 36^{o}C have been observed to decrease Soya beans yields due to reduced number of pods, number of seeds in a pod and decreased dry matter partitioning to the developing seeds (Thomas, et al 2004). Change in temperatures has been reported to influence the flowering pattern of pigeon peas (Silim et al, 2007). Slightly cooler average temperatures can significantly delay maturity in short duration genotypes (Silim and Omanga, 2001), and influences duration to flowering, on different maturity groups in Kenya (Silim *et al*. 2006). Manyasa *et al* (2009) reported low mean pods per plant at Kampi ya Mawe (66 pods per plant), which was attributed to high temperatures. High night temperatures decrease crop production by decreasing photosynthetic function, sugar, and starch content (Loka and Oosterhuis, 2010), causing male sterility and low pollen viability (Makelo et al 2013). High temperature also has potential to initiate fewer fruits being set on a plant because of low pollen viability and to some extent reduces amount of pollen produced and their tube growth (Makelo et al 2013), leading to poor or no fertilization.

2.4.2 Variability in photoperiod on pigeon peas growth and development

Pigeon pea is grown in the areas where day length varies from 11 to 14 h and large differences in temperature are experienced, largely due to variations in altitude and latitude (Choudhary *et al*, 2011). Flowering is triggered by short days while long days trigger vegetative growth at the expense of flowering (Silim *et al*., 2006). Silim *et al*, (2007) observed that long duration genotypes were the most sensitive, while short-duration genotype was insensitive and extra short-duration genotype was the least sensitive to photoperiod. This has increased the flexibility of Pigeon pea cultivation and facilitated its use in different cropping systems (Nene, 1991). However, the new genotypes developed are sensitive to temperature and are not adapted to cool production areas (Silim and Omanga, 2001).

2.4.3 Terminal, intermittent drought stress on pigeon peas

Progress in developing drought tolerant grain legume varieties have been slower than in the cereals, with literature pertaining to screening, identification of tolerant genotypes and their utilization for improving tolerance to such abiotic stress, is scanty and also not well documented (Turner *et al*. 2003). Intermittent water stress occurs in crops that are planted during the rainy season and where gaps in rainfall can expose plants to water stress at any time during the cropping cycle (Serraj *et al.* 2005). Pigeon pea requires an optimum rainfall range of 600-1000mm per annum but flowers well even with rainfall of 1500mm to 2000mm per annum (Silim *et al*., 2006). Extreme weather conditions, such as erratic precipitation, have become more common as a result of climate change (U.S. Seasonal Protection Agency. 2016), which can cause drought stress and negatively impact crop production (Ye et al, 2018). Reduction in moisture levels during pigeon pea growth and development has negative impact on vegetative development, flowering, and podding behaviour. Moisture stress induces cell dehydration, which inhibits cell expansion and division, leaf size, stem elongation, root proliferation, disrupted stomatal oscillations, plant water, nutrient uptake, and water-use performance (Kaushal et al 2016). There is a need to find solutions that increase moisture stress tolerance of green vegetable pigeon peas and enable crop productivity to meet food demands even when water is scarce Mancosu, et al (2015).

Studies have shown that reduced rainfall during pod setting and flowering reduces yields in pigeon peas (Chauhan et al, 1992). Ojwang, (2015) observed that improved soil moisture, as a result of supplementary irrigation improved all the characters, except on shelling percent, which recorded a negative seven (-7) percent. Sarintha *et al* (2012) observed that reduced moisture levels at early stages of development, leads to reduced pods per plant, which is a key yield determinant in vegetable pigeon peas, probably due to flower and pod abortion.

In evaluation of extra short duration pigeon peas, Nam *et al* (2001) observed that when plants experience reduced moisture levels at flowering phase of growth, grain yield is reduced by 40-55%, compared to when moisture stress was imposed during pod filling stages of growth. Ojwang et al (2016b) reported yields reduction of 66%, from 5,881Kg per hectares under irrigation at Kiboko to 3,786Kg per hectares under rainfed production systems at Kambi ya Mawe, due to moisture stress. Supplementary irrigation increases plant height, due to prolonging plant growth period, as a result of increased vegetative growth, resulting in production of higher plants (Oweis et al. 2004). Seed yield in chickpeas decreased by 50% when moisture stress was induced at podding and 44% when induced at flowering (Gan *et al* 2004). Rezene (2011) reported that lower yield in small seeded common beans, was associated with moisture stress which reduced the rate of photosynthesis and partitioning of the carbohydrate to the reproductive parts of the plant.

2.4.4 Screening of genotypes for moisture stress tolerance

Yield losses in pigeon peas under moisture stress is a main concern among breeders in the recent past. Previous assessments of genotypes for drought tolerance have been through inducing moisture stress at different growth phases of the crop (Nam *et al*., 2001) followed by use of drought indices to determine the level of tolerance among the genotypes. Assessment of genotypes for drought tolerance has been through inducing moisture stress at different growth phases of the crop development (Nam *et al*., 2001) followed by use of drought indices to determine the level of tolerance among the genotypes. Yield stability indices such as Drought Susceptibility Index (DSI) and Yield reduction rates (YRR) proposed by Fischer and Maurer (1978) and Relative water Content (RWC) have been used to determine how much yield has been reduced during crop growth under moisture stress. Parameshwarappa, *et al.,* (2008) observed that the minimum yield reduction in chickpea genotypes was shown among genotypes which had the highest Drought tolerance efficiency (DTE) and the lowest DSI (Ouji et al 2016). In spring wheat cultivars, Guttieri *et al.,* (2001) suggested that DSI more than 1 (one), indicating above-average susceptibility and DSI less than 1 (one), indicated below-average susceptibility to drought stress. Ghanbari*et al.,* (2013) reported that RWC was an integrative indicator of internal plant water status under drought conditions and that it has successfully been used to identify drought-resistant cultivars of common bean.

2.5 Pigeon pea genotype adaptability and yield stability

2.5.1 Genotype x environment interaction (GEI)

Varieties evaluated in different locations do have fluctuations in yield due to response to environmental factors such as soil fertility and presence biotic and abiotic environmental stresses (Mitrovic, et al 2012). These fluctuations are often referred as genotype × environment interaction (GIE). A genotype or variety is more adaptive or stable if it has high mean yield but a low degree of fluctuation in yielding ability when grown over diverse environments (Kimaro *et al.*, 2021). Chand *et al* (2014) reported that pigeon pea hybrids grain yield performance was highly influenced by environmental effect, followed by the magnitude of GEI and genotypes contributed the least effect. Kamau, (2013) in a different study on Utilization of Multi-Locational pigeon pea Performance Data for Determination of Stability, observed that there was genotype by environmental interaction for the medium duration pigeon pea varieties in the trial sites selected. Results of evaluation by Khaki, (2014) on Malawi accessions across two locations showed statistical differences between locations and that the effects of genotypes by environment interactions, were highly significant on grain yield, 100 seed weight, pods per plant, days to flowering, pod maturity and plant height. Previous reports on common bean in Ethiopia also indicated that environmental effects accounted for the largest part of the total variation (Zeleke et al., 2016).

2.5.2 AMMI for stability analysis

Additive Main Effects and Multiplicative Interaction (AMMI) analysis is one of the popular parametric but multivariate methods to predict adaptation and stability of cultivars (Mortazavian *et al*, 2014). The model is frequently applied in yield trials in agricultural research when both main effects and interaction are important (Kamau, 2013). This procedure has been shown to increase estimation accuracy, since it fits additive main effects for genotypes and environment by an ordinary analysis of variance (ANOVA) procedure. It has led to more insight in the complicated patterns of genotypic responses to the environment (Gauch, 2006). AMMI stability value (ASV) and Yield Stability Index (YSI) have been used, as reported by Purchase *et al.,* (2000), who developed the AMMI stability value (ASV) based on the AMMI model's IPCA1 and IPCA2 (Interaction principal components axis 1 and 2, respectively) scores for each genotype. The larger the absolute value of IPCA, the greater the adaptability of a specific variety for a certain environment. Conversely, lower ASV values indicate greater stability in different environments, while lower YSI indicates high yields and stable (Farshadfar, 2011).

2.5.3 Stability analysis based on GGE-Biplot

Biplots are graphs in which aspects of genotypes and environments together are plotted on the same axes so that interrelationships can be visualized (Kulsum *et al* 2013). The model provides breeders a more complete and visual evaluation of all aspects of the data by creating a biplot that simultaneously represents mean performance and stability, as well as identifying mega-environments. (Mare *et al.,*2017). Genotype main effect (G) plus GEI interaction (GGE) biplot model has been used to identify genotypes performance at different environments (which-won-where pattern) which has led to identification of adapted and stable genotypes and discriminating and representative test environments (Yan *et al.,* 2001). It is also considered to be an effective tool to diagnose GEI patterns graphically (Mukherjee et al., 2013).

2.6 Pigeon pea nutrition characteristics

The pigeon pea seed contain vitamins and minerals, which are micronutrients because the body needs these components in small amounts (Gharibzahedi and Jafari, 2017). The nutrition profile of pigeon peas has been influenced by difference in genotypes, duration to maturity, post-harvest management practices including storage and handling (Kinyuru, et al 2011). Singh et al., (2018) has reported presence of genetic diversity for nutritional traits in immature pods of pigeon pea genotypes. The nutrition profile of green vegetable pigeon peas has been noted to be richer than that of ordinary peas (Aruna et al 2018). Based on the trace element profile in both products, the green vegetable peas were superior in phosphorus by 28 percent, potassium by 17percent, zinc by 48 percent, copper by 21 percent, and iron by 15 percent than dhal (Singh et al., 1984).

Vegetable pigeon pea therefore complements the nutritional profile of cereals, and is a good source of protein, vitamins (A, C, B complex) and minerals (Ca, Fe, Zn, Cu) (Njung'e et al., 2016). 100 grams of immature seed of pigeon peas contains 39 mg/100g of vitamin C, supplying an equivalent of 65 percent of daily vitamin C requirement in Human being. Vitamin C also known as ascorbic acid facilitates the absorption of iron and calcium from the gastrointestinal tract, involved in fats and amino acid metabolisms, increases resistance to infection and contributes to brain functioning

(Michels, 2011). 100 grams of green pigeon peas contains 67 IU of Vitamin A, providing 2% of the total daily recommended Vitamin A intake in human being. Protein is important in human body as the building material for all body parts, such as muscle, brain, blood, skin, hair, nails, bones, and body fluids. It is essential for growth, repair of worn-out tissues, replacement of used-up blood and resistance against infections. The variability for protein content in pigeon peas has been, reported in previous studies, varied from 16.7 to 26.8% (Choi et al., 2020), whereas, in wild species, the range is from 16.3 to 33.8% (Upadhyaya et al., 2013). Wang and Daun (2006) also noted differences in crude protein due to variety in lentils.

Among the vitamins, vitamin C retention is an important indicator of vegetables qualitative changes during processing, storage, and preparation for consumption (Slupski, 2011). Vitamin C concentration and retention are mainly influenced by high temperature and oxygen concentration, therefore any change in concentration is an indicator for either improvement or reduction in product quality. Antinutritional factors in pigeon peas have tendency of masking its nutritive elements, inhibiting their availability and uptake by the human body (Nix *et al*., 2015). Some of the anti- nutritional factors such as Phyto-lectins are heat sensitive and are destroyed during cooking. The antinutritional factors are also influenced by the colour of the seed coat. The white seeded pigeon pea cultivars are believed to contain relatively less amounts of polyphenols, compared to the dark seeded types. Such cultivars, white seeded, are preferred in many countries where de-hulling facilities are not available and whole seeds are consumed.

2.6.1. Influence of freezing on green vegetable pigeon pea quality

Vegetable pigeon peas are highly perishable and thus have an inherently short shelf life (Babatola and Lawal, 2008). They remain in stable condition at O^{0}C and 95 to 100 percent Relative Humidity (RH) for 7-9 days (Babatola and Lawal, 2008). Low temperature storage such as freezing, at -18^{0}C, has been applied in several products for preservation and has potential in improving nutrient retention and extended shelf-life. Czaikosk *et al*. (2012) indicated that vegetable soybean quality might change during cold storage, such as loss of moisture, vitamin C, minerals, sugar, amino acid, and chlorophyll degradation. Refrigerated storage resulted in very little changes in reduced ascorbic acid, soluble sugars, and moisture contents of the vegetable. Onyango and Silim, (2000) reported that storage of shelled pigeon peas at ambient temperatures (21±3^{o}C) led to the highest losses of reduced ascorbic acid, moisture, and soluble sugars, but increased total titratable acidity (TTA). She concluded that low temperature storage (4 ± 1^{o}C and blanching before freezing) minimizes loss of nutrients such as sugars and protein and more loss of TTA hence may be adopted during postharvest handling of vegetable pigeon peas.

Freezing of foods enables the products to be available all year round and improves the transport efficiency through establishment of functional cold chain, by minimizing damage and retention of quality. Though freezing maintains the product freshness and enhance nutrient retention, some products have been reported to development un-wanted qualities that most consumers are not comfortable with. The practice has been characterized by loss of important nutrients such as vitamins, moisture, chlorophyll (Martins and Silva, 2002). Onyango and Silim, (2000), in evaluation of early maturing pigeon peas that takes 2-3 months to mature at Kiboko, reported that storage of shelled pigeon peas at about 4^{0}C resulted in reduction in vitamin C, soluble sugars concentration, seed mass and moisture.

2.6.2 Influence of blanching on green vegetable pigeon peas quality

During storage, certain chemical reactions continue because of enzymatic reactions, after harvesting (Schafer, 2014). The intensity and speed of these chemical reactions depends on the mode, duration of storage and post-harvest treatments of the products before storage. Practices such as blanching has been known to reduce such chemical reactions in stored products (Njoroge et al 2015). Bahceci et al., (2005), reported that when green bean was blanched, the half-life of vitamin C was increased. Xu et al., (2012) reported that blanching of soya bean reduces the enzymatic activity by 98 percent when done for 2.5 min, while Song et al., (2003) observed that blanching of vegetable soybeans, at a higher temperature for a short period of time (100°C for 1min), led to prevention of greenness/chlorophyll losses, reduced seed hardness, lessened leaching of sugars and water-soluble vitamins compared with other temperature-time combinations. Onyango and Silim, (2000) suggested that blanching and keeping the peas at lower temperatures of about 4^{o}C improves nutrient retention and proposed its promotion as a post-harvest management and handling option for vegetable pigeon pea. Blanching has potential in improving nutrient retention during storage.

2.6.3 Influence of dehydration on green vegetable pigeon pea quality

Traditionally, households in the rural areas have capitalized on solar energy in drying their food products. Spreading of the food crops, especially cereals and legumes on the open sun for dehydration, before storage (Ismail et al., 2014) has been adopted by majority of the households. Though it has been successful for many years, the greatest challenge with this method has been contamination, un-equal drying, and inability to monitor moisture content during drying. This has potential in reducing quality and uneven drying, which can be a problem during storage. Seed size has also been mentioned as a factor that determines the drying efficiency, with heavy seeded genotypes takes more time to attain the required moisture levels compared to smaller seeded genotypes. Yadav *et al*., (2018) noted that seed weight and hydration capacity of legumes are linked to the cooking process (Yadav *et al*., 2018). Moussou *et al*., (2019) noted that legumes with a higher hydration capacity require less cooking time, affecting consumer preference for the seeds. The introduction of solar drying has tried to solve some of these challenges, with the product being free from microbial proliferation, leading to enhanced of quality (FAO, 2004). Solar drying has ability to enhance more nutrient retention and improve the mineral concentration of the final product (Vega-G´alvez et al 2008). Comparison of solar and sun-dried vegetable product indicated high protein and mineral concentration in the former (Ukegbu and Okereke, 2013), because of loss of moisture which in turn has an influence on dry matter.

2.7 Application of sensory evaluation in consumer preference

In the past, selection for most adaptable and preferred genotypes by consumers relied on the physical characteristics of the seed to assess its nutritive value. Such visual appraisal does not always provide information regarding the cooking quality, which is key to consumer selection (Fasoyiro et al 2019). Consumer sensory evaluation is a process for evaluating personal opinions of a particular product in terms of specific sensory attributes or overall liking (Happiness, et al, 2011). Therefore, sensory factors remain very important for consumer acceptance and uptake of these novel products (Cardello et al., 2022). Several studies such as Mkanda (2007) on common beans, Yeung (2007) on cowpeas and Ojwang, (2015) on green vegetable pigeon peas, have employed this method to evaluate leguminous products. Human beings have been used to interpret the sensory characteristics of food, providing real cases on how consumers react to different food products. They provide better analytic reports compared to instruments (Lawless and Heymann, 2010). Against this, the use of human being has potential challenges of its own. Their ability to choose food is influenced by other factors, which may be interrelated (Prescott, 2002). These factors include convenience, price, production technology, personal health, branding, culture, and societal issues. Culture provides the strongest determinant, which are reflected in dietary histories (Rozin, 2000).

2.7.1 Physical appearance of green vegetable products

Preference among consumers for green vegetable pigeon peas has been based on seed and pod colour and easiness of threshing of the green pods, majorly informed by visual appraisal. Visual appearance, in terms of size and colour of a product can influence consumer product choice. Large seeded creamy coloured seeds have been reported to be preferred by consumers (Lartha et al., 2008). Ability and easiness to thresh the pods has been reported to be a determining factor among different genotypes with varying pod sizes. Fresh seeds harvested from purple pods have been found to have to be of poor organoleptic characteristics compared to pods that are of green colour. Against this, after cooking, there is no noticeable difference between peas from purple compared to the green types. Ojwang *et al.,* (2016a) observed that consumers and farmers did not prefer vegetable pigeon pea with dark-coloured seeds, which have been suspected to have high content of phenolic compounds on their seed coat. Local genotypes are white or cream in colour, and therefore any colour apart from these, may not be popular with the local consumers.

2.7.2 Odor, taste, and mouth feel

The flavour of food has three components- odor, taste and a composite of sensation known as mouth feel. A food substance which produces odor must be volatile and the molecules of the substance must encounter the receptors in the epithelium of the olfactory organ. The volatility of aromas is related to the temperature of the food. High temperatures tend to volatilize aromatic compounds, making them quite apparent for judging. Cool or cold temperatures inhibit volatilization. Taste sensation which the taste buds register is categorized as sweet, salty, sour, or bitter. Mkanda, (2007) reported that smell is one of the main determinants among the consumers on acceptance of food before they are eaten.

CHAPTER THREE: ADAPTABILITY AND STABILITY OF SELECTED GREEN VEGETABLE PIGEON PEA GENOTYPES UNDER DIFFERENT PLANTING SEASONS

ABSTRACT

Pigeon peas is an important crop in the arid and semi-arid lands of Kenya, as source of food and incomes. The crop is exposed to several biotic and abiotic challenges during growth and development, that affects its adaptability and stability for optimum yield performance. This study determined the adaptability and stability of selected green vegetable pigeon pea genotypes to different planting seasons within the main agro-ecological zones in Kenya. Five (5) green vegetable pigeon peas genotypes; MZ 2/9, ICEAP 00554, ICEAP 00557, KAT 60/8 and KIONZA as the control genotype were evaluated in six seasons, Katumani (October), Kambi ya Mawe (October), Kiboko (March), Kiboko (October) and Kabete (March) and Kabete (October) . Combined analysis of variance for the six seasons revealed highly significant ($P<0.01$) variations in genotype and season (GIS) interactions for yield (Kg/ha), 100 Seed mass (g/100 seed), days to flower and maturity were significant ($P<0.05$). Similarly, pods per plant, number of racemes per plant, secondary branches per plant and plant height, differed significantly ($P<0.01$), indicating difference in response among genotypes to different seasons. The cultivars KIONZA and MZ 2/9 and KAT 60/8 had significantly ($P<0.05$) greater yield of 878.5 and 1,349 Kg/ha) respectively. AMMI model for grain yield IPCAs, explained 96.5% of the total yield variation. The cultivar MZ 2/9 and KAT 60/8 recorded a lower IPCA1, indicating a wider adaptation and stability. Planting of pigeon peas at Kambi ya Mawe (October), Katumani (October) and Kiboko (October) produced a higher IPCA1, indicating greatest interactive environments for the adapted genotypes. This study recommends Kambi ya Mawe (October) as the most ideal season for evaluating green vegetable pigeon pea genotypes, while KIONZA as the most ideal genotype for yield performance evaluation, followed by MZ 2/9 and KAT 60/8 cultivars. Promotion of these genotypes through on farm demonstrations will increase adoption with potential to improve the livelihood of pigeon peas producing household.

Key words: *multi-environmental trial, Additive main effects, and multiplicative interactions (AMMI), Principal component analysis (PCA), GGE biplot, Kenya*

3.1 Introduction

Pigeon pea is the third most important legume in Kenya, in terms of area under cultivation, after dry beans (*Phaseolus vulgaries L*) and cowpea (*Vigna unguiculata L.*) (Lartha et al 2008). Due to its nutritious content, pigeon pea is often used to supplement cereal-based diets and consequently, used extensively by many smallholder farmers in Kenya. There is also an increasing market potential and demand for the vegetable pigeon peas in the region given its potential for household incomes and food security (Shiferaw *et al.*, 2008). The crop's tolerance to both biotic and abiotic stress makes it adaptable to semi-arid areas that are perennially water stressed, characterized by high temperatures and poor management systems. Among stresses, moisture stress is common because pigeon pea is grown as a rain-fed crop (Chaudhary *et al*. 2011). Despite its importance in improving nutrition and food security, pigeon pea productivity has remained low, due to poor management practices, inadequate genotype adaptation (Cheboi *et al.*, 2016), biotic and abiotic constraints. Karanja et al (2019) has also confirmed that low productivity of the crop has been its major drawback in Kenya.

Much research work has focused on dry pigeon peas (Turner *et al.*, 2003), with vegetable pigeon pea remaining largely under researched even though it has immense potential for the semi-arid regions of Eastern Kenya (Saxena *et al.*, 2010). The mean yield potential of pigeon pea in Kenya ranges between 0.40 to 0.70 t/ha; (Wambua, 2021). this is relatively low compared to the yields produced in India (the largest producer), that range between 1.5 and 2.5 t/ha (Hluyako *et al.*, 2017). The greatest challenge in pigeon pea production system has been inability to fit genotypes to the right agroecological zones in Kenya, leading to lack of stability and adaptability. Understanding the adaptation is critical to performance improvement and cultivar deployment in diverse cropping systems (Lule *et al* 2014), which requires understanding of the effect of genotypes and their interaction with the environment to a particular location (Arshadi et al, 2018). Previous research in determining stability and adaptability has relied on yield data to identify genotypes that are stable to different environmental conditions.

There is need to estimate the environmental adaptability during genotype selection process (Mohammadi and Amri, 2009), apart from only yield. Several methods have been used by different researchers to undertake stability analysis and identification of crop cultivars with stable performance and positive response to diverse environmental conditions. These include Additive main effects and multiplicative interactions (AMMI) analysis. AMMI stability values (ASV) and yield stability values (YSV) which are based on the principal component axis (PCA) scores (Mulema *et al*. 2014). Genotype plus genotype by environment (GGE biplot) analysis have also been used to extensively explore multi-environment trials (Hugo and Abay, 2013), based on assessment of GxE interaction (GEI) pattern. The GGE biplot can be useful tool to display the data pattern, high-yield, and stable cultivars (Yan *et al.,* 2001). Stability of various crops have been studied by applying AMMI and GGE biplots successfully in soybean (*Glycine max* L. Meril) (Ikeugo and Nwofia, 2013), sweet potatoes (*Ipomoea batatas*) (Moussa, *et al.,* 2011), finger millet (*Eleusine coracana*) (Lule *et al.,* 2014), grain sorghum (Patil *et al.,* 2007) and Gasura et al (2015) in sorghum.

Vegetable pigeon pea genotypes with potential for high yield under irrigation and rainfed and with good acceptance by consumers have been identified (Ojwang *et al.,* 2016a). However, their adaptation and stability across Agro-ecological zones and intensive production zones in Kenya are not adequately quantified. This study was therefore conducted at six environments in Kenya: Katumani (October planting), Kambi ya Mawe (October planting), Kiboko (May and October planting) and Kabete (May planting) to evaluate the stability and adaptability of green vegetable pigeon peas genotypes; MZ 2/9, ICEAP 00554, ICEAP 00557, KAT 60/8 and KIONZA for production under varying environmental conditions.

3.2 Materials and methods

3.2.1 Description of the study location

The field experimentation to determine the adaptability and stability of the selected genotypes was carried out at Katumani (October), Kambi ya Mawe (October), Kiboko (March), Kiboko (October) and Kabete (March) and Kabete (October), between 2016 and 2018. In May 2016, planting was done at Kabete and Kiboko under supplementary irrigation. These months are usually off-seasons at Kambi ya Mawe and Katumani, which relies purely on rainfed. In this study, therefore, seasons have been referred to as environments.

Kiboko Research Station is 975m above sea level (m.a.s.l), under agroecological zone V (Michieka and van der Pouw 1977). Kambi ya Mawe is at elevation of 1,250 m.a.s.l, while Katumani is in the Upper Middle Zone IV agroecological zone (AEZ) at an altitude of 1,600m. Kabete Field station is in agroecological zone II at 1,850 m.a.s.l (Table 2). The Monthly rainfall (mm) and temperature (°C) were recorded at all the locations where the research was conducted. Soil Samples were collected from all locations before land preparation was done, for a complete analysis to determine the mineral profile, the soil acidity/alkalinity and carbon content.

Table 2: Description of the experimentation location

Agro-zones	Altitude (M)	Latitude	Longitude	Rain (MM)	Mean Temp (^{o}C)	Location (County)
Katumani	1,600	1^{o}35’S	37^{o}14’E	717	19.6	Machakos
Kambi Ya Mawe	1,250	1^{o}57'S	37^{o}40'E	550	22.0	Makueni
Kabete	1,850	1^{o}15'S	36^{o}44'E	1100	20.0	Kiambu
Kiboko	975	2^{o}10'S	34^{o}40'E	561	24.0	Makueni

3.2.2 Genetic materials

The study evaluated five (5) Green vegetable pigeon peas genotypes coded as ICEAP (International Crops Research Institute for the semi-arid tropics East Africa pigeon pea program) 00557, ICEAP 00554, KAT (Katumani) 60/8, KIONZA (a local Kamba name indicating pods with seven (7) seeds and MZ (Mozambique) 2/9. The genotypes were previously selected under rainfed and supplementary irrigation (Ojwang et al 2016a), for better yields and preferred by consumers. Their adaptability and stability across different planting seasons within the main agroecological zones for pigeon peas production had not been documented.

ICEAP 00557 and ICEAP 00554 were previously selected from germplasm collected in Nachingewa in Tanzania by International Crops Research Institute for the semi-arid tropics (ICRISAT). They flower within 85-90 days and maturity duration within 150-160 days. The potential yield of immature grain has been recorded at 7-10 tons per hectare. KAT 60/8 was developed by Kenya Agriculture and Livestock research organizations (KALRO) with plant height of 85-130cm, depending on the altitude and season, and has a spreading growth habit. KAT 60/8 flowers within 95-120 days. MZ 2/9 was selected from germplasm collection in Mozambique by ICRISAT in 2007. It flowers early within 70-100 days, with seed mass of 30-40 g/100 seed. KIONZA is an early maturing local genotype, flowering within 120-220 days and grown by majority of pigeon pea producer in the Eastern region of Kenya for both dry and green vegetable peas. In this trial, KIONZA was used as a control or a test cultivar. The seeds planted in the experiments were provided by ICRISAT through their research stations located at Kiboko and Kambi ya Mawe in Makueni County.

3.2.3 Experimental design and field management

The five (5) genotypes were planted in a Randomized Complete Block design (RCBD), replicated three times during all seasons in a field plot of 3.0m x 4.5m, with 1m between plots and 1.5m between blocks keeping inter and intra row spacing of 1.5m and 0.3m, respectively. Each plot had a total of 3 rows, with seeds being drilled at a depth of 10 cm. The rainfall at Kiboko (May and October) and Kabete (May and October) seasons were supplemented with irrigation. Seedlings were thinned to one plant per hill two weeks after germination, to a spacing of 30cm. Fields were kept clean of weeds by hand weeded, whenever there was need. On average, 3-4 weeding's were done during the growth period of the crops during the seasons. The crop was protected from pod borers, pod suckers, and pod flies by the application of broad-spectrum, non-systemic, pyrethroid alpha-cypermethrin and dimethoate, a systemic organophosphate, after field scouting. Cypermethrin was mixed and applied at rate of 1.25 liters ha^{-1} (equivalent to 25 ml in 20 liters of water), while 35 ml of dimethoate, was applied at the rate of 1,000 liters ha^{-1}.

3.2.4 Soil Sampling and analysis

Soils sampling and analysis was undertaken before planting was done during the seasons, using a soil auger, in a zig zag method. This was to determine the nutrient profile of the soil's characteristics of the respective trial seasons. The auguring depth was 15 – 20 cm, with the extracted sample from each spot being put in clean plastic bucket, and thoroughly mixed to form a composite sample, from which 100gms sub-sample was obtained. The composite sample was preserved in sampling bag inside a cool box to prevent dehydration and transported to University of Nairobi Soil laboratory for analysis. Soil pH was determined using pH meter (EYELA model pH M2000) in water 1:2.5 and 0.01 M $CaCl_2$ 1:2.5 suspensions (Okalebo *et al.*, 1993). Exchangeable cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were determined after extraction by ammonium acetate buffered at pH 7.0. K^+ and Na^+ concentrations in soil extracts were read on 410-flame photometer while Ca^{2+} and Mg^{2+} concentrations in soil extracts were read using atomic absorption spectrophotometer (AAS). Available phosphorus in the soil was determined using Bray P1 method

(Gary and John, 2009). Mn was extracted with 0.1M HCl (Okalebo *et al.,* 1993) and its concentration in soil extracts was read on AAS.

3.2.5 Field data collection

The data were collected from five plants in the mid row of the plot of three lines, based on the guideline outlined in International Board for Plant Genetic Resources (IBPGR) and ICRISAT, (1993). Data on nine variables were collected and recorded on pre-determined data collection sheets at all the respective locations.

Days to 50 percent flowering (Days): Data collected based on the number of days from irrigation at Kabete and Kiboko or first rainfall at Kambi ya Mawe and Katumani, to when half of the plants in each plot had at least one flower open.

Days to harvesting (Days): Data collected on the number of days from irrigation or first rainfall to when the pods were ready for harvest. Determination of maturity was done through physical appraisal and pressing of pod for hardness as a sign of maturity, typical of the local farmer's practice. Majority of pigeon pea producers uses this method as a determinant of pod maturity.

Seed per a pod: Five pods were selected from each of the five plants in each plot and seeds within the pods counted. The mean of the five plants were generated per plot.

Seed mass (grams): After harvesting and shelling, 100 whole undamaged seeds were counted and weighed at harvest to give the weight per plot in grams.

Length and Width of Pod (cm): Pod width, (the mid-pod distance in centimetres, from one side to the other), and length, were taken from three pods and five plants per plot at harvesting.

Number of pods per plant at harvest (Number): Pods per plant was determined, by counting the total number of pods, ready for harvesting at every time, harvesting was being done, per plant.

Final plant height (cm): Final plant height was taken, using a 200 cm long graduated ruler. The distance from the tip of the plant in centimetres, to the soil surface, of each of the 5 randomly selected plants were taken.

Shelling Ratio (%): After harvesting, the pods and grains were weighed and shelling percent calculated by dividing threshed seed by the Pod plus grain weight, multiplied by 100.

Number of branches: The number of primary and secondary branches were counted manually at pod harvesting, for five plants in every plot selected randomly.

3.3 Stability and adaptability analysis

3.3.1 Analysis of variance (ANOVA)

Software GenStat (16th ed.; VSN Intl., Hemel Hempstead, UK) was used for data analysis, initially for each location and combined across all the environments, to understand the effect of environment, genotype and interaction of environment and genotype (GIE). Fisher's Least Significant Difference (LSD) was used to separate mean differences among the genotypes at ($p<0.05$).

The model employed in the analysis was: $Yijk = \mu + Gi + Ej + Bk + GEij + \varepsilon ijk$

where:

Yijk is the observed mean of the ith genotype (Gi) in the jth environment (Ej), in the kth block (Bk); μ is the overall mean; Gi is effect of the ith genotype; Ej is effect of the jth environment; Bk is blocking effect of the ith genotype in the jth environment; GEij is the interaction effects of the ith genotype and the jth environment; and εijk is the error term.

3.3.2 AMMI and AMMI stability analysis

The yield stability of genotypes was computed by using the additive main effects and multiplicative interaction (AMMI) model (Gauch and Zobel, 1987) as described in the equation: $Yij = \mu + Gi + Ej + \Sigma k=1\ \lambda k\ \gamma ik\ \alpha jk + \rho ij + \varepsilon ij$

Where:

Yij is the yield of genotype i in environment j; μ grand mean; Gi the genotype mean deviations (the genotype means minus the grand mean); Ej the environment mean deviations; λk the singular value for the PCA axis k; γik and γik αjk are the genotype and environment PCA scores for PCA axis k; K is the number of PCA axes; ρij is the additional residue and εij is the ijth error associated with the model replicated, an error term εijr, which is the difference between the Yij mean and the single observation for replicate r, should be added.

AMMI Stability value (ASV) was determined using the formula developed by Purchase *et al.*, (2000), while Yield stability index (YSI) was computed by summing up the ranks from ASV and mean seed yield, as developed by Farshadfar, (2011).

3.3.3 GGE Biplot analysis

Genotype main effect (G) plus genotype by environment interaction (GE) (GGE) Biplot analysis was undertaken in the Meta-analysis of GenStat 16th Edition (GenStat, 2015), to graphically visualize the relationship between genotypes and environment, determine the 'Which won where' portion and to identify mega environment.

3.4 Results and discussions

3.4.1 Weather and Soil characteristics

During the off-season planting, Kabete (S3) received a higher rainfall amounts of 899.3 mm cumulative over a period of 48 rain days, compared to 179 mm at Kiboko (S4), cumulative over a period of 19 rain days. Rainfall at Kiboko (S4) was supplemented with irrigation, providing an equivalent of 832 mm of water. The temperatures at Kabete (S3) were lower compared, recording an average daily temperature of 18°C, compared to Kiboko (S4), with an average daily temperature of 24°C (Figure 1).

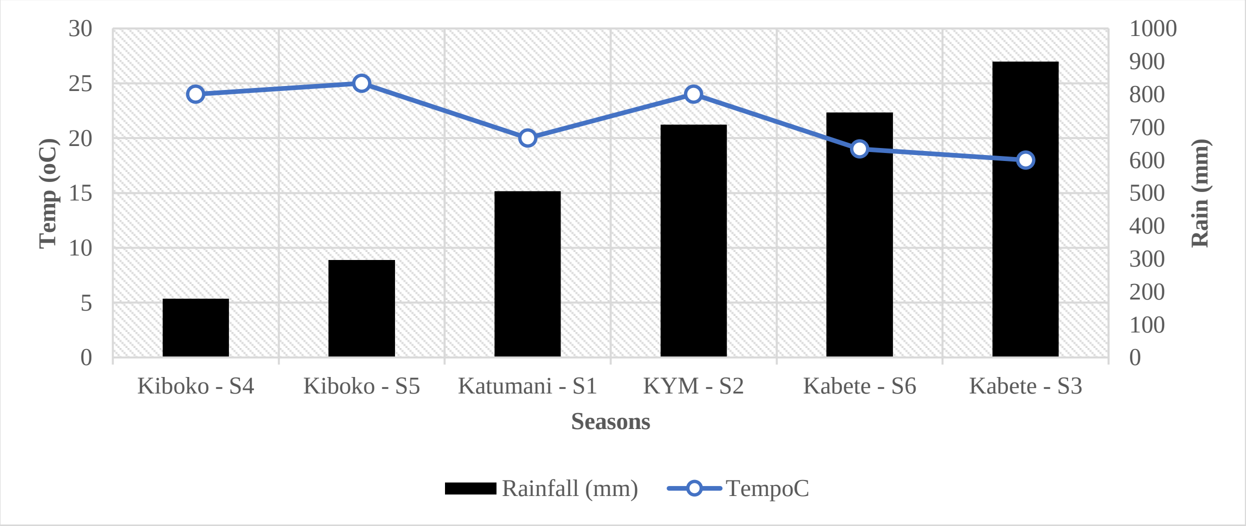


Figure 1: Average daily temperature (°C) and total rainfall (mm) at Kiboko, Kambi ya Mawe and Katumani during different planting seasons. *Kiboko S4 (March season), Kiboko S5 (October season), Katumani S1 (October season), Kambi ya Mawe S2 (October season), Kabete S6 (October season) and Kabete S3 (March season)*

In October 2016, planting was done at all the locations, Kabete (S6), Katumani (S1), Kambi ya Mawe (S2) and Kiboko (S5), with final harvesting being done in August 2017. Kabete (S6) recorded a lower mean temperature of 19^{o}C, followed by Katumani (S1) of 20^{o}C, Kambi ya Mawe (S2) recording 24^{o}C and Kiboko (S5) recording 25^{o}C. Kiboko reported 296 mm, Katumani, 505 mm, Kambi ya Mawe, 708 mm, while Kabete recorded 745 mm.

The study noted that seasons that recorded a lower mean temperature, such as Kabete (S3) and Kabete (S6), also recorded enhanced rainfall amounts of 899 mm and 745 mm respectively, compared to locations such as Kiboko (S5) and Kambi ya Mawe (S2), which recorded a higher average temperature. Similar trend was observed by Nkuna and Odiyo (2016), while analysing long term rainfall and temperature data (1964/65 and 2009/2010) in South Africa, arriving at a conclusion that when average daily temperature decreases, there is observed enhanced rainfall. Variation in temperature and rainfall could therefore impact the growth and development of green vegetable genotypes, influencing the specific genotype adaptability and stability.

3.4.2 Soil characteristics

Soil sampling was only done in March 2016 at Kiboko and Kabete, while at Katumani and Kambi ya Mawe, it was done in the month of October 2016. The analysis indicated that the soil Ph ranged from 5.8 at Kabete, 6.2 at Kiboko and Kambi ya Mawe and 5.9 at Katumani (Table 3).

Table 3: Characteristics of the Katumani, Kambi ya Mawe, Kabete and Kiboko soils during 2016-18 planting season

Site^x	Ph	%N^y	% OC	K (cmol/ kg)	Na (cmol/ kg)	Ca (cmol/ kg)	Mg (cmol /kg)	P (ppm)	Mn (ppm)	Zn (ppm)	Fe (ppm)	Cu (ppm)
KAT	5.9	0.2	0.7	1.2	0.3	4.2	1.8	14.5	75.5	9.2	75.2	1.3
KYM	6.2	0.1	0.8	1.1	0.4	6.9	3.2	12.5	49.6	11.2	56.2	1.1
KAB	5.8	0.3	2.6	1.2	0.5	5.2	2.1	12	57.4	11.5	98.2	5.4
KIB	6.2	0.1	1.0	1.1	0.9	7.0	4.0	65.6	89.5	7.9	59.6	1.1

^{x}***KAT*** *Katumani Research station;* ***KYM*** *Kambi ya Mawe Research Station;* ***KAB*** *Kabete University Field Station;* ***KIB*** *Kiboko Research station.*

^{y}*N-Nitrogen; OC (Organic carbon); Na (Sodium); Ca (Calcium); Mg(Magnesium), P (phosphorus); Mn (Manganese); Zn (Zinc); Fe (Iron); Cu (Cupper).*

On Mineral content, Kiboko reported higher levels of Calcium (7.0 cmol/Kg), Phosphorus (65.6 ppm), Manganese (89.5 ppm) and Sodium (0.9 cmol/Kg), compared to other locations. According to Mallikarjuna *et al.*, (2011), pigeon peas tolerate pH values of 4.5 to 8.0. Generally, the soil characteristics at all the four locations were within the requirement for normal growth, development, and reproduction of pigeon peas.

3.4.2 Genotype performance based on vegetative growth variables.

3.4.2.1 Combined Analysis of Variance among vegetative variables

Combined analysis of variance was done for the individual seasons and later combined for all the seasons as presented in table 4. There was significant influence of the season on all the vegetative variable measures (P≤0.001), while GIS interaction was only significant for duration to flower, duration to maturity and plant height (P≤0.001).

Table 4: Mean squares for combined analysis of variance of vegetative growth variables during 2016-2018 planting Season

Source of variation	d.f.	Duration to 50% flower	Duration to 75% Maturity	Plant Height (CM)	Pod Length (CM)	Pod Width (CM)	Seed per Plant
Replication	2	103.3NS	92.6NS	236.6NS	0.0187NS	0.00259NS	0.2979NS
Genotype (G)	4	10521.08***	12374.7***	9007.9***	2.0029*	0.03607*	1.1932***
Season (S)	5	19618.39***	18277.6***	24060.5***	19.2163***	0.08089***	1.6028***
GIE	20	1141.21***	1260.8***	1709.3***	0.7717NS	0.0115NS	0.1881NS
Residual	58	78.78NS	99.3NS	215NS	0.6211NS	0.011NS	0.1473NS
% Genotype	4	25.1	28.8	17.7	5.1	10.1	18.6
% Season	5	58.5	53.1	59.1	61.8	28.4	31.2
% GIS	20	13.6	14.7	16.8	9.9	16.2	14.6

, **, and * represent significance level at P≤0.05; P≤0.01and P≤0.001 each, NS= non-significant; d.f; Degree of Freedom; CM: Centimeters; %: Percent contribution; GIS: Genotype by season interaction.*

The analysis observed significant difference among the genotypes (P≤0.001) on duration to flower, Days to Maturity, Plant height and seed per plant and (P≤0.05) for Pod width and pod length, showing great genetic diversity among the genotypes at the respective seasons that can be beneficial in future for genotype selection and improvement within those seasons. The high contribution of season towards the variables, indicates that genotypes respond differently to variation in seasons, such as moisture levels, temperatures, and therefore the genotypes can be selected for specific seasons. Highly significant GIS suggests that the genotypes responded differently in different seasons. Genotypes contributed highly towards variation in duration to maturity, by 29%, followed by duration to flower by 25%, while the lowest contribution was in pod length by 5% followed by pod width by 10%. The contribution of the season to the variation among the reproductive variables was high for pod length (62%), followed by plant height (59%) and duration to flower (59%), indicating that selection of genotypes which are adapted to specific seasons can be based on these variables. The analysis produced significant interaction, (GIS) for duration to flowering, maturity, and plant height ($P \leq 0.001$), indicating interactive effect of both genotypes and season towards these variables. Cheelo, (2016) reported significant GIE interaction among soybeans vegetative variables for duration to flower and plant height, while Gerrano *et al*., (2020) observed significant GIE interaction for plant height in cowpeas (Rao *et al.,* 2020).

3.4.2.2 Duration to flowering among the green vegetable pigeon peas genotypes.

The study observed a significant difference among the genotypes ($P \leq 0.001$), for duration to flower at Katumani (S1), Kambi ya Mawe (S2), Kiboko (S4) and Kiboko (S5) (Table 5). At Kabete (S3), the genotypes were significant at ($P \leq 0.05$). No significant difference was observed among the genotypes at Kabete (S6), indicating no genetic diversity among the genotypes, when planting is done in the month of October.

Table 5: Mean vegetable pigeon pea duration to flower for five pigeon pea genotypes at Kambi ya Mawe, Kabete, and Kiboko during 2016-2018 season

Genotype	KAT (S1)	KYM (S2)	KAB (S3)	KAB (S6)	KIB (S5)	KIB (S4)
ICEAP 00554	106.7b	88.3b	188.7b	75.7	128.3a	122.7b
ICEAP 00557	120.3b	86.3b	176.7b	81.0	129.0a	122.0b
KAT 60/8	98.0b	84.3b	184.7b	74.0	128.7a	112.3a
KIONZA	194.0a	130.0a	189.7b	96.0	246.7b	154.7c
MZ 2/9	97.0b	83.0b	156.0a	78.7	128.7a	113.0a
Mean	123.2	94.4	179.1	81.1	152.3	124.9
SEM	7.9	3.3	5.7	6.5	2.4	2.2
SED	11.2	4.6	8.0	9.2	3.4	3.1
LSD>0.05	25.89***	10.68***	18.47*	NS	7.87***	7.22***
CV%	11.2	6.0	5.5	13.9	2.7	3.1

, **, and * represent significance level at $P < 0.05$, $P < 0.01$ and $P < 0.001$ each, ns= non-significant; KIB S4: Kiboko S4 (March season); KIB S5: Kiboko S5 (October season), KAT S1: Katumani S1 (October season), KYM S2: Kambi ya Mawe S2 (October season), KAB S6: Kabete S6 (October season) and KAB S3: Kabete S3 (March season); SEM: Standard error of a mean; SED: Standard Error of Difference, LSD: Least Square Difference, CV: Coefficient of variation*

Among the genotypes, KIONZA was consistently late at all locations, while MZ 2/9 was early at S1, flowering within 97 days, S2 within 83 days and S6 within 79 days. The study also noted that genotypes planted during season 3 at, where the temperatures were lower (18°C), they took longer (179 days) to flower compared to Kiboko (Season 5), with a higher mean temperature of 25°C, where the genotypes flowered early after 152 days post planting. Genotype flowering was therefore influenced by average daily temperatures. These findings are consistent with the observations made by Ojwang *et al*., (2016a), that lower temperatures delay flowering in green vegetable pigeon peas, and therefore, duration to flowering can be used to select for early maturing genotypes, which is associated with drought escape characteristics. The study noted a significant ($P \leq 0.001$) and positive correlation between duration to flower and maturity. Duration to flower was negatively correlated to secondary branches ($r=^{-}0.327$), Pod length ($r=^{-}0.0163$) and shelling % ($r=^{-}0.036$). These results indicate that genotypes that takes shorter time to flower produces fewer number of secondary branches, smaller pods, and reduced shelling percentage.

3.4.2.3 Duration to pod maturity among vegetable pigeon peas genotypes.

The study observed a significant difference ($P \leq 0.001$) among the genotypes on duration to maturity at Katumani (S1), Kambi ya Mawe (S2), Kiboko (S4) and Kabete (S3) and ($P \leq 0.05$) at Kabete (S5) (Table 6), while no significant difference was observed at Kabete (S6). The genotypes matured early at Kabete (S6) after 109 days compared to Kabete (S3) within 203 days of planting.

Table 6: Mean vegetable pigeon pea duration to pod maturity for five pigeon pea genotypes at Kambi ya Mawe, Kabete, and Kiboko during 2016-2018

Genotype	KAT (S1)	KYM (S2)	KAB (S3)	KAB (S6)	KIB (S5)	KIB (S4)
ICEAP 00554	133.3b	115.7b	211.3b	105.7	151.0a	150.3b
ICEAP 00557	145.7b	110.3b	200.0b	110.3	159.3a	145.0ab
KAT 60/8	123.0b	109.7b	209.3b	102.3	152.7a	138.3a
KIONZA	233.0a	161.0a	213.7b	126.0	274.3b	181.7c
MZ 2/9	120.3b	105.7b	180.0a	102.7	154.3a	138.0a
Average	151.1	120.5	202.9	109.4	178.3	150.7
SEM	8.4	4.5	5.8	6.8	3	2.7
SED	11.9	6.3	8.2	9.6	4.2	3.9
LSD>0.05	21.4***	14.53***	18.97*	22.13NS	9.74***	8.92***
CV%	9.6	6.4	5	10.7	2.9	3.1

, **, and * represent significance level at $P < 0.05$, $P < 0.01$ and $P < 0.001$ each, ns= non-significant; KIB S4: Kiboko S4 (March season); KIB S5: Kiboko S5 (October season), KAT S1: Katumani S1 (October season), KYM S2: Kambi ya Mawe S2 (October season), KAB S6: Kabete S6 (October season) and KAB S3: Kabete S3 (March season); SEM: Standard error of a mean; SED: Standard Error of Difference, LSD: Least Square Difference, CV: Coefficient of variation*

Among the genotypes, KIONZA, a local genotype took longer to mature, across all locations, taking more days, 233 at Katumani (S1), compared to 161 days at Kambi ya Mawe (S2) and 126 at Kabete (S6), 214 at Kabete (S3), 274 at Kiboko (S5) and 182 at Kiboko S4. MZ 2/9 was consistently early at Katumani (S1) (120 days), Kambi ya Mawe (S2) (106 days), Kabete (S6) 180 Days, while KAT 60/8 was earlier at Kabete (S6) maturing at 102 days post planting. The difference in duration to maturity within the seasons could be due to diversity among the genotypes, while differences between seasons was brought by diversity in soil and temperature. Supplementary irrigation at Kiboko (S5 and S4) and Kabete (S3 and S6) have potential to influence duration to maturity, leading to delay in duration to maturity of the genotype. This indicates that seasons with enhanced moisture levels prolongs the duration that genotypes take to maturity. This may expose the genotypes to intermittent and terminal moisture stress.

3.4.2.4 Final plant height among vegetable pigeon peas genotypes

There were significant differences among the genotypes ($P \leq 0.001$) at Katumani (S1), Kambi ya Mawe (S2) and Kiboko (S3) for final plant height, and significant at ($P \leq 0.05$) at Kiboko (S4) and Kiboko (S5) (Table 7). The final plant height ranged from 66cm at Kabete (S3) to 180cm at Kiboko (S5). Among the genotypes, KIONZA was consistently taller across all the seasons except at Kiboko (S3), recording 62 cm against the mean of 64 cm.

Table 7: Mean vegetable pigeon pea final plant height (cm) for 5 pigeon pea genotypes at Kambi ya Mawe, Kabete, and Kiboko during 2016-2018 season

Genotype	KAT (S1)	KYM (S2)	KAB (S3)	KAB (S6)	KIB (S5)	KIB (S4)
ICEAP 00554	150.3b	109.3b	76.2c	84.7	177.8a	115.3a
ICEAP 00557	144.6b	108.7b	71.7bc	89.4	180.0a	115.6a
KAT 60/8	156.9b	107.5b	77.5c	87.1	174.3a	109.4a
KIONZA	176.3a	234.0a	62.1bc	112.5	195.7b	195.7b
MZ 2/9	99.0c	102.5b	39.8a	93.9	170.3a	115.4a
Mean	145.4	132.4	65.5	93.5	179.6	130.3
SEM	3.9	7.2	4.1	11.3	4.1	14.2
SED	5.5	10.2	5.8	16	5.9	20.1
LSD>0.05	12.75***	23.56***	13.4***	NS	13.48*	46.25*
CV%	4.7	9.5	10.9	21	4	18.9

, **, and * represent significance level at $P < 0.05$, $P < 0.01$ and $P < 0.001$ each, ns= non-significant; KIB S4: Kiboko S4 (March season); KIB S5: Kiboko S5 (October season), KAT S1: Katumani S1 (October season), KYM S2: Kambi ya Mawe S2 (October season), KAB S6: Kabete S6 (October season) and KAB S3: Kabete S3 (March season); SEM: Standard error of a mean; SED: Standard Error of Difference, LSD: Least Square Difference, CV: Coefficient of variation*

MZ 2/9 was consistently shorter in height at all the seasons except at Kiboko (S3), recording 93.9cm against a genotype mean of 93.5cm. The study observed that genotypes planted in the seasons where mean daily temperatures were lower, such as Kabete (S3) and Kabete (S6), with a mean temperature of 18°C and 19°C also recorded shorter plants, with a mean of 66cm and 94 cm respectively. Comparatively, locations with higher mean temperatures such as Kiboko (S5) with a mean of 25°C, Kiboko (S4) with a mean of 24°C and Kambi ya Mawe (S2) with a mean of 24°C, recorded plant heights of 180cm, 130cm and 132cm respectively. The study observed that genotypes that take longer to mature are generally tall due to longer time they take to reach maturity compared to genotypes that take shorter time to mature. Genotypes planted in the seasons where rainfall was supplemented with irrigation, produced taller plants, such as Kiboko (S5) with genotypes recording 180cm, compared to purely rainfed plants at Kambi ya Mawe (S2) and Katumani (S1), which recorded a mean height of 145 and 132 cm respectively, due to improved and consistent moisture access. Khourgami et al (2012) and Ojwang et al (2016a) noted that when pigeon peas were put under supplementary irrigation, they became taller by an average of 34 cm, compared to those growing under purely rainfed. The study further noted that plant height was positively and significantly ($P \leq 0.001$) correlated to secondary branches (r=0.4516), seed per pod (r=0.542), yields (r=0.6088), pods per plant (r=0.5465).

3.4.2.5 Vegetable pigeon peas pod width.

Combined analysis of variance indicated significant differences among the seasons ($P \leq 0.001$) (Table 4), but interaction between season and genotypes was not significant (Table 8).

Table 8: Mean vegetable Pigeon pea pod width (cm) for 5 pigeon pea genotypes at Kambi ya Mawe, Kabete, and Kiboko during 2016-2018 season

Genotype	KAT (S1)	KYM (S2)	KAB (S3)	KAB (S6)	KIB (S5)	KIB (S4)
ICEAP 00554	1.19	1.06	1.14	1.05	0.93a	1.16
ICEAP 00557	1.26	1.21	1.15	1.01	1.11b	1.16
KAT 60/8	1.16	1.12	1.15	1.04	1.15b	1.10
KIONZA	1.19	1.23	1.09	1.07	1.08b	1.22
MZ 2/9	1.33	1.21	1.19	1.03	1.09b	1.38
Mean	1.23	1.17	1.15	1.04	1.07	1.20
SEM	0.05	0.05	0.06	0.22	0.03	0.09
SED	0.08	0.08	0.08	0.03	0.05	0.12
LSD>0.05	NS	NS	NS	NS	0.11**	NS
CV%	7.5	8	9.4	3.7	5.4	12.6

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant; KIB S4: Kiboko S4 (March season); KIB S5: Kiboko S5 (October season), KAT S1: Katumani S1 (October season), KYM S2: Kambi ya Mawe S2 (October season), KAB S6: Kabete S6 (October season) and KAB S3: Kabete S3 (March season); SEM: Standard error of a mean; SED: Standard Error of Difference, LSD: Least Square Difference, CV: Coefficient of variation*

While genotypes were significantly different for pod width (P≤0.05), at Kiboko (S5), no significant difference among the genotypes were observed in the other seasons, indicating lack diversity among the genotypes (Table 8). The pod width varied from 1.04cm at S6 to 1.23cm at S1, with seasons that recorded lower mean temperatures such as Kabete (S6) and Kabete (S3), recording a daily average temperature of 19°C and 18°C respectively, produced pods with short width of 1.04cm and 1.15cm respectively compared to seasons that recorded a higher mean temperature such as Kiboko (S4) with a mean temperature of 24°C, recording pod with wider average width of 1.20cm.

3.4.2.6 Vegetable pigeon peas pod length.

Combined analysis of variance for pod length revealed significant differences among the genotypes (P≤0.05) and season (P≤0.001), but no interaction between the genotypes and the season was note. The genotypes were significantly different for pod length at Kambi ya Mawe (S2) (P≤0.05), and Kabete (S3) (P≤0.01) (Table 9). Among the genotypes, MZ 2/9 recorded produced shorter pod of 7.16cm at Kabete (S3), compared to the overall season's mean 8.6cm by 1.44cm.

Table 9: Mean pod length (cm) for selected green vegetable pigeon pea genotypes at different seasons (2016-2018)

Genotype	KAT (S1)	KYM (S2)	KAB (S3)	KAB (S6)	KIB (S5)	KIB (S4)
ICEAP 00554	7.82a	7.68b	9.32b	8.21	5.47	8.41
ICEAP 00557	8.08a	7.74b	8.89b	8.05	5.47	7.71
KAT 60/8	7.97a	7.08b	8.50b	7.93	5.53	7.92
KIONZA	8.23a	9.65b	9.17b	8.55	5.47	8.27
MZ 2/9	7.99a	7.29a	7.16a	8.22	5.33	8.19
Average	**8.02**	**7.89**	**8.61**	**8.19**	**5.45**	**8.1**
SEM	0.77	0.48	0.33	0.25	0.32	0.4
SED	1.08	0.68	0.47	0.36	0.45	0.56
LSD>0.05	NS	1.56*	1.08**	0.83NS	NS	NS
CV%	16.5	10.5	6.7	5.4	10	8.5

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant; KIB S4: Kiboko S4 (March season); KIB S5: Kiboko S5 (October season), KAT S1: Katumani S1 (October season), KYM S2: Kambi ya Mawe S2 (October season), KAB S6: Kabete S6 (October season) and KAB S3: Kabete S3 (March season); SEM: Standard error of a mean; SED: Standard Error of Difference, LSD: Least Square Difference, CV: Coefficient*

At Kambi ya Mawe (S2), KIONZA recorded longer pods of 9.65cm, which was above the season's average of 7.89cm, by 1.76cm. The study further noted that pod length was negatively correlated but not significant (P≥0.05) to duration to flower, duration to maturity, yield, pods per pods, secondary branches, and plant height. Genotypes that took longer time to mature, such as KIONZA (198 days) produced longer pods (7.89cm) compared to early maturing genotypes, such as MZ 2/9

(135 days). Delay in maturity provides the plant with more time to build its pod sink, leading to longer and wider pods. The length of the pods and their width are important indicator, important for vegetable pigeon pea genotypes selection (Saxena *et al.*, 2010). Pod length is also known to influence consumer selection of vegetable cowpea (Nwofia, 2012), as longer pods contains more peas, that translate to more peas for cooking.

3.4.2.7 Vegetable pigeon peas seeds per Pod

Combined analysis of variance revealed significant differences among the genotypes (P≤0.001) and season (P≤0.001) (Table 4) for seed per pod, but no interaction between the genotypes and the season was noted (Table 10).

Table 10: Average number of seed per pod of selected green vegetable pigeon pea genotypes at different seasons (2016-2018)

Genotype	KAT (S1)	KYM (S2)	KAB (S3)	KAB (S6)	KIB (S5)	KIB (S4)
ICEAP 00554	5.7	5.2b	5.2	4.6	5.2	5.5bc
ICEAP 00557	5.6	5.4b	5.2	4.6	5.4	5.4ab
KAT 60/8	5.3	5.1b	4.9	4.3	5.5	5.2ab
KIONZA	6.1	6.1a	5.7	5.0	5.0	5.9c
MZ 2/9	5.0	5.1b	4.6	4.6	5.4	5.0a
Average	5.6	5.4	5.1	4.6	5.3	5.4
SEM	0.29	0.13	0.26	0.29	0.16	1.14
SED	0.41	0.18	0.37	0.42	0.22	0.19
LSD>0.05	NS	0.48**	NS	NS	NS	0.46*
CV%	9.0	4.0	8.8	11.0	5.3	4.5

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant; KIB S4: Kiboko S4 (March season); KIB S5: Kiboko S5 (October season), KAT S1: Katumani S1 (October season), KYM S2: Kambi ya Mawe S2 (October season), KAB S6: Kabete S6 (October season) and KAB S3: Kabete S3 (March season); SEM: Standard error of a mean; SED: Standard Error of Difference, LSD: Least Square Difference, CV: Coefficient*

The genotypes were significantly different at Kiboko (S4) (P≤0.05) and Kambi ya Mawe (S2) (P≤0.01) for seed per pod, ranging from 4.6 at Kabete (S6) to 5.6 at Katumani (S1). KIONZA produced pods with the highest number of seeds, with a mean of 5.6 seeds, compared to MZ 2/9, which had recorded shorter pods, produced a mean of 4.96 seeds per pod. Study of germplasm materials in India by Saxena *et al.,* (2010) indicated a range of 5-7 seeds in a pod, which they recommended as a qualification for vegetable pigeon peas genotypes. Seed-producing companies also consider the number of seeds per pod as a valuable attribute in seed multiplication process. Pods from Kiboko (S4), with 4.6 seed per pod pods, was below the range recommended for selection for vegetable pigeon peas of 5-7 seeds. This could have been contributed by pods not receiving more photosynthates due to many pods, occasioned by taller plants and more branches. Thagana *et al.,* (2013) observed that lower number of seeds in a pod could be due to occurrence of abortion in legumes, catalysed by moisture constraint, more sink, and high ambient temperatures.

3.4.3 Genotype performance based on reproductive variables.

3.4.3.1 Combined analysis of variance for reproductive variables

Combined analysis of variance was done to determine the extent of genotype, season, and their interaction (GIS) on yield, pods per plant, seed mass and shelling percent. This was done for each of the season, then for all the season combined. There was significant difference among the genotypes (P≤0.001) for yield (Kg/ha) and seed mass (g/100 seeds), while for the shelling percent, genotypes were significantly different at (P≤0.01) (Table 11).

Table 11: Analysis of variance on the effects of genotypes, locations and genotype x season interaction on yield and yield variables across six seasons.

Source of variation	d.f.	Yield (Kg/ha)	No of pods per plant	100 Seed Mass (g/100)	Shelling (%)
Replications	2	810NS	161NS	35.97NS	105.9NS
Genotype (G)	4	826541***	5550**	449.49***	603.5***
Season (E)	5	3620675***	23354***	465.46***	740***
GXE	20	358144**	3601**	33.35*	131NS
Residual	58	137149NS	1368NS	13.2NS	109.5NS
% Variation due to G	4	9.1	7.6	31.9	15.8
% Variation due to E	5	49.6	40.2	41.3	24.2
% Variation due to GxE	20	19.6	24.8	11.8	17.1

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant; KIB S4: Kiboko S4 (March season); KIB S5: Kiboko S5 (October season), KAT S1: Katumani S1 (October season), KYM S2: Kambi ya Mawe S2 (October season), KAB S6: Kabete S6 (October season) and KAB S3: Kabete S3 (March season); SEM: Standard error of a mean; SED: Standard Error of Difference, LSD: Least Square Difference, CV: Coefficient*

The study further observed significant difference among the locations (P≤0.001) for yield, pods per plant, seed mass and shelling percent. The study noted significant GIS for shelling percent (P≤0.05), yield and pods per plant (P≤0.01) and seed mass (P≤0.05). The contribution of both genotypes and season was determined, with genotypes contributing 32% towards variation in seed mass, 16% towards the shelling percentage, number of pods per plant by 8% and yield by 9%. Similarly, the seasons contributed 50% to the yield variability, 40% to pods per plant, 41% towards seed mass and 24% towards shelling percent. Generally, the GIS interaction contributed 25% towards variation in pods per plant, 20% on yield and 17% shelling percent. Ashango *et al.*, (2016) reported significant contribution of the season of above 50% towards chickpeas yield and (Sameer, 2018) on grain pigeon peas.

3.4.3.2 Green vegetable pigeon pea yield (Kg/ha)

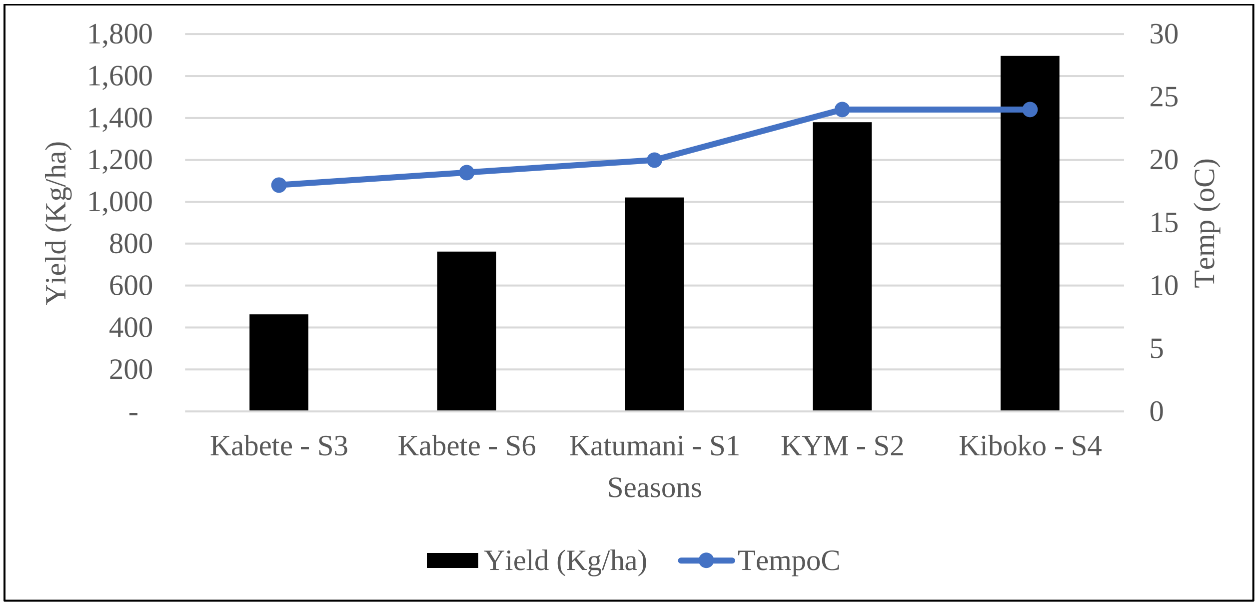
There was significant difference among the genotypes (P≤0.01) at Katumani (S1) and (P≤0.05) at Kambi ya Mawe (S2) for yield (Table 12). No significant difference was noted among the genotypes (P≥0.05) at Kabete (S6), Kabete (S3), Kiboko (S4) and Kiboko (S5), indicating lack of adequate genetic variability among the genotypes in these seasons for yield (Kg/ha).

Table 12: Average yield (Kg/ha) of selected green vegetable pigeon pea genotypes at different seasons (2016-2018)

Genotype	KAT (S1)	KYM (S2)	KAB (S3)	KAB (S6)	KIB (S5)	KIB (S4)
ICEAP 00554	1,160.0a	711.0b	709.0	478.0	1,613.0	559.0
ICEAP 00557	867.0bc	958.0b	622.0	437.0	1,679.0	406.0
KAT 60/8	669.0c	1,099.0b	857.0	264.0	1,909.0	473.0
KIONZA	1,083.0ab	2,754.0a	1,243.0	572.0	1,687.0	759.0
MZ 2/9	1,323.0a	1,377.0b	381.0	566.0	1,588.0	359.0
Average	1,020.40	1,379.80	762.4	463.4	1,695.20	511.2
SEM	87	354.8	184.1	122.1	302.6	124
SED	123	500.3	260.4	175.5	427.9	175.3
LSD>0.05	283.6**	1153.7*	NS	NS	NS	NS
CV%	14.8	44.4	41.8	46.4	30.9	42

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant; KIB S4: Kiboko S4 (March season); KIB S5: Kiboko S5 (October season), KAT S1: Katumani S1 (October season), KYM S2: Kambi ya Mawe S2 (October season), KAB S6: Kabete S6 (October season) and KAB S3: Kabete S3 (March season); SEM: Standard error of a mean; SED: Standard Error of Difference, LSD: Least Square Difference, CV: Coefficient*

Combined analysis of variance produced significant differences (P≤0.001) among the genotypes, season (P≤0.001) and genotype and season interaction (GIS) (P≤0.01). Genotypes contributed 9% towards the yield variability, while season contributed 50%. Interaction GIS contributed 20% of the yield variability. Yields (Kg/ha) ranged from 463 Kg/ha at Kiboko (S6) to 1695 Kg/ha at Kiboko (S5). Enhanced yield at Kiboko (S5), was noted due to supplementary irrigation, indicating in a favourable season, with no limitation in moisture, green vegetable pigeon peas have potential to produce higher yields, due to longer growing duration, taller plants, and more pods per plant. High yields observed at Kambi ya Mawe (S2) and Katumani (S1) was due to early planting at both locations, which enabled the plants to utilise the available moisture before the terminal drought set in, which has potential to reduce yields at this location. The study observed that the yielding ability among the genotypes across different seasons could have been influenced by daily mean temperature and supplementary irrigation. The weather data collected across all the locations indicated that Kiboko (S4) recorded a higher average temperature of 24^{o}C, compared to Kabete (S6) with an average mean temperature of 19^{o}C (Figure 2).



KIB S4: Kiboko S4 (March season); KIB S5: Kiboko S5 (October season), KAT S1: Katumani S1 (October season), KYM S2: Kambi ya Mawe S2 (October season), KAB S6: Kabete S6 (October season) and KAB S3: Kabete S3 (March season).

Figure 2: Variation in green vegetable pigeon pea yields with changes in average daily temperatures at different seasons.

This influenced the yielding ability of the genotypes at these locations. The study observed that yields at S4 (Kiboko) were significantly higher ($P \leq 0.001$), (1,695 Kg/ha), followed S2 (1,379 Kg/ha) and S1 (1,020 Kg/ha), which confirms the extent to which temperature influenced yields. Seasons such as Kabete (S3), located at a higher altitude (1,850 masl), recorded a lower temperature, produced lower yields, compared to S2 (Kambi ya Mawe), located at 1,250 masl, which recorded higher yields, during the October-December planting seasons. The study observed a positive association ($P \leq 0.001$) between yield and pods per plant, number of seed in a pod ($r=0.359$) and plant height ($r=0.6088$). The observed significant relationships indicate the importance of these variables in yield improvement and can therefore be used in future in the selection of genotypes with high yielding potential. Similar results have also been reported by Manyasa et al (2009) among pigeon pea genotypes.

3.4.3.3 Green vegetable pigeon peas pods per plant.

Combined analysis of variance produced significant differences ($P \leq 0.01$) among the genotypes, season ($P \leq 0.001$) and genotype and season interaction (GIE) ($P \leq 0.01$) (Table 11). The study observed significant differences ($P \leq 0.05$) among the genotypes at Kabete (S3) and ($P \leq 0.001$) at Kiboko (S4), indicating genotypes responds differently at Kabete and Kiboko and therefore selection of adapted genotypes can be done based on pods per plant for that specific location (Table 13). Genotypes contributed 8% towards the pod's variability, while season contributed 40%. Interaction GIE, contributed 25% of the pods per plant variability.

Table 13: Average number of pods per plant of selected green vegetable pigeon pea genotypes at different seasons (2016-2018)

Genotype	KAT (S1)	KYM (S2)	KAB (S3)	KAB (S6)	KIB (S5)	KIB (S4)
ICEAP 00554	212.5	98.9	90.3b	108.7	150.5	67.6ab
ICEAP 00557	152.1	121.1	80.2b	108.0	156.4	51.7ab
KAT 60/8	223.6	109.4	119.1b	106.3	180.3	82.3b
KIONZA	154.3	155.1	96.0b	124.0	168.2	204.1c
MZ 2/9	164.4	158.2	25.2a	121.3	148.1	35.1a
Average	**181.4**	**128.5**	**82.2**	**113.7**	**160.7**	**88.2**
SEM	38.2	24.9	15.3	5.3	14.2	12.4
SED	54	35.2	21.6	7.4	20.1	17.5
LSD>0.05	NS	NS	49.82*	NS	NS	40.38***
CV%	36.5	33.5	32.2	8	15.3	24.3

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant; KIB S4: Kiboko S4 (March season); KIB S5: Kiboko S5 (October season), KAT S1: Katumani S1 (October season), KYM S2: Kambi ya Mawe S2 (October season), KAB S6: Kabete S6 (October season) and KAB S3: Kabete S3 (March season); SEM: Standard error of a mean; SED: Standard Error of Difference, LSD: Least Square Difference, CV: Coefficient*

While MZ 2/9 produced more pods 158 pods at Kambi ya Mawe (S2), Kionza recorded more pods, 124 pods at Kabete (S3) and 204 pods at Kiboko (S5). Across the locations, Pods per plant varied from 82 pods at Kabete (S6) to 181 pods at Katumani (S1). Locations that reported higher yields such as Kiboko (S4), with 1,695 Kg/ha recorded more pod population per plant, of 160, compared to Kiboko (S5), that reported 511 Kg/ha with 88 pods per plant.

3.4.3.4 Green vegetable pigeon peas 100 Seed weight (g/100 seed)

Combined analysis of variance indicated significant difference among genotypes (P≤0.001), season (P≤0.001) and interaction GIS (P≤0.05) (Table 11). The study noted a 32% contribution of the genotypes towards the variation in seed mass, while season contributed 41%. The interaction GIS contributed 12% towards the variation in seed mass. The study noted that Kiboko S5 produced peas with the lowest seed mass, of 22 g/100 seeds compared to all other seasons. There is possibility that planting pigeon peas at this location at this season (March season) could be affected by low temperatures, affecting seed mass compared to Kiboko (S4), which recorded higher average daily temperature and therefore heavier seed. The study observed significant difference among the genotypes (P≤0.01) for seed mass at Katumani (S1); Kambi ya Mawe (P≤0.01); (P≤0.001) at Kabete (S3), Kabete (S6) and (P≤0.05) at Kiboko (S4) (Table 14).

Table 14: Average 100 seed mass (g/100 seeds) of selected green vegetable pigeon pea genotypes at different seasons (2016-2018)

Genotype	KAT (S1)	KYM (S2)	KAB (S3)	KAB (S6)	KIB (S5)	KIB (S4)
ICEAP 00554	23.27b	24.47b	35.87b	24.32a	21.86	31.60ab
ICEAP 00557	22.67b	24.07b	34.5b	24.37b	23.18	27.27a
KAT 60/8	21.40b	20.77b	27.7a	19.99b	21.18	23.57a
KIONZA	21.47b	34.60a	42.63c	31.27c	17.72	38.00b
MZ 2/9	28.73a	38.33a	45.97c	34.30c	27.25	38.17b
Average	23.51	28.45	37.33	26.85	22.24	31.72
SEM	0.859	2.147	2.059	1.177	2.35	3.24
SED	1.215	3.037	2.911	1.664	3.32	4.59
LSD (0.05)	2.801**	7.003**	6.714**	3.838***	NS	10.58*
CV%	6.3	13.1	9.6	7.6	18.3	17.7

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant; KIB S4: Kiboko S4 (March season); KIB S5: Kiboko S5 (October season), KAT S1: Katumani S1 (October season), KYM S2: Kambi ya Mawe S2 (October season), KAB S6: Kabete S6 (October season) and KAB S3: Kabete S3 (March season); SEM: Standard error of a mean; SED: Standard Error of Difference, LSD: Least Square Difference, CV: Coefficient*

Genotype MZ 2/9 consistently produced heavy peas, ranging from 27 g/100 seed at Kiboko (S5) to 38 g/100 seed at Kambi ya Mawe (S2) and Kiboko (S4). Kionza produced heavy seeds, 43 g/100 seeds at Kabete (S3), and lowest, 18 g/100 seed at Kiboko (S5). Kiboko (S3 and S5) and Kabete (S6 and S3), which were under supplementary irrigation and recorded lower temperatures, produced heavier seed with seed mass of 32 g/100 seed and 37 g/100 respectively, compared to Katumani (S1) (24 g/100 seed) and Kambi ya Mawe (S2) (29 g/100 seed). Shinde and Laware (2010) reported that reduced 100 seed weight under moisture stress and higher mean temperatures was due to closure of stomata to reduce further water loss, leading to lower photosynthesis efficiency.

High rainfall amounts and supplementary irrigation elongates the plant growing duration leading to heavier seeds. Manyasa *et al.*, (2009) observed that a higher seed mass at Kabete, compared to Kambi ya Mawe could be because of temperature difference. The study observed a positive association between seed mass ($P \leq 0.001$) and pod length ($r=0.922$) but negatively correlated to plant height. Seed mass was also positively but not significantly ($P \geq 0.05$) correlated to duration to flower ($r=0.061$), and maturity ($r=0.044$) and shelling percent ($r=0.371$). The positive association with duration to maturity and flower indicates that genotypes that takes longer to mature has enough time put more biomass for seed development compared to shorter duration genotypes. Seed mass was negatively correlated to number of seeds per pod ($r=-0.145$), indicating that as the size of the seed increase within the pod, it occupies more space leading to reduced number of seeds. The negative association between seed mass and plant height indicates that as the plant grow taller, the biomass is partitioned towards vegetative growth at the expense of seed development, leading to smaller seeds.

3.4.3.5 Green vegetable pigeon pea shelling percent (%)

There was significant difference among the genotypes at Katumani (S1) ($P \leq 0.05$) and Kambi ya Mawe (S2) ($P \leq 0.05$) for shelling percent. No significant difference ($P \geq 0.05$) was observed at Kabete (S6), Kabete (S3), Kiboko (S4) and Kiboko (S5) for shelling percent (Table 15). Genotype MZ 2/9 recorded a higher shelling percentage of 70% at Katumani (S1), 73% at Kabete (S6), 58% at Kambi Ya Mawe (S2) and 39% at Kiboko (S5). Kabete (S6) produced the highest shelling % of 56%, followed by Kambi ya Mawe with 55%, Kabete (S3) with 54%. Kiboko (S5) recorded the lowest shelling of 37%. Combined analysis indicated as significant difference among the genotypes and season ($P \leq 0.001$). No significant interaction between Genotype × season (GIS) was detected at ($P \leq 0.05$ (Table 11). Genotypes contributed 16% of the total variation in shelling percentage, while season contributed 24% and GES contributed 17%. Nganyi, (2009) observed that shelling percent only varied significantly among the genotypes but was not influenced by interaction between location/season and genotypes. He concluded that shelling percentage is primarily controlled by the genetic makeup of the plants and is not by the season/location and or management practices.

Table 15: Average shelling % of selected green vegetable pigeon pea genotypes at different seasons (2016-2018)

Genotype	KAT (S1)	KYM (S2)	KAB (S6)	KAB (S3)	KIB (S4)	KIB (S5)
ICEAP 00554	46.30b	56.60ab	54.50	61.60	58.40	35.80
ICEAP 00557	35.10b	52.50bc	44.30	51.90	41.80	34.40
KAT 60/8	37.70b	50.60c	44.90	54.70	44.50	39.80
KIONZA	48.90ab	56.50ab	61.40	48.60	49.90	36.20
MZ 2/9	70.10a	58.40a	72.70	53.20	54.50	38.70
Average	**47.62**	**54.92**	**55.56**	**54.00**	**49.82**	**36.98**
SEM	6.6	1.32	6.21	5.05	7.8	5.98
SED	9.4	1.86	8.78	7.13	11.04	8.45
LSD>0.05	21.6*	4.31*	NS	NS	5NS	NS
CV%	21.1	4.2	19.4	16.2	27.1	28

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant; KIB S4: Kiboko S4 (March season); KIB S5: Kiboko S5 (October season), KAT S1: Katumani S1 (October season), KYM S2: Kambi ya Mawe S2 (October season), KAB S6: Kabete S6 (October season) and KAB S3: Kabete S3 (March season); SEM: Standard error of a mean; SED: Standard Error of Difference, LSD: Least Square Difference, CV: Coefficient*

3.4.4 Vegetable pigeon pea yield stability analysis

The study observed a significant difference among the genotype (P≤0.001), seasons (P≤0.001), and their interaction (GIS) (P≤0.01) (Table 16). Significant difference among the genotypes, season, and their interaction (GIS) in a multi-seasonal/location trial has also been reported in grain pigeon peas by Sameer (2018) and in bread wheat by Hintsa *et al.*, (2013). The significance of the interaction between genotype and seasonal effects showed that the seasons can be arranged in groups according to the effects of interaction (Arshadi *et al.*, 2018). To determine the stable and adapted genotypes, this study applied the IPCA Scores from the AMMI analysis. Similar application has been reported by Hagos and abay (2013). The two IPCAs from the interaction component, explained 96.5% of the variability in grain yield, with only IPCA1 being significant at (P≤0.001) (Table 16). The first IPCA sum of squares (TSS) was greater than the second IPCA 2, indicating the presence of differences in vegetable pigeon pea genotype yield performance because of the GIS. In this study therefore, IPCA1 was used to explain the stability and adaptability of the selected genotype across the six seasons. Gebremethin *et al.*, (2014), while studying the stability and adaptability of barley, recommended that a significant IPCA can be used to explain the relationship between the genotypes and locations.

Table 16: Combined AMMI model analysis of variance of four vegetable pigeon pea genotypes grain yield evaluated at six locations in Kenya (2016-2017).

Source	df	TSS	TSS%	GIS Explained	Cumulative (%)	MS
Genotypes	4	3,306,164	9.1			826541***
Seasons	5	18,103,375	49.6			3620675***
Block (Within Seasons)	12	1,021,597	2.8			85133NS
GIS Interactions	20	7,162,881	19.6			358144**
IPCA1	8	5,516,967		77.0	77.0	689621***
IPCA2	6	1,396,489		19.5	96.5	232748^{NS}
Residuals	6	249,426				41571^{NS}
Error	48	6,934,666				144,472
Total	89	36,528,683	410,435			*

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant*

3.4.4.1 Green vegetable pigeon pea genotype stability analysis

There was significant difference among the genotype (P≤ 0.001) on yields, with KIONZA, a local reference genotype, recording high yields across all the seasons, with an overall mean of 1,349.7 Kg/ha, followed by MZ 2/9 (932.3 Kg/ha) (Table 17). Genotype ICEAP 00557 recorded the lowest yields among the genotypes, recording 828.2 Kg/ha.

Table 17: Mean yield (Kg/ha) for the five-vegetable pigeon pea genotype, the magnitude (absolute value) of the IPCA's scores and stability parameters from AMMI Model

Genotype	Average (Kg/Ha)	Rank (Yield)	IPCAg [1]	IPCAg [2]	ASV	Rank (ASV)	Yield Stability Index
ICEAP 00554	871.8	4	16.63744	-1.86583	65.8	4	8
ICEAP 00557	828.2	5	8.43214	2.74037	33.4	3	8
KAT 60/8	878.7	3	4.38311	17.35355	24.5	2	5
KIONZA	1349.7	1	-31.38836	0.98557	124.0	5	6
MZ 2/9	932.3	2	1.93568	-19.21366	20.7	1	3

Based on IPCA, KIONZA recorded a higher absolute value of $^-$31.3, followed by ICEAP 00554, with an IPCA of 16.64. The high IPCA recorded by KIONZA and ICEAP 00554 indicates they are more specific adapted, compared to other genotypes. This means that they were more responsive but are the most unstable genotypes, contributing largely to the interaction component and may be considered as specifically adopted genotypes, to specific season. MZ 2/9, which recoded IPCA of 1.93 and KAT 60/8 with an IPCA of 4.38 contributed least to the interaction component, indicating a wider adaptability and high stability. They can perform better across the season. According to Hago and Abay (2014), genotypes that score IPCA close to zero, in this case, MZ 2/9 and KAT 60/8, are stable and adapted to all seasons under evaluation.

3.4.4.2 Season adaptability and stability analysis

The study observed that yields from six seasons were significantly different ($P \leq 0.001$), with Kiboko (S4) producing of 1,695 Kg/ha compared to Kambi ya Mawe (S2) with 1,380 Kg/ha, Katumani (S1) with 1,021 Kg/ha, Kabete (S6) with 762.5 Kg/ha and Kabete (S3) with 463 Kg/ha (Table 18). Variation in yield across the seasons was due to several factors such as soil moisture regimes and temperature difference. The study noted that seasons such as Kiboko (S4), which recorded a higher mean temperature of 25^oC and was also under supplementary irrigation, recorded higher yields (1695.2 Kg/ha).

Table 18: Average yield (Kg/ha) for the six seasons, the magnitude (absolute value) of the IPCA's scores and stability parameters from AMMI Model

Seasons^x	SM^y	Rank (Yield)	IPCAe [1]	IPCAe [2]	ASV	Rank (ASV)	YSI
Katumani (S1)	1,020.7	3	9.832	-17.339	42.5	4.0	7.0
Kambi ya Mawe (S2)	1,379.8	2	-32.328	-3.907	127.8	6.0	8.0
Kabete March (S3)	762.5	4	-1.679	14.435	15.9	1.0	5.0
Kiboko March (S4)	511.3	5	5.088	4.126	20.5	2.0	7.0
Kiboko October (S5)	1,695.2	1	10.856	9.631	44.0	5.0	6.0
Kabete October (S6)	463.1	6	8.231	-6.945	33.3	3.0	9.0

^{x} *Kiboko S4 (March season), Kiboko S5 (October season), Katumani S1 (October season), Kambi ya Mawe S2 (October season), Kabete S6 (October season) and Kabete S3 (March season)*
^{y} *SM: Season Mean yield; ASV (AMMI Stability Value); YSI: Yield Stability Index*

Seasons such as Kambi ya Mawe (S2) and Katumani (S1), which were both under rainfed, and lower mean daily temperature, recorded lower yields of 1,379.8 Kg/ha and 1,020.4 Kg/Ha respectively. Improved soil moisture due to supplementary irrigation elongated the genotype maturity period, leading to plants with more branches, more pods, and therefore more yields. The study observed that three seasons Kambi ya Mawe (S2), Katumani (S1) and Kiboko (S5), recorded higher absolute IPCA of 32.3, 9.8 and 10.9 respectively and higher yields of 1,379.8 Kg/ha, 1,020.7 Kg/ha and 1,695 Kg/ha respectively (Table 18). They were therefore the most interactive seasons and most suitable only for the specifically adapted genotypes, which were KIONZA and ICEAP 00554. The seasons that reported a lower IPCA such as Kabete (S3), with IPCA of 1.67, Kiboko (S4), with IPCA 5.09 and Kabete (S6) with 8.23, were stable locations and are generally good for testing all the genotypes. Locations with a lower IPCA indicates stability among the genotypes and can be good for testing pigeon pea genotypes (Pagi et al., 2017).

3.4.4.3 AMMI stability value (ASV) and yield stability index (YSI)

The yield stability among the genotypes and seasons were also tested based on AMMI Stability Value (ASV) and Yield Stability Index (YSI), to validate the AMMI model. According to Purchase and Hatting, (2000), ASV is the distance from the coordinate point of origin in a two-dimensional scatter gram of IPCA1 scores against IPCA2 scores in the AMMI model. Yield stability index (YSI) is calculated by summing the rank of mean yield across seasons and rank of AMMI stability value ASV) of genotypes (Farshadfar, 2011).

Genotypes that score the lowest ASV are therefore categorized as very stable. This study observed that genotypes MZ 2/9, that recorded a lower ASV of 20.7 and KAT 60/8, with a ASV score of 24.5, were generally stable genotypes, compared to KIONZA, with ASV of 124 and ICEAP 00554 with ASV of 65.8, being most the unstable but specifically adapted. When stability of the genotypes was analysed based on YSI, MZ 2/9 recorded a YSI of 3, while KAT 60/8 recorded a YSI of 5, which were lower than other genotypes, indicating high levels of stability with general adaptability. ICEAP 00554 (8) and ICEAP 00557 (8), KIONZA (6) had a higher YSI, indicating instability and therefore specifically adapted to a particular season.

Kambi ya Mawe (S2) recorded ASV of 128, Kiboko (S5) reported ASV of 44, while Katumani (S1) recorded ASV of 42.5. These locations reported a higher ASV and therefore were unstable seasons, therefore favourable to unstable genotypes. Kiboko (S4) recorded ASV of 20.5, Kabete (S3) with and ASV of 15.9 and Kabete (S4) with ASV of (20.5) and Kabete (S6) had the lowest ASV of 33.3, indicating highly stable season (Table 18). These finding supports and validates the findings made when AMMI model was used in this study, to determine stable genotypes and seasons and therefore the use of AMMI, ASV or YSI can be used interchangeably in determination of stable and adaptable genotypes and season. Similar recommendation has been made by Rono *et al*., (2016) in sorghum.

3.4.4.4 Determination of ideal season for testing genotypes

Ideal season for evaluating the green vegetable genotypes was determined based on GGE biplot analysis, which considered both genotype (G) and GS interaction effects. The analysis then graphically displayed GS interaction in a two-way table, as recommended by Yan *et al.*, (2001). Scatter plot analysis (Figure 3) was used to determine the most discriminating and responsive season. S5 (Kiboko – October planting) (S6 (Kabete – October planting) and S4 (Kiboko (March planting), were observed to be the most responsive seasons, but with poor discriminative ability. S2 (Kambi ya Mawe – October planting), has both the discriminative ability and representativeness, as shown by a long distance from the centre and therefore a larger absolute IPCA1 of -32.31 and a lower IPCA2 of -3.907, (Table 3), making it the most discriminating and responsive season or planting season for testing green vegetable pigeon pea genotypes.

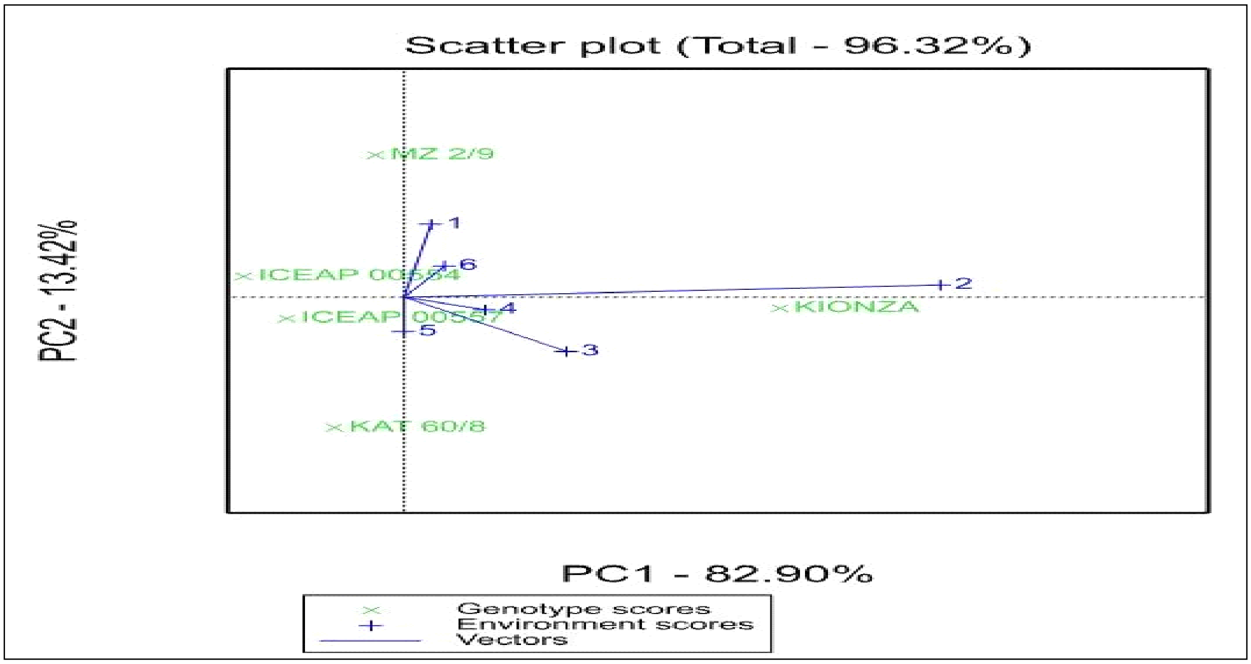


Figure 3: The Season vector view of the GGE among the test seasons in discriminating seasons.

An ideal location should have large IPCA1 scores to discriminate genotypes in terms of the genotypic main effect and absolute small PC2 scores to be more representative of the overall locations. S2 (Kambi ya Mawe) fell within the intrinsic cycle, making it more stable season for genotype testing, and therefore the most ideal location. Locations such as S3 (Kabete – March) and S1 (Katumani) with a lower IPCA values and nearer to the centre were discriminative but non-representative and can be best locations for future selections of genotypes that are specifically adapted, such as KIONZA and ICEAP 00554 (Figure 4).

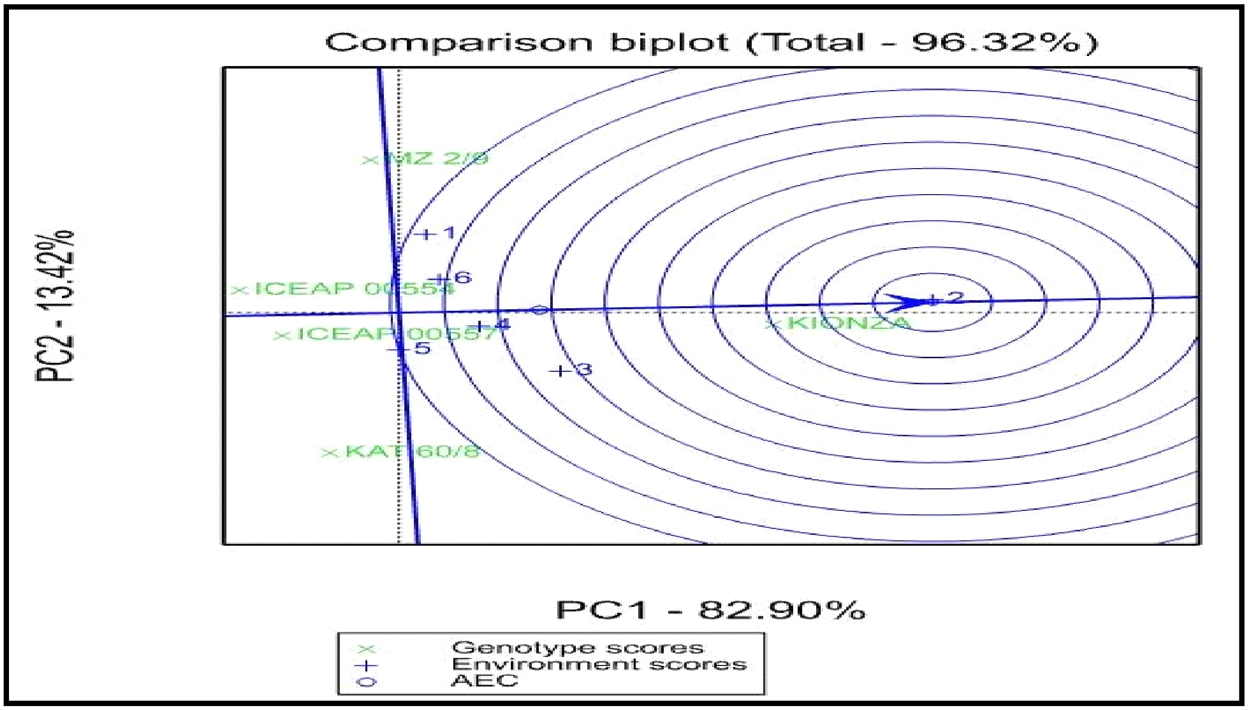


Figure 4: GGE Biplot of Ideal test location and comparison of the locations with respect to the ideal location

3.4.4.5 Determination of ideal genotype

Comparison biplot analysis was used to determine the ideal season for genotype evaluation (Figure 3). Mitrovic *et al.*, (2012) observed that even if such ideal genotype may not exist, identified genotype with such quality could be used as a reference for future genotype evaluation. The most ideal genotype was identified based on GGE biplot analysis. Genotype KIONZA was the most ideal genotype as shown by its proximity to the concentric circle (Figure 5). The closer a genotype is to the concentric cycle, the higher the mean yield and therefore an ideal genotype (Kaya *et al.*, 2006). KIONZA can therefore be used in future as a reference genotype when evaluating new materials and breeding initiatives. Genotypes whose position in the plot are located far from the concentric circle are considered as the worst performing one. According to Yan and Kang, (2003), an ideal genotype is the one that is the highest yielding across the test seasons and its stable in performance and ranks the highest in all test seasons. That it has the highest average value of all genotypes, in that it does not exhibit any genotype by season interaction, therefore, broad adaptation. KIONZA consistently produced high yields, recording an average of 1349.7 Kg/ha across all the seasons (Table 18).

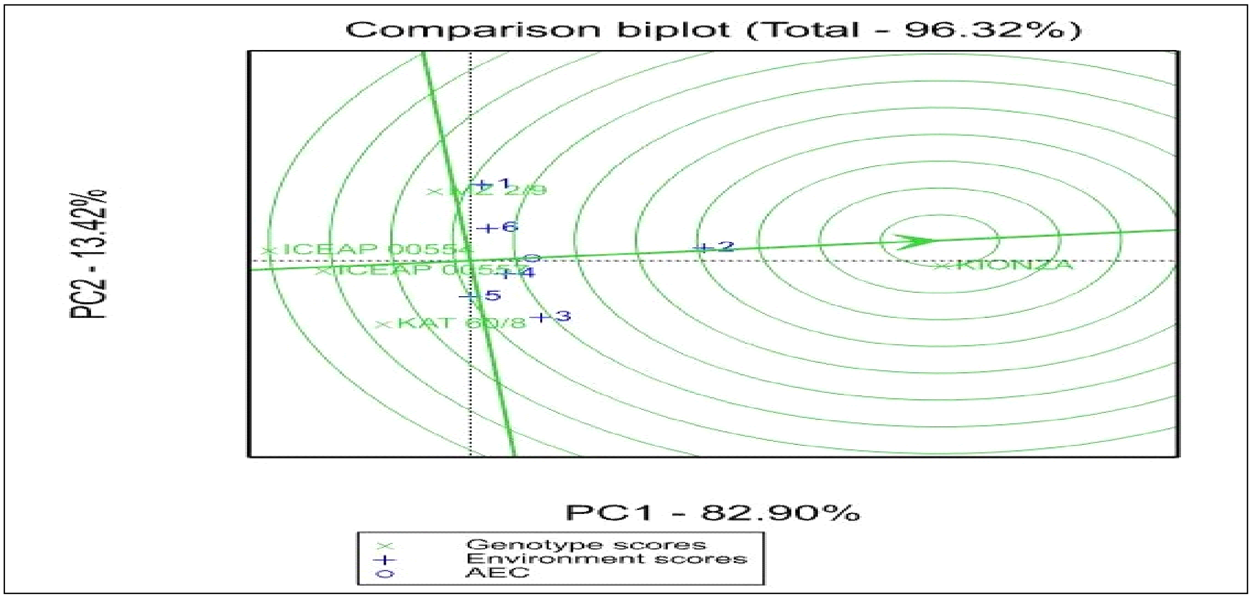


Figure 5: GGE Biplot of Ideal genotype and comparison of the genotypes with respect to the ideal genotype

3.4.4.6 Determination of the mega Season

Mega-season is a group of locations that consistently share the most suitable set of genotypes across years (Mustapha and Bakari (2014). GGE biplots was instrumental in showing which genotype won-where, using mega-seasons (Figure 6). The study revealed three mega-seasons: Mega-Season 1, made up of S1 (Katumani) and S2 (Kiboko October Planting); Mega-season 2 made up of S2 (Kambi ya Mawe), S3 (Kabete March), and S4 (Kiboko March); Mega-season 3: S5 (Kiboko October planting). I

n mega-season identification process, furthest genotypes are connected to form a polygon (Mare *et al.*,2017). The vertex genotypes were: KIONZA, MZ 2/9, ICEAP 00554 and KAT 60/8. These genotypes are the best or the poorest genotypes in some or all season, because they are the furthest from the origin of the biplot (Hagos and Abay, 2013). Mustapha and Bakari, (2013) in their GGE biplot study of Millet, reported that vertex genotype for each sector is the one that yielded the highest for the seasons falling within that sector. Yan and Tinker (2006) observed that the vertex genotypes, like in this case, KIONZA, MZ 2/9, ICEAP 00554 and KAT 60/8, were the most responsive genotypes, as they have the longest distance from the origin in their direction. The winning genotype in each sector, are those positioned at the vertex, MZ 2/9 was the winning genotype in S1 (Katumani) and S6 (Kiboko October planting), KIONZA was the winning genotype in S2 (Kambi ya Mawe), S3 (Kabete March) and S4 (Kiboko March). KAT 60/8 was the winning genotype in S5 (Kiboko October). Hagos and Abay (2013) used the same method to evaluate bread wheat genotypes in Ethiopia and Kamau, (2013) on pigeon pea analysis in Kenya, using multi-location meta-data, to determine the mega-seasons and high yielding genotypes within those seasons.

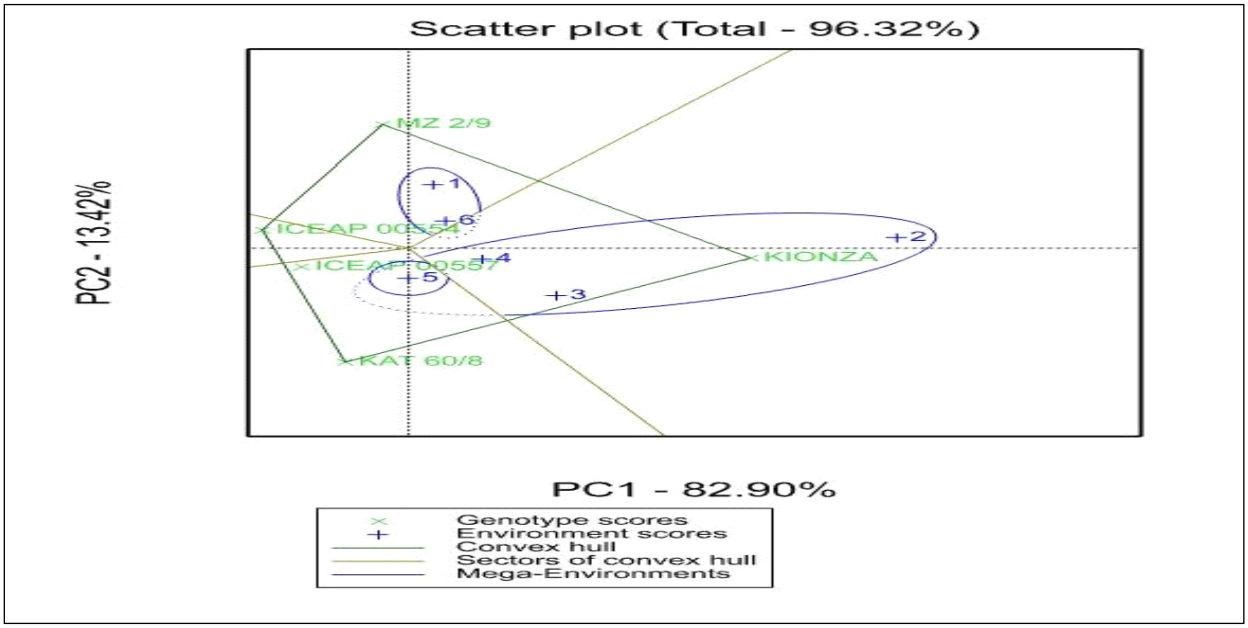


Figure 6: Polygon view of the GGE-biplot showing the mega-seasons and their respective highest yielding and stable.

3.5 Conclusions and recommendations

Stability and adaptability of selected green vegetable pigeon peas was conducted in six seasons between 2016-2018, to identify the stable and adapted green vegetable pigeon peas genotypes under the varying Agro-ecological zones. Genotype KIONZA was the most ideal genotype due to its high mean yield across all the season, while Kambi ya Mawe, has both the discriminative ability and representativeness. The trial at Kabete in March 2016 (S3) and October 2016 (S5) was to inform ICRISAT on the location performance and whether it can be used as an ideal location for green vegetable pigeon pea genotype testing especially during off seasons in Eastern Kenya. The study noted that this location can be used to unstable genotypes still on preliminary selection.

The significant difference among the genotypes for days to flower, maturity, Plant height, pods width, pod length, seeds per pod, yield, number of pods per plant, seed mass and shelling percent, showed great genetic diversity, and they can be of benefit in future selection either within the seasons or across the seasons. Supplementary irrigation and changes in temperature influenced the duration to flower and maturity, yield, and yield variables such as seed weight, confirming the potential impact of climate change. Lower temperatures accelerate early flowering and maturity, while supplementary irrigation to delay in flowering and maturity due to prolonged growth period.

This research identified the ideal location, Kambi ya Mawe, for future testing and a reference genotype, KIONZA, to evaluate new materials. Two stable genotypes, MZ 2/9 and KAT 60/8, with wider adaptability and high stability, have been identified for commercialisation in the Eastern region. Future research opportunities need to promote the MZ 2/9 and KAT 60/8 through participatory on-farm demonstrations and trials for increased adoption among the pigeon pea producing households.

CHAPTER FOUR: RESPONSE OF GREEN VEGETABLE PIGEON PEA GENOTYPES TO MOISTURE STRESS UNDER VARIOUS ENVIRONMENTS.

ABSTRACT

Pigeon peas (*Cajanus Cajan*) production is affected by several challenges during growth and development, with moisture stress being the most challenging abiotic factor. The study aimed at establishing the effect of intermittent and terminal moisture stress at different growth and development stages of green vegetable pigeon pea. Genotypes ICEAP 00554, ICEAP 00557, MZ 2/9 and KAT 60/8 were evaluated at Kiboko in 2017/18, under open field and at Kabete in 2018/2019 under high tunnel. There was significantly different ($P \leq 0.001$) among the moisture regimes for 100 seed weight, duration to flower, duration to harvest, number of pods and seed per pod at both locations. Combined analysis revealed a significant ($P \leq 0.01$) interaction between moisture regimes and genotypes for seed weight, days to flower, days to harvest under open field and 100 seed mass, Days to flower, Harvest index, pods population per plant and plant height under high tunnel ($P \leq 0.001$). Yield was positively associated ($P \leq 0.001$) with drought tolerance efficiency (DTE) ($r=0.933$) and Pods per plant ($r=0.848$) under high tunnel, and Harvest index ($r=0.539$), Pods per plant (PPP) ($r=0.564$), seed mass ($r=0.543$) and DTE ($r=0.893$) under open field. Under high tunnel, when moisture stress was initiated at flowering, yields, pods per plant and secondary branches were reduced by 77%, 72% and 60 % respectively, while under open field, it reduced yield, pod length and harvest index by 43%, 14% and 10%. ICEAP 00557 and KAT 60/8 were considered to respond well to moisture stress based on their low values Drought susceptibility index (DSI) scores of 0.97 and 0.98 respectively and low yield reduction rate (YRR) of 75% and 60% respectively. Flowering and early podding phases of green vegetable pigeon pea growth and development are the most sensitive to moisture stress, and therefore intensive supplementary irrigation need to target these phases, providing information for irrigation scheduling. Future research needs to inform on the cost-benefit analysis for irrigation scheduling. ICEAP 00557 and KAT 60/8 need to be promoted as the genotype with tolerance to moisture stress through on-farm trials and demonstrations.

Key Words: *Yield, water stress, drought tolerance, genotype*

4.1 Introduction

Pigeon pea is a major staple crop grown in Eastern regions of Kenya, accounting for 67% of the total production in the country (Wambua *et al.*, 2017). The crop is mainly grown by small holder farmers under rainfed conditions, which are increasingly subjected to unreliable rainfalls, exposing the households to frequent famines, due to poor harvests (Jayne, 2016). Green vegetable pigeon peas production in the Eastern region of Kenya is limited because of biotic and abiotic stresses during growth and development, with moisture stress being the most challenging abiotic stress (Chaudhary *et al*., 2011). The pigeon pea has been noted to be a drought tolerant crop, therefore adaptable to harsh conditions (Wambua *et al.*, 2017). The greatest challenge in this region is therefore to develop climate resilient pigeon pea genotypes, with potential to provide yields under limited soil moisture.

Climate change in the recent past, especially in the Eastern region of Kenya, has led to variation in rainfall patterns, that require development of stable green vegetable Pigeon pea genotypes adapted to a different major production area with high yield performance under low moisture regimes. Genetic improvement is one of the options for identification and development of pigeon peas genotypes that can tolerate moisture stress with potential to mitigate against climate change (Porch et al., 2009). The morphological and physiological changes in response to moisture stress can be used to help identify moisture stress tolerant genotypes for better productivity under moisture stress (Nam *et al.*, 2001), which can be utilized in genetic improvement initiatives. pigeon peas, by virtue of being grown majorly in ASALs, region that is characterized by perennial water stress, need to have the ability to tolerate both biotic and abiotic stress, for successful adaptation. A better understanding on the effects of moisture stress during Pigeon pea crop growth at vegetative, flowering and podding will be important for breeding in the face of climate change.

There is limited information on the response of green vegetable pigeon peas genotypes to variation in moisture at different stages of growth and development. Recent study by Ojwang, *et al.*, (2016) reported that green vegetable pigeon peas produced under improved moisture conditions under supplementary, recorded enhanced yields by 47% compared to those under rain fed in Makueni County. The yield improvement was because of more pods and enhanced seed mass, which were positively related to yield, because of increased and sustained moisture levels at Kiboko. Previous studies by Ambachew, (2015) observed that reduction in moisture levels at early stages of pigeon pea growth leads to poor flower fertilization and increased pod abortion, which affects pod population and therefore results to poor yield (Sarintha *et al.*, 2012). In common beans, reduction in soil moisture decreases photosynthesis and movement of photosynthate to the developing seed, leading to reduced seed mass (Munoz-Perea et al 2006)). In soya beans, moisture stress especially when it overlaps at flowering and pod setting leads to yield reduction (Liu *et al.*, 2003), because of poor flowering and reduced pod population. Drought tolerance indices have been developed to assess drought tolerance (Sabaghnia and Janmohammadi, 2014) based on how much yield reduction is realized under drought stress (Nam *et al.*., 2001). These include Drought tolerance efficiency (DTE), Drought Susceptibility Index (DSI) and Yield Reduction rate (YRR) proposed by Fischer and Maurer (1978) and Relative water Content (RWC). Parameshwarappa, *et al.*, *(*2008), in evaluating chickpeas for drought tolerance, noted that minimum yield reduction in chickpea genotypes was shown in a line which had the highest DTE and the lowest DSI). Cultivars with the lowest DSI values have been rated to be drought resistant (Sio-Se Mandeh, *et al.,* 2006), while those with high RWC under stress condition could retain more water in the leaves under stress. This study assessed the effect of moisture stress at different growth and development phases of green vegetable pigeon pea.

4.2 Materials and method

4.2.1 Description of genetic materials

Four pigeon pea genotypes of medium duration: ICEAP 00557, ICEAP 00554, KAT 60/8 and MZ 2/9, were evaluated to establish the effect of intermittent and terminal moisture stress at different growth stages on yield and yield variables of green vegetable pigeon pea genotypes. In this research, KIONZA, a local reference genotype was left out due to its lateness in flowering and maturity, compared to the test genotypes, with respect to the high tunnel trial. The description, origin and sources of the genetic materials have been presented in chapter three (3) section 3.2.2 of this thesis.

4.2.2 Location description

The field trials were established at Kiboko research station, located in Makueni County and Kabete field station, located at the University of Nairobi in a high tunnel. The Kiboko site was selected due to access to irrigation water, that would ensure no-stress treatment (full irrigation) continuously receive moisture during the growth cycle and enable variation in moisture levels when initiating intermittent moisture stress. Terminal moisture stress was achieved later in the growth season in April-August 2018, which is characterized by drought. Kabete was selected due to availability of high tunnel and proximity to the university making it easy for supervision. The Monthly rainfall (mm), temperature (°C) and relative humidity, were recorded at both locations. The description of both locations has been presented in section 3.2.1 of this thesis. The trial at Kiboko was established in November 2017 and harvesting completed by August 2018, while the trial at Kabete was established in August 2018 and harvesting completed by February 2019.

4.2.3 Experimental design open field at Kiboko

The four genotypes were planted in a randomized complete block design (RCBD), replicated three times in a plot area of 3.0m x 4.5m, with 1m space between plots and 1.5m space between blocks keeping inter and intra row spacing of 1.5m and 0.3m, respectively. Each plot, with a total of 3 rows, measured 7.5 m^2 with a harvestable net plot area of 4.5m^2. Seeds were planted at a about 10 cm deep and thinned one plant per hole, to a spacing of 30 cm after 14 days post planting.

4.2.4 Field Management and data collection at Kiboko

Land preparation was done by ploughing the land twice to achieve a fine seed bed suitable for pigeon pea crop establishment, using a disc plough, followed by a disk harrower. Immediately after planting, irrigation, using overhead sprinkler, was done to achieve germination and establishment, equally among all the treatments. Subsequently, supplementary irrigation was varied based on the treatments. Six portable rain gauge were placed at different sections of the trial before the start of the irrigation, to determine the amount of water supplemented during irrigation. This was done in the initial irrigation after planting, at flowering and podding phases of crop development. Water captured in the rain gauge was measured to determine the amount of irrigation water supplemented to the normal rainfall amounts.

To prevent water from reaching the other plots that doesn’t need water, a buffer zone was created between the treatments, by planting tall variety of sorghum at high density, in a space of 10 meters width, to avoid sprinkler water overlapping to other treatment plots, at different stages of pigeon pea development. Major pest which attacked the crop were mainly pod suckers and pod fly, which were controlled using recommended pesticides, applied uniformly and interchangeably. Five (5) plants were randomly selected and tagged, when the plants had reached one metre high, for subsequent data collection. The Agro-morphological data was collected as those explained in section 3.2.5 of this thesis.

4.2.5 Experimental design under high tunnel at Kabete

The high tunnel trial was laid in 4 (genotypes) x 4 (moisture stress) treatments factorial combinations providing 16 treatments, replicated in 4 blocks, in a 15m x 8m tunnel. The blocks were arranged such that they ran parallel to the long side of the high tunnel in an East - West direction, as explained by Nyabundi (1980). The 16 treatments were randomly distributed in each block. The planting was done in containers with capacity to handle 20 lits of water, of 60cm height, providing room for roots development and expansion. The containers were filled with about 25.5 Kgs of soil, which was obtained from the nearby forest. The forest soil was mixed with cow manure, from the Kabete cattle shed, in the ratio of 10:1 by volume per pot as proposed by Nyabundi, (1980). The forest soil, before mixing with cow manure, was analysed to ascertain the soil PH and mineral composition. Three holes were made at the bottom of the plastic containers to enable proper drainage.

4.2.6 Determination of pot moisture capacity under high tunnel

Field capacity was determined based on the procedure described by Million *et al.*, (2005). Three pots per treatment were filled with an average of 25.5 Kgs of soil and 3.73 lits of water added. The pots were covered with a polythene bag to reduce water loss through evaporation and allowed to drain for 48 hours. After 48 hours, the weight had reduced by 40%. Subsequently, the pots were maintained between field capacity and 60% available water depletion for all the pots. This was done by weighing each pot on weekly basis for three (3) pots to maintain at initial target weight by adding the weekly water loss back to the pots.

4.2.7 Meteorological and soil data collection under high tunnel

In the open field experiment, daily weather information, which included daily precipitation (mm), daily temperatures (^oC) and relative humidity (%) were collected from the nearby weather stations, located about 200 m from the trial site. At Kabete under high tunnel, a digital thermometer was placed inside the tunnel, which recorded Maximum, Minimum daily temperature (°C) and relative humidity (%). At both locations, temperatures were read and recorded on a pre-set data book at 0900Hrs, while relative humidity at 0900 and 1500 Hrs. Soil samples were collected before land preparation at Kiboko using a zigzag method at trial site using a soil auger. The auguring depth was 15 – 20 cm, with the extracted sample from each pot put in clean plastic bucket and mixed ready for analysis. Soil sample collected from the forest at Kabete were also analysed for nutrient and Ph profile.

4.2.8 Watering regime treatments under high tunnel

Non-Drought Stress (NS)- (control): Under open field, treatments were watered on a regular basis, by use of sprinkler to pod harvest. Under the high tunnel, treatments were irrigated regularly, maintaining moisture levels at 60% field capacity, to pod harvesting.

Drought Stress (DS1): (Terminal Moisture stress): Under both open field and high tunnel, the treatments were irrigated to initiate germination and initial establishment for 3 weeks, then left to grow under normal conditions, without supplementary irrigation till pod were mature for harvesting.

Drought Stress (DS2): (Intermittent moisture stress at flowering) The treatments in the field and high tunnel experiments were irrigated till flower initiation, when at least 50% of the plants within the mid row in the open field and a plant in the pot under high tunnel, had at least one open flower, thereafter, intermittent moisture stress was initiated through cessation of irrigation.

Drought Stress (DS3): (Intermittent moisture stress at podding) The treatments at both locations were irrigated till pod initiation, when random/intermittent drought initiated by cessation of irrigation.

4.2.9 Agro-morphological data

The Agro-morphological data on duration to flower and maturity, seed per pod, 100 seed mass, pod length and width, number of pods, shelling percent, branches, percent harvest index (HI) and yields were collected based on the procedure outlined in chapter 3, section 3.2.5 of this thesis. Under the high tunnel, plant height was initially taken after three (3) weeks post planting, and subsequently on weekly basis for the next 10 weeks.

4.2.10 Drought tolerance indices determination

In addition to direct measurements, drought tolerance indices were calculated from the primary data, as outlined below:

Drought Intensity Index (DII) = $\frac{1-\mathrm{XDS}}{\mathrm{XNS}}$ ---------------------- Fischer and Maurer (1978)

Drought Susceptibility Index = $[\frac{1-\mathrm{XDS}}{\mathrm{XNS}}]$ /$[\frac{1-\mathrm{XDS}}{\mathrm{XNS}}]$------------- Fischer and Maurer (1978)

Where:

(i) Y_{DS} and $Y_{NS:}$ Mean yields of a given genotype evaluated under drought stress and non-drought stress conditions, respectively.

(ii) X_{DS} and $X_{NS:}$ Mean seed yields over all genotypes evaluated under drought stress and non-drought stress respectively.

4.2.11 Data analysis

A general linear model (GLM) was used for data analysis, as outline in GENSTAT 16th edition statistical program (Payne *et al.,* 2011). Data collected and cleaned from each treatment were analysed separately followed by combined analyses. The treatment effects were separated into effects due to: Moisture regimes (M), Genotypes (G) and interaction between genotypes and moisture regimes (GIM). Least significant difference (LSD) test at 5% level of probability was done for the significant mean values using Fisher's protected least significant difference test. A simple correlation coefficient between yield variables, drought indices and moisture regimes were computed to understand their inter-relationship, with yield and yield variables.

4.3 Result and discussions

4.3.1 Soil characteristics

The soil pH was 5.4 and 6.2 at Kabete and Kiboko, respectively, indicating moderate acidity level. According to Mallikarjuna *et al.,* (2011), pigeon peas tolerate pH values of 4.5 to 8.0. The percent organic carbon was higher in Kabete soils (1.9%) compared to Kiboko soils (1.0%). The high organic carbon at Kabete was due to sampling of the forest soils, which was covered by vegetation, compared to Kiboko, where crop cultivations have happened previously. Kiboko soils were high in sodium (0.9 cmol/kg), Magnesium (4 cmol/kg), Phosphorus (65.6 ppm), Manganese (89.5 ppm) and Iron (59.6 ppm) (Table 19). Kabete soils was high in Potassium (2.4 cmol/kg), Calcium (7.5 cmol/kg) and Zinc (11.2 ppm). Generally, the soil and weather characteristics at both locations were within the pigeon pea soil requirements for proper growth and development.

Table 19: Soil chemical and organic matter characteristics of Kiboko and Kabete soils during the 2017-2018 planting season

Location	Ph	%N	%OC	K (cmol/kg)	Na (cmol/kg)	Ca (cmol/kg)	Mg (cmol/kg)	P (ppm)	Mn (ppm)	Zn (ppm)	Fe (ppm)	Cu (ppm)
KAB Forest Soil	5.4	0.2	1.9	2.4	0.8	7.5	3.9	18.5	44.3	11.2	58.5	1.0
KIB Open Field Soil	6.2	0.1	1.0	1.1	0.9	7.0	4.0	65.6	89.5	7.9	59.6	1.1

Where: KAB Kabete University Field Station; KIB – Kiboko Station; N-Nitrogen, OC – Organic carbon; Na – Sodium; Ca – Calcium; Mg – Magnesium, P – phosphorus; Mn – Manganese; Zn – Zinc; Fe – Iron; Cu – Cupper.

4.3.2 Rainfall Intensity and distribution

Kiboko open field trial: Kiboko received a total of 1,205 mm of rains, ranging from 2.8mm to 512mm, within 48 rainy days (Table 20), between October 2017 to August 2018. The first quarter of the season (October-December 2017) recorded a lower rainfall, representing fifteen percent of the total rainfall received, compared to the following quarter (January-March 2018), third (April to August 2018) with 47% and 38% respectively, necessitating the need for supplementary irrigation.

Table 20: Rainfall (mm), Average Relative Humidity (%) and temperatures during the vegetable pigeon pea growing season at Kiboko 2017-18

Month	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Mean
Rain (mm)	2.8	177.8	-	52.0	0.5	512.0	424.7	37.5	-	-	-	1,207.3
Mean Temp °C	25.2	24.1	24.3	25.0	25.0	24.3	24.4	23.2	21.4	21.7	21.2	23.6
Mean RH	73.9	83.8	82.6	79.7	79.9	91.3	90.2	85.3	85.4	82.0	82.1	83.3

In total, 988mm of water, was supplemented 38 times. Saritha et al., (2012) suggested two irrigations one at flower initiation and another at early pod formation stage significantly increased yields of pigeon pea as compared to control and one irrigation at early pod formation stage. The mean average temperature was 24°C and mean relative humidity was 83%. Months with high mean daily temperatures also reported lower relative humidity, but also high rainfall.

Kabete High tunnel: The mean temperature within the high tunnel was 27^{o}C, ranging from 26^{o}C in August to 27^{o}C in March, while the mean daily relative humidity was 71% ranging from 57% in March and 77% in October. The high temperatures of 27^{0}C and low relative humidity of 71% compared to the open season of 24^{0}C and 83% respectively accelerated the flowering and maturity of the genotypes under the high tunnels, compared to the open field. Genotypes under high tunnel at Kabete averagely flowered 46 days and matured 51 days earlier compared to open field at Kiboko.

4.3.3 Effect of moisture regimes on genotype yield (Kg/ha) performance

Combined analysis of variance of green vegetable pigeon pea genotypes under different moisture regimes under open field at Kiboko recorded significant differences among the genotypes ($P \leq 0.001$) and moisture regimes ($P \leq 0.01$) (Table 21).

Table 21: Combined Analysis of variance on the effects of intermittent moisture stress yield and yield variables under open field at Kiboko (2017-2018)

Moisture Regime	Yield (Kg/ha)	Pods/ Plant	100 Seed Mass (Gms)	Harvest Index (HI)	Shelling %	Days to Flower	Plant Height (cm)
Non-Irrigation	406.0a	67.60a	24.92a	17.42a	54.14ab	198.7c	211.4a
Irrigation to Flower	1135b	237.2c	28.29b	25.85bc	58.76b	126.8b	255.8b
Full Irrigation	1991c	210.2b	28.52b	28.55c	46.07a	122.1a	282.5b
Irrigation to Podding	1721c	220.0bc	29.71b	23.13b	52.18ab	128.5b	268.0b
Average	1313.3	183.8	27.9	23.7	52.80	144	254.40
LSD>0.05 Genotype (G)	335.7***	27.01***	1.94***	4.26***	8.58*	2.95***	28.1***
LSD>0.05 Moisture (M)	335.7**	27.01***	1.94***	NS	NS	2.95***	28.1*
LSD>0.05 GIM	NS	NS	3.87**	NS	NS	5.89**	56.19*
CV%	30.7	17.6	8.3	21.5	18.6	2.5	13.2

[w] *Full irrigation: Water applied to pod maturity/harvesting.*
[x] *Irrigation to flower: Water applied to when 50% of the flowers in the plot are open.*
[y] *Irrigation to Podding: Water applied till 50% of the plant's pod are set.*
[z] *Non-Irrigation: Water applied till 4th week, then stopped till pod maturity/harvest.*
, **, and * represent significance level at $P < 0.05$, $P < 0.01$ and $P < 0.001$ each, ns= non-significant*

In the high tunnel at Kabete, there was significant difference among the genotypes for yield and Moisture regime (P≤0.001). Yield ranged from 0 Kg/ha under terminal moisture stress to 1,518 Kg/ha under no moisture stress (full irrigation) (Table 22).

Table 22: Combined Analysis of variance on the effects of intermittent/random moisture stress yield and yield variables under high tunnel at Kabete (2017-2018)

Moisture Regime	Yield (Kg/ha)	Pods per Plant	100 Seed Mass (Gms)	Harvest Index	Shell %	Days to Flower	Final Plant Height
Full Irrigation	1,518d	28.7d	31.0d	29.4b	57.9c	99.0b	105.3d
Irrigation to Podding	904.2c	18.5c	28.7c	34.2b	54bc	96.5b	91.7c
Irrigation to Flowering	350b	8.2b	26.0b	30.5b	49.5b	100b	83.1b
No Irrigation	0a	0a	0a	0a	0a	0.00a	53.2a
Average	924.1	18.4	28.6	31.4	53.8	98.5	83.3
LSD (0.05) Genotype	114.4***	1.1***	1.4***	6.1***	5.2***	3.3***	3.0***
LSD (0.05) Moisture	114.4***	1.1***	1.4***	6.1***	NS	3.3***	3.0***
LSD (0.05) GIM	NS	2.2***	2.8***	12.3***	10.4*	6.7***	6.0***
CV%	19.8	9.7	7.8	31.3	15.5	5.4	4.3

*, **, and *** represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant

In the open field, genotypes performed differently for yields under no-stress (full irrigation) (P≤0.05) and in the high tunnel when moisture stress was initiated at flowering (P≤0.001) (Table 23). Under the high tunnel, there was no significant difference (P≥0.05) was noted among the genotypes under no moisture stress (full irrigation), moisture stress at podding and terminal moisture stress (no supplementary irrigation) under high tunnel.

Table 23: Effect of intermittent and terminal moisture stress on pigeon pea genotype performance on yield (Kg/ha) under open field and high tunnel during the 2017/2018 season

	Full Irrigation		Irrigation to Flower		Irrigation to Podding		Non-Irrigation	
Genotype	Open Field	High tunnel	Open Field	High tunnel	Open Field	High tunnel	Open Field	High tunnel
ICEAP 00554	1,692.0	1390	1,424.0	208.0a	1,634.0	676.40	273.0	0
ICEAP 00557	1,696.0	1279	672.0	259.6a	1,672.0	811.60	396.0	0
KAT 60/8	1,745.0	1712	871.0	451.6b	1,365.0	962.70	624.0	0
MZ 2/9	2,832.0	1691	1,574.0	480.9b	2,214.0	1,166.2	332.0	0
Average	1,991	1,518	1,135	350	1,721	904	406	-
LSD (0.05) G	827*	NS	NS	60.92***	NS	NS	NS	
CV%	20.8	12.4	34.9	8.7	24.8	23	41.9	

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant*

Genotypes were not significantly different (P≥0.05) for yield when moisture stress was initiated at flowering, podding and under terminal drought. The average yield among the genotypes was higher, 1,991 Kg/ha under no stress (full irrigation), followed by 1,721 Kgs/ha, when moisture stress was initiated at podding and 1,135 Kgs/ha when initiated at flowering. Genotypes production under terminal moisture stress recorded the lowest yields of 406 Kgs/ha. MZ 2/9 produced higher yields across all the moisture regimes, producing of 2,832 Kg/ha under no moisture stress (full irrigation), 1,574 Kg/ha when moisture stress was initiated at flowering, and 2,214 Kg/ha when moisture stress was initiated at podding. KAT 60/8 performed better than other genotypes, producing yields of 624 Kg/ha, under moisture stress (No supplementary irrigation). These results indicate that yield of green vegetable pigeon peas is enhanced when produced under optimum moisture condition.

Moisture stress was more severe in the high tunnel, producing 42% less yield compared to the open field yields at Kiboko. with open field at Kiboko recording 42% more yields compared to that of high tunnel. When intermittent moisture stress was introduced at flowering, yield was reduced by 43% compared to 14% when it was introduced at podding phase of development. (Appendix 1). These results indicate that flowering phase of green vegetable pigeon pea development is the most sensitive to moisture stress. Saad, (2012) observed that reduction in yield under low moisture was because of reduction in pods numbers and abortion of the embryo. In evaluation of extra short duration pigeon peas, Nam *et al*., (2001) observed that moisture stress at flowering caused reduction grain yield by 40-55% than when moisture stress imposed during pod filling stages of growth. Moisture stress at reproductive phase affects plant ability to produce more pods, which is positively associated with yield. Further, low moisture levels during podding phase reduces the rate of photosynthesis and translocation of the carbohydrates to the developing pods, leading to poor seed development (Sadeghipour 2008).

4.3.4 Effect of moisture stress on green vegetable pigeon pea pods per plant

Combined analysis of variance of green vegetable pigeon pea genotypes under different moisture regimes at Kiboko under open field recorded significant differences among the genotypes, moisture regimes and their interaction (GIM) ($P \leq 0.001$) for number of pods (Table 21). Pods per plant ranged from 68 pods under terminal drought to 237 pods per plant when moisture stress was initiated after flowering. In the tunnel, there was significant difference among the genotypes, Moisture regime and interaction GIM ($P \leq 0.001$) for number of pods per plant. No significant interaction was noted for GIM at this location. Pods per plant ranged from 0 pods under terminal moisture stress to 29 pods under no moisture stress. Number of pods started reducing when moisture stress was initiated at flowering, then at podding.

Green vegetable genotypes pigeon peas produced under the tunnel were significantly different for pods per plant under no-stress (full irrigation) (P≤0.001) and when moisture stress was initiated at podding stage of development (P≤0.01) (Table 22). MZ 2/9 consistently produced more pods per plant, with the highest, 38 pods under full irrigation (no-stress), 10 pods when moisture stress was initiated at flowering stage of development and 25 pods when initiated at podding stage of development. Under open field, genotypes were significantly different for number of pods only when moisture stress was initiated at podding phase (P≤0.05) (Table 24). Under full irrigation (No-stress), ICEAP 00554 produced more pods 241 pods/plant and 299 pods when moisture stress was initiated at flowering. KAT 60/8 produced more pods, 103 pods under stress (no-irrigation) and 257 pods when moisture stress was initiated at podding development phase. The lower pod numbers under high tunnel trial at Kabete could be due to high temperatures, low relative humidity, and restricted moisture access, which could have led to pod abortion.

Table 24: Effect of intermittent/random and terminal moisture stress on pigeon pea genotype performance on number of pods per plant under open field and high tunnel during the 2017/2018 season

	Full Irrigation		**Irrigation to Flower**		**Irrigation to Podding**		**Non-Irrigation**	
Genotype	Open Field	High tunnel	Open Field	High tunnel	Open Field	High tunnel	Open Field	High tunnel
ICEAP 00554	240.8a	25.00a	298.7a	7.667a	205.3a	17.67a	80.0a	0
ICEAP 00557	207.8a	28.67a	229.1a	7.667a	223.2a	16.67a	49.6a	0
KAT 60/8	223.4a	23.33a	218.2a	7.333a	257.3a	15.00a	102.9a	0
MZ 2/9	168.7a	37.67b	203.0a	10.00a	194.3a	24.67b	37.9a	0
Average	210.2	28.8	237.3	8.17	220	18.5	67.6	-
LSD (0.05) G	NS	4.07***	NS	NS	60.13*	3.65**	NS	
CV%	12.2	7.1	19.3	13.9	12.7	9.9	23.1	

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant*

The study observed a higher reduction of 72% in number of pods produced under high tunnel, when intermittent moisture stress was introduced at flowering and 36% reduction at podding phase, when compared to non-stressed plants (Appendix 1). Reduction in pods population when moisture levels were reduced at flowering was because of reduced photosynthesis efficiency, leading to floral and embryo abortions and therefore poorer pod development (Castaneda-Saucedo *et al.*, 2009).

4.3.5 Effect of moisture stress on green vegetable pigeon pea seed mass (g/100 seeds)

Combined analysis of variance of green vegetable Pigeon pea genotypes under different moisture regimes at Kiboko under open field recorded significant differences among the genotypes, moisture regimes (P≤0.001) and interaction (GIM) (P≤0.01) for seed mass (g/100 seeds) (Table 21). Seed mass varied when moisture stress was initiated at different growth phases of green vegetable pigeon pea genotypes, under high tunnel and open field, with significant reduction being observed when moisture stress was initiated at flowering phase, representing 16% compared to when initiated at podding, with an 8% reduction in seed mass.

Seed mass varied from 30 grams/100 seeds when moisture stress was initiated at podding to 25 grams/100 seeds, under terminal drought. In the tunnel, there was significant difference among the genotypes, Moisture regime and interaction GIM (P≤0.001) for seed mass (g/100 seeds). Seed mass ranged from 0 grams/100 seeds under terminal moisture stress to 31 grams/100 seeds under no-stress (full irrigation). Intermittent Moisture stress during podding phase produced peas which were heavier (29 grams/100 seed) compared to when moisture stress was initiated at flowering (26 grams/100 seeds). Green vegetable pigeon pea genotypes produced under open field were significantly different for seed mass (g/100 seed) when intermittent moisture stress was initiated at podding and under stress (no-irrigation) (P≤0.01). The genotypes performed differently for seed mass (g/100 seeds) under no moisture stress (full irrigation), intermittent moisture stress at flowering and intermittent moisture stress at podding (P≤0.001).

Genotype MZ 2/9 produce heavier seed across all moisture regimes, at both locations, recording a mean of 32 g/100 seed, under open field and 38 g/100 under high tunnel. Moisture stress at flowering stage affects pod initiation process, which require water to translocate photosynthate to support pod initiation and development. These statistics indicates that under optimum moisture condition, seed size improves leading to heavier peas. Photosynthate and nutrient movement is facilitated by moisture in the plant towards the sink (the seed), especially at podding phase of growth and development. Random, and intermittent moisture stress leads to reduced efficiency of the xylem and phloem tissues, to move both water and photosynthates that influence seed development.

Table 25: Effect of intermittent/random and terminal moisture stress on pigeon pea genotype performance on seed mass (g/100 seeds) under open field and high tunnel during the 2017/2018 season

	Full Irrigation		Irrigation to Flower		Irrigation to Podding		Non-Irrigation	
Genotype	Open Field	High tunnel	Open Field	High tunnel	Open Field	High tunnel	Open Field	High tunnel
ICEAP 00554	28.7	27.77ab	27.0	24.87b	26.6c	29.43b	22.0b	0
ICEAP 00557	26.3	31.73b	27.0	25.37b	30.0ab	26.50b	19.3c	0
KAT 60/8	25.3	22.27a	27.3	19.9a	28.7c	20.53a	28.0b	0
MZ 2/9	33.7	42.37c	31.9	34.03c	33.5a	38.37c	30.3a	0
Average	28.5	31	28.3	26.04	29.7	28.71	24.9	-
LSD (005)	NS	6.13***	NS	1.36***	2.85**	3.01***	4.5**	-
CV%	11.3	9.9	7.2	2.6	5.1	5.2	9.1	

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant*

4.3.6 Effect of moisture stress on green vegetable pigeon pea harvest Index (%)

Combined analysis of variance of green vegetable Pigeon pea genotypes under different moisture regimes under open field recorded significant differences among the genotypes (P≤0.001) (Table 21). Moisture regimes and interaction (GIM) were not significant (P>0.05) for harvest index, indicating that variation in harvest index was mainly due to genotypic and not variation in moisture regimes. Harvest index varied from 17% under terminal drought to 29% under no stress (full irrigation), indicating that under optimum moisture levels, the plants produce heavier peas, leading to increased harvest index, though the increase was not significant among the genotypes. In the high tunnel at Kiboko, there was significant difference among the genotypes, Moisture regime and interaction GIM (P≤0.001) for harvest index (Table 22). Seed mass ranged from 0 grams/100 seeds under terminal moisture stress to 31 grams/100 seeds. Harvest index ranged from 0% under terminal moisture stress to 34% when intermittent drought was introduced at podding, indicating that improved moisture levels at podding phase leads to improved harvest index (%) and therefore increased biological yields.

In the open field, genotypes there was no statistical differences among the genotypes (P≥0.05) for harvest index, across all the moisture regimes, indicating lack of diversity among the genotypes for harvest index (Table 26). However, genotype ICEAP 00554 recorded a higher harvest index of 19% under stress (no-irrigation) and 26% when moisture stress was initiated at podding and 29%

when initiated at flowering, while KAT 60/8 produced the highest HI of 32% under no stress in the open field. In the high tunnel, significant difference was noted among the genotypes, when moisture stress was initiated at flowering (P≤0.001), at podding (P≤0.05) and non-stress (full irrigation) (P≤0.05).

Table 26: Effect of intermittent/random and terminal moisture stress on pigeon pea genotype performance on harvest index (%) under open field and high tunnel during the 2017/2018 season

	Full Irrigation		Irrigation to Flower		Irrigation to Podding		Non-Irrigation	
Genotype	Open Field	High tunnel	Open Field	High tunnel	Open Field	High tunnel	Open Field	High tunnel
ICEAP 00554	28.5	23.81ab	28.7	11.17a	26.2	17.43a	19.2	0
ICEAP 00557	31.2	23.42a	24.0	14.19a	24.5	33.31ab	16.0	0
KAT 60/8	31.5	25.92ab	24.4	29.70a	22.2	46.39b	16.4	0
MZ 2/9	23.0	44.39b	26.3	66.83b	19.6	39.83ab	18.1	0
Average	28.5	29.3	25.9	30.4725	23.1	34.24	17.4	-
LSD (0.05)	NS	14.75*	NS	19.4***	NS	19.16*	NS	
CV%	21.4	25.1	15.9	31.9	13.3	28	13.5	

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant*

Genotype MZ 2/9 produced a higher HI when moisture stress was initiated at flowering (67%) and 44% at no-stress (full irrigation), while, KAT 60/8 performed better, recording a 46% harvest index (HI%), when moisture stress was initiated at podding. Generally, genotypes that recorded higher yields such as ICEAP 00554 and MZ 2/9, also recorded higher harvest index. Under high tunnel, harvest index was reduced by 16.5% when the moisture stress was introduced at podding and 3.7% when introduced at flowering. These results indicate that genotypes respond differently to different moisture regimes and interaction between GIM influences the harvest index.

The study noted that under the open field at Kiboko, harvest index reduced by 19% when intermittent moisture stress was introduced at podding, 9.5% when introduced at flowering, and 39% when there was no supplementary irrigation (terminal moisture stress). These results shows that moisture stress during flowering provides poor foundation for pod establishment and ultimately pea development. Improved moisture levels during podding phase of development in green vegetable pigeon peas lead to increased harvest index, due to heavier seeds. The plants in the high tunnel experience shorter growth period, leading to reduced number of sinks, which improved translocation of the photosynthates towards the developing seed, and therefore improved harvest index, compared to open field, where the plant took more time to maturity, with more photosynthates being directed towards vegetative development.

4.3.7 Effect of moisture stress on green vegetable pigeon pea duration to flower

Combined analysis of variance of green vegetable Pigeon pea genotypes under different moisture regimes under open field at Kiboko, recorded significant differences among the genotypes, moisture regimes (P≤0.001) and Moisture regimes and interaction (GIM) (P≤0.01) for duration to flower (Table 21). The duration to flower ranged from 199 days under moisture stress to 128 days when moisture stress was initiated at podding. In the tunnel, there was significant difference among the genotypes, Moisture regime and interaction GIM (P≤0.001) for duration to flower. Duration to flowering under high tunnel ranged from 0 under stress (no irrigation) to 100 days when moisture stress was initiated at flowering (Table 22). Under Moisture stress (no supplementary irrigation), the plants were not able to reach maturity, leading to total failure to flower. The significant difference among the moisture regimes for duration to maturity indicates that genotype can be selected for performance under different moisture regimes, for duration to maturity.

Table 27: Effect of intermittent/random and terminal moisture stress on pigeon pea genotype performance on duration to 50% flower (days) under open field and high tunnel during the 2017/2018 season

	Full Irrigation		Irrigation to Flower		Irrigation to Podding		Non-Irrigation	
Genotype	Open Field	High tunnel	Open Field	High tunnel	Open Field	High tunnel	Open Field	High tunnel
ICEAP 00554	127c	106.0b	129.00	110.70b	135.67	109.33b	200.67	-
ICEAP 00557	120b	108.0b	122.67	108.70b	129.33	105.00b	198.67	-
KAT 60/8	116a	96.67ab	128.00	94.00a	125.00	88.33a	189.67	-
MZ 2/9	125c	85.33a	127.67	86.70a	124.00	83.33a	205.67	-
Average	**122.1**	**99.00**	**126.8**	**100.0**	**128.5**	**96.5**	**198.7**	**-**
LSD (005) G	2.51**	10.1**	NS	7.7***	NS	10.5**	9.32**	
CV%	1.0	5.1	1.1	3.8	4.4	5.4	2.3	

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant*

The study observed differences among the genotypes for duration to flower under open field for non-stress (Full irrigation), irrigation to podding, and full stress (No irrigation) (P≤0.01) (Table 27). Under high tunnel, genotypes were significantly different under full irrigation (P≤0.01), irrigation to flower (P≤0.001) and irrigation to podding (P≤0.01) for duration to flower. Under open field trial, KAT 60/8 was significantly early compared to other genotypes at full irrigation by

116 days and no-irrigation by 190 days. The genotype was early under high tunnel under full irrigation (no stress) by 97 days and when moisture stress was initiated at flowering (irrigation to flower) by 94 days.

Prolonged growth duration among the late flowering and maturing vegetable pigeon peas, exposed them to terminal drought, leading to reduced yields. In red-seeded common beans, Rezene *et al.*, (2011) observed genotypes that take longer to mature are exposed to moisture stress, leading to yield reduction, due to high net water requirement to support the duration of plant growth and development, compared to those that mature early. These results indicate that genotypes respond differently to different moisture regimes and interaction between GIM influences the duration to flower, and low moisture levels accelerates flowering in green vegetable pigeon peas.

The study observed that genotypes producing higher yields, took less days to flower and were also shorter. Genotypes such as such as ICEAP 00554 that delayed to flower (127 days) produced lower yields (1692 Kg/ha) compared to KAT 60/8, that matured early (116 days), and produced higher yields (1745 Kgs/ha) under open field trial (Figure 7), confirming that late maturing genotypes are exposed to terminal moisture stress compared to the early maturing genotypes leading to yield loss.

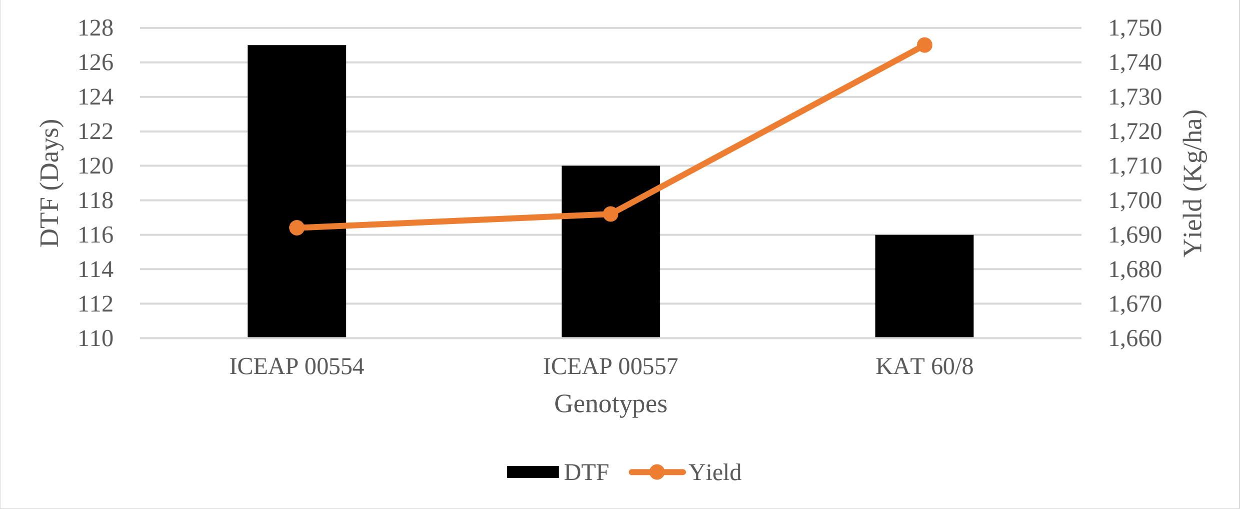


Figure 7: Relationship between duration to flower and yield of three genotypes under open field trial 2018-2019

Further analysis of the open field and high tunnel indicated that the high mean daily temperatures under high tunnel of 27^{o}C, accelerated the flowering of the genotypes by 46 days, compared to open field, which recorded mean daily temperature of 24^{o}C. Therefore, Increased moisture stress, coupled with high temperatures under the high tunnel, led to genotypes flowering early, at 99 days, compared to 122 days under open field. These results indicates that high temperatures, combined with low moisture levels accelerates genotypes to flower early.

4.3.8 Effect of moisture stress on green vegetable pigeon pea final plant height

Genotypes were significantly different for plant height under non-stress (Full irrigation) and moisture stress at flowering and podding under high tunnel, while under open field, there was no significant difference among the genotypes under moisture stress at podding and terminal moisture stress (No-irrigation) (Table 28).

Table 28: Effect of intermittent/random and terminal moisture stress on pigeon pea genotype performance on plant height (cm) under open field and high tunnel - 2017/2019

	Full Irrigation		Irrigation to Flower		Irrigation to Podding		Non-Irrigation	
Genotype Name	Open Field	High tunnel	Open Field	High tunnel	Open Field	High tunnel	Open Field	High tunnel
ICEAP 00554	321a	103.3b	279.2a	93.33b	291.7	104.67d	164.8	53.0
ICEAP 00557	283a	106.7b	283.4a	88.33ab	260.1	96.67c	245.0	49.0
KAT 60/8	285a	116.3c	233.7a	75.33a	250.1	89.00b	257.3	54.0
MZ 2/9	241c	95.00a	227.1c	75.33a	270.0	76.33a	178.7	56.0
Average	282	105.3	255.9	83.08	268	91.67	211.5	53.2
LSD $_{(0.05)}$ G	38.7*	5.34***	25.38**	9.46**	NS	5.28***	NS	NS
CV%	6.9	2.5	5.0	5.7	5.5	2.9	28	

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant*

Combined analysis of variance of green vegetable pigeon pea genotypes under different moisture regimes at Kiboko under open field recorded significant differences among the genotypes ($P\leq0.01$), moisture regimes and Moisture regimes and interaction (GIM) ($P\leq0.05$) for plant height (Table 21). Plant height ranged from 211 cm under terminal moisture stress to 283 cm under no moisture stress (full irrigation), indicating that under optimum moisture conditions, the pigeoneers have potential to grow taller compared to those grown under intermittent and terminal moisture stress. In the tunnel, there was significant difference among the genotypes, Moisture regime and interaction GIM ($P\leq0.001$) for final plant height, with the final plant height ranging from 53 cm under terminal moisture stress to 105 cm under no stress (Full irrigation) (Table 22).

The study observed that plants under no-moisture stress (full irrigation) were taller by 34cm compared to terminally moisture stressed plants (no-irrigation), indicating that favourable moisture levels result into taller plants. Terminal moisture stress under open field trial reduced the plant height by 33%, while introduction of moisture stress at flowering reduced the plant height by 10%, moisture stress at podding stage reduced plant height by 5%. Similar trend was observed under the tunnel with terminal moisture stress reduced the plant height by 98%, while moisture stress at flowering and podding reduced plant height by 26% and 12% respectively. These finding are in line with Ntukamazina et al (2017) [who reported that plant height is reduced under moisture stress. The study noted that plant height improved as intermittent moisture stress was initiated as the plant grows, indicating that moisture is necessary for plant growth, especially during cell division leading to plant elongation.

Supplementary irrigation at early stage of development improves plant height, and when applied at flowering and podding stage, plant height is not affected. Several research has shown that plant height reduces due to moisture stress in grain pigeons (Khourgami, 2012) and Faba beans (Attia, 2013). Plant height is susceptible to moisture stress especially when it happens in early plant development (Ahmed *et al*., 2015). The reduction in plant height was accelerated by moisture stress was because of decrease in the ability of the plant to photo synthesis and move the products to the growing plant (Ohashi *et al*., 2000 and Kalima, 2013), leading to reduced cell division and therefore, shorter plants. Several studies have also reported reduction in plant height, in other crops, due to moisture stress. These include dry grain pigeon peas (Khourgami, 2012) and Faba beans (Attia, 2013).

4.3.9 Effect of moisture stress on root dry matter

The study utilized the opportunity of high tunnel planting in pots to determine the rooting characteristics of the vegetable pigeon peas. The variables considered included: root length, stem, and branches biomass and the root dry matter. This was not possible in the open field due to the soil condition. Combined analysis of variance indicated significant difference among the genotypes ($P<0.001$) and moisture regimes ($P<0.01$) for root dry matter, but no interaction between GIM (Table 29). The roots dry matter ranged from 1.7 grams under moisture stress (No-irrigation) to 16.24 grams under no stress (full irrigation), with a mean of 9.7gms. These indicates that improved moisture levels increase the root dry matter.

Table 29: Analysis of variance on the effects of Moisture regimes on reproductive variable of vegetable pigeon pea under High tunnel at Kabete (2017-2018)

Moisture Regime	Root Length (cm)	Stem + Branches (Gms)	Root Dry matter (Gms)
Full Irrigation	40.0c	65.2c	16.2c
Irrigation to Podding	37.0bc	34.1b	12.1bc
Irrigation to Flowering	32.7b	30.4b	8.9b
No Irrigation	21.3a	5.70a	1.70a
Average	32.7	33.9	9.7
LSD (0.05) Genotype	5.04*	8.53***	3.3***
LSD (0.05) Moisture	5.04NS	8.53***	3.3***
LSD (0.05) GxM	10.08NS	17.06NS	6.7NS
CV%	18.5	30.2	41

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant*

Genotypes were significantly different (P< 0.05) for roots dry matter, except when moisture stress was initiated at podding, indicating that intermittent moisture stress at podding phase negatively affect root development, as most of the photosynthate are being re-directed towards pods and peas development at the expense of the roots (Table 30). ICEAP 00554 consistently produced roots with high dry matter, followed by KAT 60/8, while MZ 2/9 produced roots with the lowest dry matter, especially when moisture stress was initiated at flowering. The study has noted that genotypes such as MZ 2/9 which produced high yields, produced roots with low dry matter, indicating that its photosynthate is mobilized towards the development of peas than to the roots.

Table 30: Effect of intermittent/random and terminal moisture stress on pigeon pea genotype performance on Roots dry matter (grams) under high tunnel - 2018/2019

Genotypes	Full Irrigation (grams)	Irrigation to flower (grams)	Irrigation to podding (Grams)	No-Irrigation (grams)
ICEAP 00554	24.3	13.0	20.4b	2.3
ICEAP 00557	13.6	8.2	10.5ab	1.4
KAT 60/8	19.0	10.0a	10.6 ab	1.2
MZ 2/9	8.1	4.6	6.8a	1.9
Average	16.24	8.92	12.06	1.71
LSD (005)	NS	NS	7.22*	NS
CV%	37.6	36.1	30	57.4

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant*

When plants are exposed to terminal moisture stress (no supplementary irrigation), the roots dry-matter was reduced by 90%, while when moisture stress was introduced at podding, the root dry matter reduced by 45% and at flowering by 25%, compared to no-stressed (full irrigation) (Appendix 1). The lack of significance difference among the genotypes at early stages when moisture stress was imposed at flowering showed that when the plants are young, they absorb moisture and access nutrients from the rhizosphere (Admasu et al (2019). This efficiency reduces as the plant grows, leading to significant difference at podding phase, of which at this stage, the pods have become a major sink.

4.3.10 Effect of moisture stress on root length (cm)

Combined ANOVA indicated that the effect of moisture and interaction between moisture and genotypes (GIM) were not significant (P<0.05) for root length, indicating that root length is mainly determined by genetic potential of the genotypes (Table 31). Plants in non-stressed moisture regimes recorded longer roots, measuring 40 cm compared to 21cm under stress (No irrigation). Root length also measured 33 cm, when moisture stress was introduced at flowering and 37 at when introduced at podding.

There was significant difference among the genotypes (P<0.05) for root length when moisture stress was initiated at podding. While MZ 2/9 produced longer roots, 45cm, under no-stress (full irrigation), ICEAP 00554 produced longer roots, 38.5 cm, when moisture stress was initiated at flowering, 45 cm at podding, and 24cm under stressed condition (no irrigation).

Table 31: Effect of intermittent and terminal moisture stress on pigeon pea genotype performance on root length (cm) under high tunnel - 2018/2019

Genotypes	Full Irrigation (cm)	Irrigation to flower (cm)	Irrigation to podding (cm)	No-Irrigation (cm)
ICEAP 00554	35.3	38.5	44.5b	23.5
ICEAP 00557	39.7	32.0	39.8ab	18.3
KAT 60/8	40.0	30.5	35.5 ab	21.7
MZ 2/9	45.0	29.7	28.0a	21.5
Average	40.0	32.7	36.96	21.3
LSD (005)	NS	NS	9.57*	NS
CV%	18.9	13.1	13	21.2

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant*

The longer roots in MZ 2/9 are part of adaptation mechanism, in search for nutrients and moisture to support pod production, confirming why genotype, MZ 2/9 recorded low root dry matter, but longer roots, and high yields. The study observed a positive association between root length

(P<0.001) and DTF, DTM and plant height, grain weight, pods per plant, primary branches, confirming that plants that take longer duration to mature develops longer roots for support of the increased biomass and increased water demand to support plant growth. Root length was reduced by 8% when moisture stress was introduced at podding, 18% at flowering and 47% under terminal drought (Stress) (Appendix 1).

When intermittent drought is introduced at podding, it finds the root growth and development is almost at final stages, and therefore, intermittent moisture stress at this stage may not significantly affect the root length. The lack of significant difference among the genotypes when moisture stress was initiated at flowering indicates plant's ability to access moisture around the rhizosphere before podding, and before stronger sink (pods) has been developed. When plants are exposed to water stress, the root cell development is reduced, which affects mineral and water uptake, ultimately affecting photosynthesis and photosynthate translocation (Guo *et al.,* 2013), leading to shorter roots.

4.3.11 Effect of moisture stress on overall plant biomass

There was significant influence of genotype and moisture stress on the overall plant dry matter. No significant interaction was observed for the two on overall plant biomass (Table 32). Dry matter ranged from 5.7 grams (stressed) to 65.2 grams (non-stressed) with a mean of 33.9 grams.

Table 32: Effect of intermittent/random and terminal moisture stress on pigeon pea genotype performance on plant dry matter (stems + branches + leaves) under high tunnel - 2018/2019

Genotypes	Full Irrigation	Irrigation to flower	Irrigation to podding	No-Irrigation
ICEAP 00554	69.9	34.4b	44.1	6.4
ICEAP 00557	69.2	36.6b	37.4	4.9
KAT 60/8	78.8	35.7b	36.8	6.1
MZ 2/9	43.0	15.1a	18.2	5.3
Average	65.22	30.44	34.12	5.66
LSD (005)	NS	13.11*	NS	NS
CV%	28.2	21.6	30.9	20.7

*, **, and *** represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant

Introduction of moisture stress at podding reduced the overall plant dry matter by 48%, at flowering, dry matter was reduced by 53% and no-irrigation (terminal drought) by 91%, compared to non-stress. Genotypes performed differently (P<0.05) for plant dry matter (biomass) only when moisture stress was initiated at flowering. While KAT 60/8 recorded a higher dry matter biomass of 78.8 grams under non-stress (full irrigation), ICEAP 00557 produced more dry matter of 36.6 grams when moisture stress was initiated at flowering and 37.4 grams at podding. ICEAP 00554 recorded a higher dry matter content of 6.4 grams under terminal moisture stress, while MZ 2/9 produced plants with the lowest dry matter weight across all the moisture regimes, indicating that most of its dry matter was being partitions towards the biological yield, leading to high yields.

The result from this study indicates that the variation in soil moisture influences the plant dry matter, but no interaction between moisture and genotypes for the same. Figure 8 shows that all the root characteristics improve with increased soil moisture levels. Improved root characteristics means that the plants have enough nutrients and moisture, leading to more yields. Plants that were under moisture stress recorded low roots dry matter; they became shorter contributing to overall reduced plant biomass.

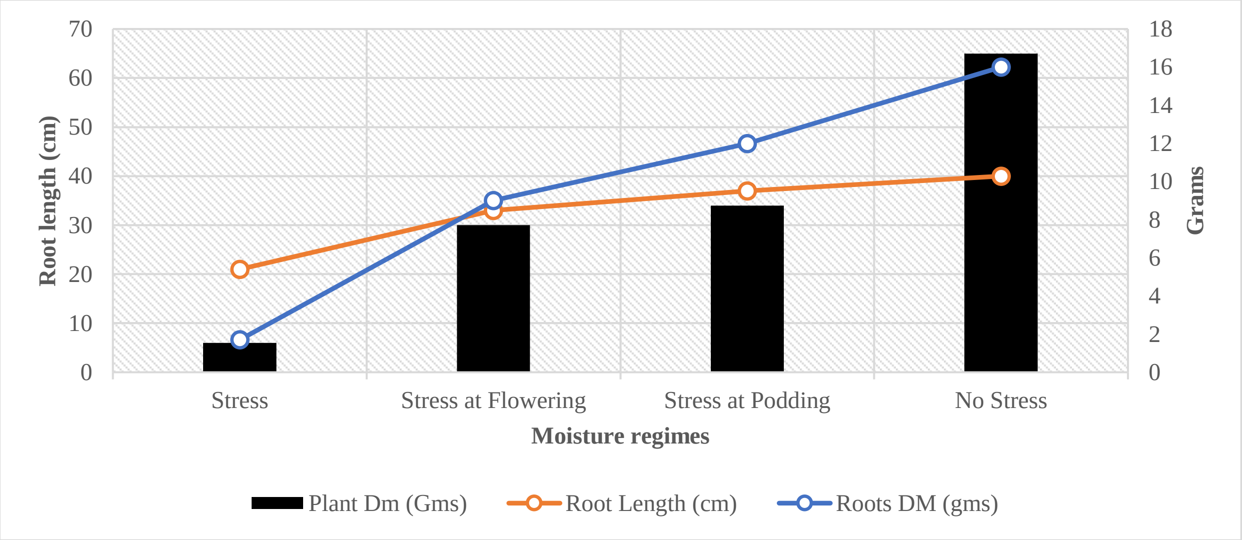


Figure 8: Relationship between moisture stress at different pigeon pea development phases and plant dry-matter (grams), root length (cm) and roots dry-matter (grams) under the high tunnel – 2018-2019.

Correlation analysis revealed that plant biomass (stems and branch dry matter) was positively and significantly correlated to all the yield variables except harvest index and secondary branches. It was observed that plant height contributes 88% towards overall plant biomass. As the plant grow taller, so are the branches, leaves and biological yield, leading improved plant biomass. High significant correlation between duration to flower (DTF), plant height, and overall plant biomass indicates that plants that take longer to mature has better roots characteristics, to sustain growth and development, as they have enough time for root development.

4.3.12 Effect of water stress on drought susceptibility index (DSI)

There were no observed differences among the genotypes for drought susceptibility index (DSI) under all the moisture regimes (P≥0.05), under open field and high tunnel. Against this, MZ2/9 scored highly for DSI, 1.022 under open field trial at Kiboko, when moisture stress was introduced at flowering, while under high tunnel, KAT 60/8 performed well with a DSI of 1.000. When moisture stress was introduced at podding, KAT 60/8 recorded a higher DSI of 0.987 under open field and 1.005 under high tunnel (Table 33). Genotype ICEAP 00557 and KAT 60/8 recorded a lower than 1 DSI of 0.973 and 0.980 respectively, indicating that they are more tolerant to moisture stress, under open field season, compared to other genotypes.

Table 33: Effect of intermittent/random and terminal moisture stress on pigeon pea genotype performance on drought susceptibility index (DSI) (%) under open field and high tunnel during the 2017/2018 season

	Irrigation to Flower		**Irrigation to Mature**		**Non-Irrigation**	
Genotype Name	**Open Field**	**High Tunnel**	**Open Field**	**High Tunnel**	**Open Field**	**High Tunnel**
ICEAP 00554	1.018	0.999	0.964	0.963	1.003	-
ICEAP 00557	0.996	0.993	0.96	0.932	0.973	-
KAT 60/8	0.951	1.000	0.987	1.005	0.98	-
MZ 2/9	1.022	0.998	0.984	0.976	1.000	-
Average	0.99675	0.9975	0.97375	0.969	0.989	-
LSD (0.05) Genotype	NS	NS	NS	NS	NS	
CV%	35.4	3.2	26.59	45.5	35	

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant*

4.3.13 Effect of water stress on drought tolerance efficiency (DTE)

Combined analysis of variance produced no significant interaction between moisture regime and genotypes GIM) for DTE. DTE ranged from 21% (Stress/full irrigation) to 80% (Moisture stress at Podding) under open field, while under high tunnel season, it ranged from 23% under irrigation to flower to 61%. There was no significant difference (P≥0.05) among the genotypes for DTE under open field trial at Kiboko, while significant difference (P≤0.05) was observed under high tunnel at Kabete, when moisture stress was introduced at flowering (Table 34). ICEAP 00557 and

KAT 60/8 recorded a higher DTE of 25% and 31% under stress (no-irrigation) respectively in the open field, indicating high levels of tolerance to moisture stress. ICEAP 00554 and ICEAP 00557 recorded 89% and 86% DTE under open field trial at Kiboko when moisture stress was initiated at podding phase. Under high tunnel at Kabete, MZ 2/9 and Kat 60/8 reported a higher DTE of 29% and 26% respectively, while when moisture stress was initiated at podding, MZ 2/9 and ICEAP 00557 recorded 70% and 66% respectively (Table 34).

Table 34: Effect of intermittent/random and terminal moisture stress on pigeon pea genotype performance on drought tolerance efficiency (DTE) (%) under open field and high tunnel during the 2017/2018 season

	Irrigation to Flower		Irrigation to Podding		Non-Irrigation	
Genotype Name	Open Field	Tunnel	Open Field	Tunnel	Open Field	Tunnel
ICEAP 00554	76.3a	18.76 a	88.5a	50.6a	14.4a	-
ICEAP 00557	39.8a	16.80 a	86.0a	65.9a	25.4a	-
KAT 60/8	44.1a	26.39 b	65.0a	56.0a	30.9a	-
MZ 2/9	54.6a	28.55 b	78.5a	69.7a	13.1a	-
Average	53.7	22.63	79.5	60.55	20.95	-
LSD (0.05) Genotype	NS	5.15*	NS	NS	NS	-
CV%	35.8	11.4	16.7	31.4	62	-

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant*

High mean DTE was noted among the genotypes when moisture stress was initiated at podding, under open field (79.5%), stressed plants (terminal drought) showed a lower DTE of 21% compared to 45% when moisture stress was initiated at flowering and 76% when initiated at podding. Similar trend was observed under high tunnel, where initiation of moisture stress at flowering led to a lower DTE of 23%, compared to when moisture stress was introduced at podding, with a DTE of 61%. Genotypes become more tolerant to moisture stress when introduced at podding, compared to a flowering, indicating that any supplementary irrigation for green vegetable pigeon peas, need to be initiated at flowering. Under open trial at Kiboko, DTE was positively correlated ($P \leq 0.001$) to Yield (Kg/ha) (r=0.8925), Harvest index (r=0.6411) and pods per plant (r=0.6308), but negatively but significantly correlated ($P \leq 0.001$) to day to flower (-0.6852) and days to harvest (-0.6627). Under high tunnel trial at Kabete, DTE was positively correlated ($P \leq 0.001$) to Yield (0.9325) and Pods per plant (0.7911). The positive association with yield in this study indicates that early maturing genotypes has capacity to hasten their phenological phases as a means of drought escape, leading to higher yields. When plants delay to flower and reach maturity, they are exposed to moisture stress at the later stage of development, leading to reduced performance dur to terminal drought (Silim *et al*., 2007).

4.3.14 Effect of water stress on yield reduction rate (YRR)

There were no significant differences among the genotypes under different moisture regimes for yield reduction rate (YRR). ICEAP 00554 recorded a lower yield reduction rate when moisture stress was introduced at flowering (16%), while ICEAP 00557 recorded the lowest yield reduction of less than 1%, when stress was introduced at podding under open field trial at Kiboko, while KAT 60/8 and ICEAP 00557 recorded a lower yield loss of 60% and 75% respectively, though not significantly different under terminal drought (Stress) (Table 35).

Table 35: Effect of intermittent and terminal moisture stress on pigeon pea genotype performance on yield reduction (%) under open field and high tunnel during the 2017/2018 season

Genotype Name	Irrigation to Flower		Irrigation to Podding		Non-Irrigation	
	Open	Tunnel	Open	Tunnel	Open	Tunnel
ICEAP 00554	16.0	81.2	2.6	49.4	83.8	-
ICEAP 00557	60.2	83.2	0.5	34.1	74.6	-
KAT 60/8	49.0	73.6	3.2	44.0	60.3	-
MZ 2/9	45.4	71.4	21.5	30.3	88.2	-
Mean	42.7	77.4	7.0	39.5	76.7	-
LSD (0.05) Genotype	NS	NS	NS	NS	NS	-
LSD (0.05) Moisture	24.03***	11.67***	24.03***	11.67***	24.03***	-
LSD (0.05) GXM	NS	NS	NS	NS	NS	-
CV%	67.40	22.80	67.40	22.8	67.40	-

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant*

Under high tunnel, ICEAP 00554 and ICEAP 00557 recorded a higher yield reduction rate of 81% and 83% respectively, while moisture stress at podding under high tunnel at Kabete, ICEAP 00554 and KAT 60/8 recorded the highest YRR of 49% and 44% respectively. Moisture stress significantly reduced YRR at flowering at both trials, compared to stress at podding. Under open field, moisture stress at podding recorded the lowest YRR mean of 7%, followed by moisture stress at flowering (43%), while terminal drought (non-irrigation) recorded the highest YRR of 77%. Under high tunnel, irrigation to podding recorded 40% loss in yield, compared to Irrigation to flower of 77%. Moisture stress at flowering reduces the number of pods and plant height, and given their positive association with yield, any reduction in these variables leads to reduction in yield. The lower yield reduction among the genotypes under open field (42%) indicated that the plants had the opportunity to extract moisture from below the profile compared to those planted in the pot, which had restricted root growth.

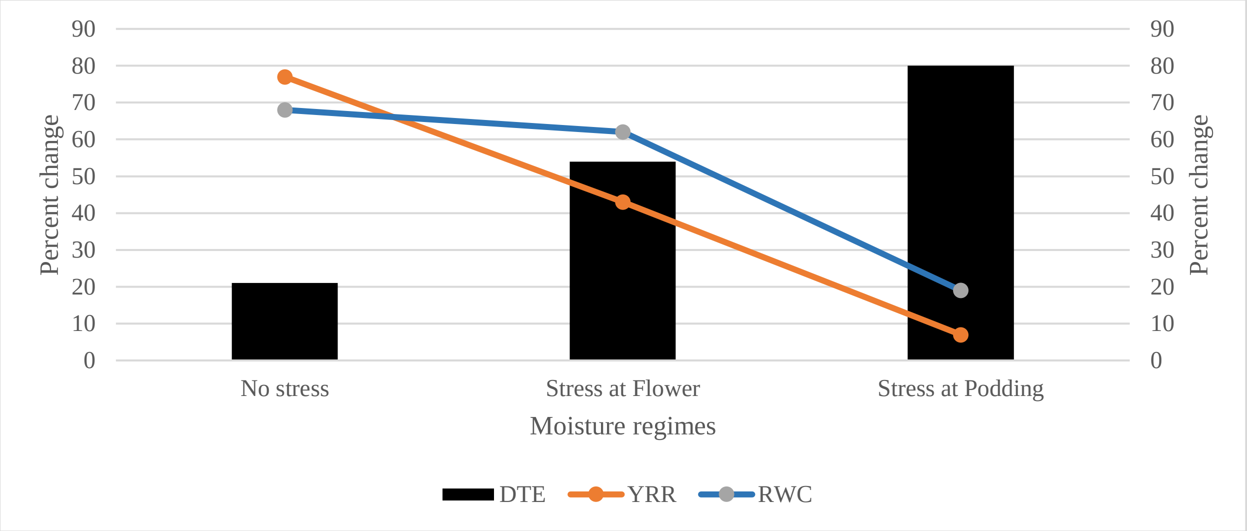


Figure 9: Relationship between drought tolerance efficiency (DTE), yield reduction rates (YRR) and relative water content in the open field at Kiboko – 2018-2019

4.3.15 Effect of water stress on relative water content (RWC)

RWC was determined at vegetative, flowering, and podding phase of green vegetable pigeon pea growth and development, only under high tunnel. There was significant difference among the moisture regimes for RWC at flowering and Podding (P≤0.001), but not significant (P≥0.05) at vegetative growth stage. When moisture stress was initiated at flowering, RWC ranged from 16% (stress) to 79% (non-stress), while when moisture stress was initiated at flowering, RWC was 75%. Moisture stress at podding recoded RWC range from 6.98% (Stressed) to 50% (No-stress). During vegetative phase of growth, RWC ranged from 53% (No irrigation) to 73.43% (Irrigation to flower), with a mean of 68% (Table 36). Terzi and Kadioglu (2006) reported a considerable decreased in relative water content when plants experienced water stress, with the greatest impact being recorded at podding stage. The study observes that water demand by green vegetable pigeon pea is more intense during flowering and podding phase and therefore, any limitation leads to reduced leaf RWC. Increasing irrigation frequency at flowering and podding phase will have a positive impact on yield, compared to frequent irrigation during vegetative phase. The variation in RWC could be associated with membrane dysfunction due to moisture stress, causing increased permeability that may lead to ion leakage, and therefore injury and loss of membrane integrity. This leads to higher water loss through stomatal regulation during photosynthesis (Lobato *et al.*, 2008) and inefficient water utilization assimilation under moisture stress in soya beans (Kaur *et al.*, 2016).

Table 36: Effect of intermittent/random and terminal moisture stress at different growth stages on relative water content (RWC) under high tunnel at Kabete during the 2018 season

Moisture regimes	Flowering Phase	Podding Phase	Vegetative phase
Full Irrigation	79.21 b	50.18 b	71.17
Irrigation to Podding	78.93 b	12.31 a	73.38
Irrigation to Flower	75.14 b	6.88 a	73.43
No Irrigation/Stress	16.07 a	6.98 a	52.88
Mean	62.34	19.09	67.72
LSD (0.05) Moisture	12.24***	10.4***	NS
CV%	10.4	18.9	16.1

*Where: *, **, and *** represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant*

4.3.16 Pearson correlation coefficient analysis for yield, yield variables, root characteristics and drought indices.

Pearson correlation coefficient method was used to evaluate the relationship between yield and other variables (Table 37 and 38). The study noted significant positive relationship (P<0.001) between yield and 100 see mass (r=0.5427), DTE (r=0.8925), Harvest index (r=0.539) and pods per plant (r=0.5644). Similar findings have been reported by Vijayalakshmi et al (2013) in grain pigeon peas. A negative corelation (P<0.001) was observed between yield and duration to flower (r=0.6663) and duration to harvest (r=0.6116) at Kiboko, under the open field (Table 37 and 38). The negative association between yield and duration to flower under rainfed condition indicates that genotypes that take longer to flower are exposed to terminal drought, that leads to yield reduction. Similar findings have been reported Ojwang et al., (2016b) in pigeon peas. Negative corelation *(P < 0.001)* was observed between DTF and harvest index (r=-0.599) and pods per plant (r=0.8953), indicating that short duration plants produce less pods comparted to long duration genotypes.

Pods per plant were positively corelated to DTE, yield and harvest index, but negatively related to DTF and DTM. Drought tolerance efficiency reduces as the plant takes long to mature as they are exposed to terminal drought. Short duration plants can capitalize on the moisture available during the rainy seasons, reaching maturity before terminal drought sets in. Under the high tunnel, the study noted that yield was positively ($P<0.001$) correlated with DTE ($r=0.9325$) and pods per plant ($r=0.8475$), while DTF was positively correlated to DTM ($r=0.9296$), number of branches ($r=0.7172$) and plant height ($r=0.7054$) ((Table 37 a and 38). Pods per plant was also positively correlated to DTE ($r=0.7911$). Plant height was positively correlated ($P<0.001$) to number of primary branches ($r=0.8299$) and DTF ($r=0.7054$).

Harvest index was negatively correlated ($P<0.001$) to DTF ($r=-0.6872$) and DTH ($r=-0.6905$). When genotypes take longer to reach maturity, it means that most of its photosynthates are directed towards vegetative growth, leading to taller genotypes, more branches, leading to competition with the developing peas. Harvest Index has been used to express the proportional remobilization of photosynthates to the developing grain or seed Klaedtke (2012). The study noted significant relationship ($P\leq0.001$) between DFT, Plant height, yield and root dry matter, root length and biomass (stem + branch dry weight). Genotypes that take longer to mature develops longer roots for support and increased water uptake efficiency, which translate to increased root dry matter and yield, since the developing peas has enough water and nutrients from the soils. The high positive correlation between yield and drought tolerance efficiency (DTE) indicates that drought tolerant genotypes have potential to produce higher yields, due to better rooting systems and proliferation of branches, providing more podding sites and therefore more yields, and that DTE and number of pods per plant could be used in selection of genotypes for moisture stress tolerance.

Table 37: Pairwise correlation coefficient of yield variables and drought indices among green vegetable pigeon peas genotypes produced at different moisture levels under open field at Kiboko 2018-2019 planting season.

Yield Variables	% 100 Seed mass	DSI	DTE	Days to 50% Flower	Days to Harvest	Grain Yield Kg/ha	HI	No of Pods	No of Pri Branches	No of Sec Branches	Plant height	Pod Length	Pod width	Seed per pod	Shell %
DSI	0.0192	-													
DTE	0.3553	-0.4381	-												
Days to 50% Flower	-0.4795	-0.0246	-0.6852***	-											
Days to Harvest	-0.4375	0.0033	-0.6627***	0.9835***	-										
Grain Yield Kg/ha	0.5427***	-0.3546	0.8925***	-0.6663***	-0.6116***	-									
Harvest Index	0.1922	-0.319	0.6411***	-0.599***'	-0.5929***	0.539***	-								
No of Pods	0.3783	0.0761	0.6308***	-0.8953***	-0.8978***	0.5644***	0.5474***	-							
No of Pri Branches	-0.151	-0.3037	0.2439	-0.124	-0.1549	0.1014	0.2011	0.1476	-						
No of Sec Branches	-0.1052	-0.0291	0.4479	-0.4282	-0.4308	0.3248	0.4234	0.4457	0.656***	-					
Plant height	0.0946	-0.0388	0.4887	-0.516	-0.4847	0.3987	0.3036	0.4403	-0.2061	0.1707	0.4215	-			
Pod Length	-0.2545	0.0796	0.0604	0.1916	0.2192	-0.0572	-0.0278	-0.213	0.0825	0.0642	0.0081	0.2591	-		
Pod width	0.1789	-0.0697	0.2489	-0.1916	-0.1556	0.357	0.1805	0.1402	-0.0152	0.1629	0.3203	0.2867	0.381	-	
Seed per pod	-0.0462	0.0317	0.4395	-0.2103	-0.1697	0.3044	0.3098	0.1628	0.0558	0.3029	0.3735	0.4023	0.5152	0.3429	-
Shell %	0.0739	-0.4567	0.2823	-0.0589	-0.064	0.3146	0.6231***	-0.0092	0.0997	0.098	0.0492	-0.0373	-0.0423	0.2544	-0.0116

- *, **, and *** represent significance level at $P < 0.05$, $P < 0.01$ and $P < 0.001$ each, ns= non-significant

Table 38: Pairwise correlation coefficient of yield variables and drought indices among green vegetable pigeon peas genotypes produced at different moisture levels under high tunnel field at Kabete 2018-2019 planting season.

Yield Variables	100 Seed mass	DSI	DTE	Days to 50% Flower	Days to Harvest	Grain Yield Kg/ha	HI	No of Pods	No of Pri Branches	No of Sec Branches	Plant height	Pod Length	Pod width	Seed per pod
DSI	-0.0927	-												
DTE	0.3425	-0.5239	-											
Days to 50% Flower	-0.3127	-0.1315	-0.2523	-										
Days to Harvest	-0.4448	-0.0949	-0.3645	0.9296***	-									
Grain Yield Kg/ha	0.3743	-0.3228	0.9325***	-0.4907	-0.5732	-								
Harvest Index (HI)	0.3259	-0.0828	0.2829	-0.6872***	-0.6905***	0.4013	-							
No of Pods	0.5738	-0.019	0.7911***	-0.3174	-0.4484	0.8475***	0.1741	-						
No of Pri Branches	-0.0813	-0.097	0.2547	0.7172***	0.5694	0.0553	-0.5513	0.2819	-					
No of Sec Branches	-0.0906	-0.4194	0.2263	0.3383	0.3291	0.0865	-0.1219	-0.0027	0.3526	-				
Plant height	-0.2068	-0.1524	0.1967	0.7054***	0.5184	-0.0243	-0.5002	0.115	0.8299***	0.347	-			
Pod Length	0.2865	0.0287	0.5784	-0.1306	-0.2648	0.5385	0.146	0.6286	0.4236	0.1577	0.233	-		
Pod width	0.4075	-0.201	-0.0692	-0.1216	-0.1441	-0.0526	0.0713	-0.0582	-0.1459	0.0195	-0.2389	0.0213	-	
Seed per pod	0.0469	0.0719	0.0118	-0.0919	-0.0855	0.0617	0.0449	0.0081	-0.0444	-0.2868	-0.1558	-0.1104	0.1389	-
Shell %	0.0808	-0.3272	0.3571	0.3115	0.2663	0.1821	-0.1896	0.1716	0.315	0.4983	0.3333	0.185	0.1328	0.1802

- **, **, and *** represent significance level at $P < 0.05$, $P < 0.01$ and $P < 0.001$ each, ns= non-significant*

4.4 Conclusions and recommendations

The response of vegetable pigeon pea genotypes to intermittent and terminal moisture Stress was determined in the open field at Kiboko and high tunnel at Kabete. The inclusion of the high tunnel at Kabete was to validate the results from the open field at Kiboko and assess the root characteristics of green vegetable pigeon peas, which was not possible under open field. Setting up the trial at Kabete was due to availability of the high tunnel structure and increased efficiency in supervision.

The severity of the moisture stress during growth and development was noted when initiated during reproductive phase, with greatest effect being realized at flowering, when yields were reduced by 77% in the high tunnel and 43% in the open field at Kiboko. The study observes that water demand by green vegetable pigeon pea is more intense during flowering and podding phase and therefore, reduction in moisture levels leads to reduced leaf Relative water content (RWC). This confirms the potential negative impact of climate change, especially with increased temperatures and reduction in precipitation, on the growth and development of green vegetable pigeon peas, which potentially can expose the households in the Eastern region to severe food insecurity.

When genotypes are faced with double challenge of increased moisture stress and high temperatures, as observed under the high tunnel, duration to flowering and maturity is accelerated. Late maturing genotypes such as ICEAP 00554 (200 Days) and MZ 2/9 (205 days) under open field were exposed to terminal drought, making them more susceptible to moisture stress, leading to higher yield reduction, compared to early maturing genotypes such as KAT 60/8 (189 days) and ICEAP 00557 (199 days). The study concludes that genotype ICEAP 00557 and KAT 60/8 are tolerant to intermittent and terminal moisture stress due to their low values of DSI, low yield reduction rate and high drought tolerance efficiency (DTE) and therefore should be promoted with producers in the Eastern region through on-farm demonstration and participatory trials. Increasing irrigation frequency at flowering and podding phase will have a positive impact on yield, compared to frequent irrigation during vegetative phase, providing the basis for irrigation scheduling.

CHAPTER FIVE: INFLUENCE OF PROCESSING AND STORAGE ON NUTRITIONAL CHARACTERISTICS OF SELECTED VEGETABLE PIGEON PEA GENOTYPES

ABSTRACT

Pigeon peas is an important crop among the households in the Eastern regions of Kenya, popularly consumed when peas are still green, as vegetable. Due to its short shelf life, keeping the harvested green vegetable peas for a longer duration is not feasible. The objective of this study was to assess the influence of processing and storage on chemical characteristics of selected vegetable pigeon pea genotypes. Five (5) pre-treatment methods: Threshed fresh sample stored in a deep freezer at $^{-}18^{0}$C; Threshed fresh sample, dehydrated then stored under room conditions; Threshed fresh sample, blanched then stored in a deep freezer at $^{-}18^{0}$C; Threshed fresh sample, blanched, dehydrated then stores under room condition; Peas stored in pods, were assessed. Iron (Fe), Zinc (Zn), protein, total sugars, vitamin A and vitamin C concentration, were determined before and after the pre-treatment, and subsequently at 0-, 14-, 22- and 60-days of storage. The effect of pre-treatment and storage duration were evaluated by performing a two-way ANOVA. There was significant difference among the pre-treatments ($P<0.001$) and duration of storage ($P<0.001$) for all the nutrients. Significant interaction between pre-treatment and storage duration was also noted ($P<0.001$) among all nutrients profiled. Blanching of threshed fresh peas led to reduction in all the nutrients, with highest reduction of 43% in vitamin C and 21% in vitamin A. The lowest reduction of 6.4% was noted in % protein concentration. Storage of peas in pods led to reduction in vitamin C, vitamin A and Protein concentration by 12%, 8% and 4% due to exposure to high temperatures during storage. There was significant reduction in all the nutrient concentration, when fresh peas were blanched, then subsequently dehydrated, with the highest loss being vitamin C (55%), Vitamin A (29%), Total sugars (26%) and Proteins (26%), due to double heat treatment of the samples. Peas which were blanched, then dehydrated recorded a higher rehydration coefficient (RC) of 274% and swelling coefficient (SC) of 115% after 22 days of storage.

Key words: *Pretreatment, Nutritive value, shelf life and storage.*

5.1 Introduction

Pigeon peas is mainly produced in the dryland areas of the Eastern region of Kenya, characterized by high levels of food insecurity and protein related malnutrition (Salome, 2014), catalyzed by poor crop and livestock production due to poor rainfall distribution and intensity. Given its drought tolerance, pigeon peas, especially when utilized when green, is an important crop as a contributor to protein deficient diets in the region. Majority of the household in the region therefore utilize pigeon peas when they are green and are either cooked as vegetable or mixed with maize, popularly known as 'Isio' in local dialect. To determine at what stage the green peas are mature, households in these regions apply physical appraisal by pressing between the fingers to determine the level of hardness. Hardened pods are an indication of pea maturity and therefore readiness for harvest.

Green vegetable pigeon peas are highly perishable, high in moisture content at harvest, with an inherently short shelf life, and therefore keeping the harvested green vegetable peas for a longer duration is not feasible. This has potential to influence household utilization and market access. Harvesting is normally done within 2-3 weeks of pod maturity and must be consumed or sold within that time to reduce post-harvest loses. Households lack access to post harvest management options that would increase the shelf life for consumption during the months of scarcity or defer sales to months when the prices are competitive.

Pigeon pea producers harvesting at green stage store the harvested peas in pods for about one week before transportation to the urban markets. Consumers with access to cold storage thresh the peas from pods and store under lower temperatures in a deep freezer or normal refrigerator. In the rural areas, majority of the households store them in pods and thresh quantities enough for family consumption. Past study on the influence of storage on nutritive value on green vegetable pigeon peas has been reported by Onyango and Silim (2000). They reported that when green peas were stored under normal room temperature at (21 ± 3^{o}C), the product recorded reduction in Vitamin C and soluble sugars, while total titratable acidity is increased. Czaikoski *et al*., (2012) also observed that when soya beans were stored under cold storage, there were changes in the nutritive profile of the product, especially minerals, sugars and vitamins. There are several pre-treatment options that are available, with potential to increase the product shelf life, which the consumers and producers are not aware of their existence. There is also limited information on the effect of these practices and storage duration on the nutrition profile and characteristics of green vegetable pigeon peas. The objective of this study was to evaluate the effect of pre-treatment and storage on nutrient profile of green vegetable pigeon peas.

5.2 Materials and methods

5.2.1 Study location

The field trials were established in November 2017, at Kiboko research station in Makueni County, with ratoon crop harvesting happening 10 months later in August 2018. During the growing season, the crops received a total of 1,207 mm, over a period of about 2 months, in the month of October and November, being the long rains for the region. This necessitated supplementary irrigation for the crops to reach maturity, through sprinkler irrigation. A total of 988 mm of water, was supplemented through 38 times of irrigation. The soils, rainfall of 1,207mm, average relative humidity of 83%, and average daily temperature of 24^{o}C, were within the range required by Pigeon pea for growth and development as reported previously (Silim *et al.,* (2006) and Nganyi *et al*., (2009).

5.2.2 Material description and trial design

The research evaluated medium duration genotypes developed by ICRISAT, through on station and on farm research. The seed of the selected genotypes were sourced from Kiboko research station located in Makueni county. Among the genotypes, 00557 and 00554 were originally from Tanzania, flowering in 90 days and mature in 160 days. KAT 60/8, developed at Katumani in Kenya, flowers in 120 days, and final plant height is about 130cm, have a spreading growth habit. MZ 2/9 was selected from Mozambique germplasm and is an early flowering genotype, short genotype, with seeds mass above 25 grams per 100 seeds. With exception of MZ 2/9, which produced peas which were speckled brown, the other genotypes peas were green to light green in seed color. The seed were planted in a randomized complete block design, with crop growth and development being monitored and agronomic practices such as weeding, and pest management protocols were followed to harvesting.

5.2.3 Sampling harvesting and preparation

The pod maturity was monitored and harvested at 26-32 days after 50% flowering, based on Singh *et al.*, (1984) who recommended that at this stage, the nutritive value is at the peak, and the peas are mature for harvesting. Harvesting was done in the evening, by hand picking. The pods from different genotypes and plots were thoroughly mixed and threshed to get at least 20 kilograms of the green peas. This was based on farmer practice of not harvesting genotypes separately for consumption. They do harvest the pods from the farm at random, bulking the pods together either for the market or home consumption. The shelled and unshelled peas (at least 10 Kgs) were packed in separate cool boxes later transported overnight to the laboratory at the University of Nairobi, for analysis. At the laboratory, before analysis, both samples (threshed peas and those in pods, were sorted out for damaged, inert materials and kept in an open air within the room for 2 h to attain room temperature, before further analysis.

5.2.4 Vegetable pigeon sample pre-treatment

T1: Fresh peas: Pods were shelled, and peas, placed in polythene bags (Zip Bags), air removed by pressing and stored in a deep freezer at $^{-}18^{0}$C for 60 days, with subsequent nutrient analysis at 14, 22 and 60 days.

T2: Fresh + Dehydration pre-treatment: 500 grams of shelled fresh peas were oven dried at 65^{o}C for 8 hours, then stored under room conditions, with a mean ambient temperature of between $20\text{-}25^{o}$C, with subsequent nutrient analysis at 14, 22 and 60 days.

T3: Fresh peas blanched + storage in Deep freezer: Two Kilograms of shelled peas were steam blanched at 72^{o}C for 2 min, immediately submerged in cold water then drained. Immediately after blanching, a 100g of the sample was analyzed to determine the nutrient profile. The remaining material were stored in a deep freezer at -18^{0}C for 60 days, with subsequent nutrient analysis at 14, 22 and 60 days.

T4: Fresh peas blanched + Dehydration pre-treatment: The shelled peas were blanched, then dehydrated at 65^{o}C for 8 hours. Immediately after oven-drying, a 100g of the sample was analyzed to determine the nutrient profile. The remaining sample was stored under room conditions, with a mean ambient temperature of between 20-25°C, with subsequent nutrient analysis at 14, 22 and 60 days.

T5: Fresh peas stored in pods (Un-threshed): This represented the traditional way household store their pods. The peas in pods were spread on an aluminum tray and kept on the table inside the laboratory. The mean ambient room temperature during the 60 days of storage varied between 20-25°C, with subsequent nutrient analysis at 14, 22 and 60 days.

5.2.5 Determination of moisture and total dry matter content

Moisture content was determined following the guidelines as outlined in AOAC methods specification 950 46, method 925.10-32.10.03 (AOAC, 2000), by oven drying method. This was carried out before nutrient profile analysis. 100grams of well-mixed sample was accurately weighed in a clean, dried crucible (W_1). The crucible was put into an oven at 100-105°C for 12 hours until a constant weight was obtained. The crucible was placed in the desiccator for 30 min to cool. After cooling, it was weighed again (W_2). The percent moisture was calculated by following formula:

(1) Percent Moisture: $((W_1-W_2)/\text{Wt. of the Sample}))*100$

(2) Total Dry matter: $(100\text{grams} - ((W1-W2)/\text{Wt. of the Sample}))*100$

Where: W_1- Initial weight of crucible + Sample

W_2- Final weight of Crucible + Sample

5.2.6 Determination of vitamin A (µg/100g)

Vitamin A was determined as beta-carotene based on Astrup *et al.*, (1971) method and previously modified (Imungi and Wabule, 1990). Pigeon peas (1 g) was mixed with acid-wash sand, grinded, and extracted with acetone (Sigma Chemicals, St. Louis, MO, USA). The homogenate was filtered, residue grinded and re-washed with acetone until the filtrate was colorless. The combined extracts were diluted in 50 mL acetone. Extract (25 mL) was evaporated to near dryness in a rotary vacuum evaporator (Solutex Ltd, Shropshire, U.K.) in a water bath at 65°C. The extracts were separated in a chromatographic column packed with silica gel (15cm depth). Anhydrous Na_2SO_4 was used to remove water traces in the sample. The evaporated sample was dissolved in petrol ether (2mL, 40°-60°C BP), and quantitatively spotted onto the column and eluted with petroleum spirit. The first yellow eluate was collected in a 25mL flask, and the optical densities of beta-carotene fraction were measured at 450nm (CE 440 UV/Vis Spectrophotometer; Spectronic CamSpec Ltd., Leeds, U.K.), calibrated with pure beta-carotene standard solutions in petroleum ether and results were calculated as beta-carotene equivalents.

5.2.7 Determination of vitamin C (mg/100g)

Ascorbic acid was determined by titration with 2,6-dichlorophenol indophenol dye (AOAC, 2000). Pigeon peas (10g) were grinded in 5% oxalic acid (30mL) and extracts filtered. Standard indophenol solution (0.05g 2,6 dichlorophenol indophenol dissolved in distilled water) was diluted to 100 mL and filtered. Ascorbic acid standard solution (0.05g ascorbic acid dissolved in 30mL of 5% oxalic acid solution) was diluted to 250mL. Ascorbic acid standard solution (10mL) was titrated with indophenol solution to endpoint (slight pink coloration). Similarly, oxalic acid (10mL) was titrated as a blank solution and ascorbic acid amount corresponding to 1mL of indophenol solution was computed. Filtered extract (10mL) was pipetted in 50mL flask containing 5% oxalic acid solution. The filtrate (10mL) and standard indophenol solution was titrated and vitamin C content in Pigeon pea was computed in mg/100g sample.

5.2.8 Determination of minerals - iron and zinc (mg/100g)

Iron and zinc content of pigeon peas were evaluated using an atomic absorption spectrophotometer (Perkin Elmer, Model 2380, and ThermoFisher, USA); equipped with air acetylene flame, hollow cathode lamp and recorder. The device was operated at standard conditions (500 nm, slit widths for each element). Dried, grinded sample (1g) was weighed in 100mL beaker and oven-dried (8h, 550^{o}C) to ashes. The ash was cooled to room temperature and residue was dissolved by heating in 20mL of 50% HCl. Distilled water (20mL) was added to sample, boiled until clear and contents were filtered in 100mL volumetric flask. Nitric acid (1mL) was added to extracts to prevent phosphorous interference and double distilled water was added to filtrate. Iron and zinc were then determined by absorption spectrophotometer in which absorption was proportional to wavelength and concentration of iron and zinc. Iron and zinc contents were estimated in the aliquots of the extract.

5.2.9 Determination of protein content (%)

Crude protein was determined as total nitrogen (N) using the semi-micro Kjeldahl method (AOAC, 2000). Dry grinded samples (0.5g) were weighed (N-free filter papers) and dispensed in 100mL Kjeldahl flasks (anti-bumping pumice). A 10mL of H_2S0_4 was added to sample and two Kjeldahl catalyst tablets were added. The flasks were heated on a Kjeldahl heating assembly at low setting until all frothing ceased. Subsequently, heat was adjusted to high setting and the mixture was digested to a clear solution and cooled. The clear digest was mixed with distilled water, dissolved, and dispensed in distillation flasks. Distillation flasks were filled to 75%, with phenolphthalein drops and zinc powder was added to contents. Adequate NaOH (40%) were added to distillation unit connected with Kjeldahl flasks. A 25 mL of 0.1N HCl solution and drops of methyl red indicator were placed in the distillation unit outlet and mixture was distilled until there was no reaction with Nessler's reagent. Ammonia in the distillate was determined by back-titration (0.1N NaOH). The total N was computed as nitrogen titre (blank determination minus sample titre) and the results were converted to crude protein by a conversion factor of 6.25 (Morris *et al*., 2004).

5.2.10 Determination of total sugars (mg/100g)

Total sugar analyses were performed on whole foliage of dried Pigeon pea prior to fermentation. Sugars were determined by calorimetric method (Dubois *et al*., 1956). A dried sample (5g) was weighed into 50mL test-tube, thoroughly mixed with 25 mL of 80% hot ethanol and centrifuged (10,000g at 5^oC) and supernatant was filtered. The extraction was repeated four times, followed by subsequent filtration. The filtrate was evaporated on a sand-bath to remove alcohol. The water phase was diluted to 100mL. A 0.1mL aliquot of evaporated /diluted sample was mixed with distilled water (4.9mL), 5% anthrone reagent (5mL) and 96% H_2SO_4 (5mL) in a tube. The mixture was placed in iced water, vortex vigorously and boiled for 15 min and tube was cooled. A blank solution was prepared (5mL of 5% anthrone+5mL of 96% H_2SO_4+5 mL distilled water). The optical density was quantified (490nm) and results determined from standard curve prepared using pure glucose solution. The total reducing sugars were calculated as equivalent mg of glucose per 100g of sample.

5.2.11 Determination of rehydration coefficient (%)

Rehydration coefficient (RC) was determined by soaking 20g of vegetable pigeon peas seeds at room temperature (25^{o}C) in 50 ml deionized water (ratio of 1:5). After 18 h the peas were removed from the soaking water, cut into two halves along the fissure and separated the Testa and cotyledon parts followed by free water removal by using a blotting paper and re-weighing. Gain in weight was taken as the amount of water absorbed and expressed as the hydration coefficient (El-Refai *et al.*, 1988). Rehydration ratio (RR) was computed using the following formulae:

$$\textbf{Rehydration coefficient} = \frac{\text{Weight of seed after soaking}}{\text{Weight of seed before soaking}}$$

5.2.12 Determination of swelling coefficient (%)

The volume of 20 grams, raw pigeon pea seeds before and after soaking in 100mls of deionized water at 25 ˚C for 16 hours at a ratio of 1:5 (w/v) (pigeon pea weight to water) was determined by water volume displaced in a graduated cylinder and expressed as the swelling coefficient (El-Refai *et al.*, 1988).

$$\textbf{Swelling coefficient} = \frac{\text{Volume of seed after soaking}}{\text{Volume of seed before soaking}}$$

5.2.13 Statistical data analysis

The effect of main (pre-treatment) and sub-treatments (storage duration) were evaluated by performing a two-way ANOVA, to test the effect of duration and pre-treatment methods on vegetable pigeon pea samples, using GENSTAT 16th edition. The mean values of the treatments for each parameter were compared by least significant difference (LSD) test at 5% level of probability.

5.3 Results and discussions

5.3.1 Effect of pre-treatment and storage duration on moisture content of pigeon peas

Moisture content of the fresh samples was carried out before subsequent pre-treatments were done (day 0), and subsequently at 22- and 60-days post-storage. The study observed that the initial moisture content before treatment (base moisture levels – 0 days) were significantly higher ($p<0.05$) than at 22 days and 60 days of storage (Table 39), among all the treatments. The moisture contents were significantly (*$P<0.05$*) reduced to less than 20% at 22 and 60 days of post-harvest storage for fresh oven dried, blanched oven dried, and podded samples. The observed moisture levels for the dry grains were similar to the findings by Kunyanga *et al.*, (2013) who reported a value of 11.3%. The moisture content in a product determines its long-term storability of pigeon peas in tropical and semi-dry land regions.

Table 39: Effects of storage duration on average moisture levels in vegetable pigeon peas

Pre-treatment^R	**0 Day**	**22 Days**	**60 Days**
Blanched + Oven Dried + Room condition (T4)	13a	16b	16b
Fresh Oven Dried + room condition (T2)	13a	15b	16b
Blanched Fresh + deep frozen (T3)	57a	56a	55a
Fresh + deep frozen (T1)	57c	55a	55a
Podded + room condition (T5)	54a	13b	11a

^{R}Data represent average moisture content for treatments and storage parameters. Different small letters within columns for 0, 22 and 60 days indicate significant ($p<0.05$).

High moisture content in day 22 and 60 for samples in a deep freezer indicates that storage under this condition minimized loss of moisture. In evaluation of dried galega kale (*Brassica olereca*), it was reported that vegetable that is not packed with water vapor and oxygen proof material in a deep freezer, may lead to ice crystals on vegetable surface to sublime to gaseous state, leading to loss of water accelerated by increases in storage temperature when freezer doors are opened (Araújo *et al.*, 2017). This explains reduction in moisture on samples kept in the deep freezer at 22 and 60 days of storage.

5.3.2 Effect of pre-treatment on green vegetable pigeon pea iron (Fe)

Iron is an important nutrient, but usually deficient in the diets of low-income subsistence farmers, particularly infants and pregnant women (FAO/WHO, 2001). The concentration of Iron (Fe) in green vegetable pigeon peas was determined before the pre-treatment and subsequently during storage. There was a significant difference among the pre-treatment ($P>0.001$) for iron concentration (Table 40), with the base concentration before pre-treatment being 4.7 mg/100g. Blanching of the sample reduced the Iron concentration by 18.8% from 4.7 to 3.8 mg/100g. This is within the range previously reported by Singh *et al* (2018) of 4.0 to 6.3 mg/100g. Dehydration a lone of the fresh sample increased the concentration by 9.6%, from 4.7 mg/100g to 5.1 mg/100g, while dehydration of blanched sample increased the concentration by 2.8% from 3.8 mg/100g after blanching to 3.9 mg/100g, probably due to moisture loss that led to concentration of Iron. When the sample was blanched, then dehydrated, there was a 16.5% reduction in Iron concentration in the sample, due to leaching during sample preparation. Peas in pods recorded iron concentration of 5.1 mg/100g, which differed with threshed sample, by 7.8%.

Table 40: Effect of pre-treatment and storage on mineral and nutrient concentration of pigeon peas

Sources	Df	Iron (mg/100g)	Zinc (mg/100g)	Protein (%)	Total sugars (mg/100g)	Vitamin A (µg/100g)	Vitamin C (mg/100g)
Treatment^{R}	4	10.19**	1.33**	2.93**	1.04**	5198.8**	111.9**
Storage^{S}	3	6.21**	0.09**	7.57**	6.36**	32061.2**	550.5**
Residual^{T}	12	0.61	0.0056	0.15	0.05	456.3	9.7

^{S}Pigeon peas were stored for 0, 14, 22, and 60 days at $^{-}18^{o}C$ (deep freezer).

^{T}Refers to error degrees of freedom and associated mean squares.

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns = non-significant*

5.3.3 Effect of storage on green vegetable pigeon peas on iron (Fe)

Iron concentration was determined at 0-, 14-, 22- and 60-days post pre-treatment. There was significant difference in iron concentration in all the storage duration (p<0.001) (Table 41). Significant interaction between duration and pre-treatment of the sample was also significant (P<0.001), indicating that pre-treatment and storage interact to influence the final Iron concentration after 60 days of storage.

Table 41: Analysis of variance on the effect of storage on mineral and nutrient concentration of pigeon peas.

Storage Duration	**Iron (mg/100g)**	**Zinc (mg/100g)**	**Protein (%)**	**Total sugars (mg/100g)**	**Vitamin A (µg/100g)**	**Vitamin C (mg/100g)**
0 days of storage	4.728a	2.528a	22.99d	3.994d	331.6e	27.66d
14 days of storage	4.45ab	2.372b	22.38bc	3.71b	308.6c	20.15c
22 days of storage	4.51b	2.42bc	22.3b	3.512b	250.3b	18.22b
60 days of storage	4.516b	2.448c	20.55a	2.386a	200.9a	8.8a
SEM	0.350	0.034	0.173	0.103	9.550	1.390
SED	0.495	0.047	0.245	0.146	13.510	1.970
LSD>0.05	1.05***	0.100***	0.52***	0.309***	28.64***	4.17***
CV%	14.10	3.20	1.70	6.00	7.10	13.10

, **, and * represent significance level at P < 0.05, P < 0.01 and P < 0.001 each, ns= non-significant*

The study noted a reduction in Iron concentration after 60 days of storage, with the highest, 9.90% for fresh peas stored in a deep freezer, followed by peas stored in pods at room condition by 8.75%

(Table 42). The sample stored in a deep freezer undergoes double leaching during sample preparation, initially during thawing, leading to reduction in Iron concentration (Guiné (2018). This double treatment led to significant leaching of Iron. Dehydration of fresh sample and storage in a room condition recorded the lowest loss of 2.55%. When the green vegetable pigeon peas are dehydrated, further leaching during storage is reduced, due to reduced moisture levels and constant temperatures. The fresh-blanched sample stored in a deep freezer recorded a 6.25% loss in Iron concentration after 60 days of storage. Storage of sample that was blanched, then subsequently dehydrated and stored under room condition, recoded 7.50% reduction in Iron concentration (Table 44).

Table 42: Effects of storage duration on mean iron levels in vegetable pigeon peas subjected to pre-treatment at post-harvest.

Treatment^{R}	0 Days	14 Days	22 Days	60 Days	% Change
Fresh Blanched + Deep Freezer	3.84e	3.78e	3.75 c	3.60c	- 6.25
Fresh + Deep freezer	4.73d	4.69c	4.55c	4.26c	- 9.90
Blanched + Dehydrated + Deep freezer	3.95c	3.67b	3.66b	3.65b	- 7.50
Fresh + Dehydrated + Room	5.18c	5.10b	5.07a	5.05a	- 2.55
Stored in Pod + Room	5.10d	5.09c	5.01c	4.65c	- 8.75

^{R}Data represent average iron content for treatments and storage parameters. Different small letters within columns for 0, 14, 22 and 60 days indicate significant ($p<0.001$) differences in protein content in vegetable pigeon peas.

5.3.4 Effect of pre-treatment on green vegetable pigeon pea zinc (Zn)

The concentration of Zinc (Zn) in green vegetable pigeon peas was determined before the pre-treatment and after the pre-treatment. There was a significant difference among the pre-treatment ($P>0.001$) for zinc concentration after pre-treatments. The base concentration before pre-treatment was 2.53 mg/100g. Singh et al. (2018) reported a range of 0.8 mg/100 g to3.6 mg/100 g for zinc on different vegetable Pigeon pea cultivars at green stage. In another study, Patil et al. (2015) reported zinc levels of 2.7-2.9 mg/100g in Pigeon pea cultivars. The difference in zinc concentrations in this study as opposed to other published research could be explained by cultivar differences, growth conditions, and storage durations. Moussou *et al*. (2019) also noted that different locations, where the genotypes are planted may cause minerals content variations. Based on WHO, a daily intake of 12 mg/100g of zinc is required for women (FAO/WHO 2001).

Table 43: Variation in nutrient composition of vegetable pigeon peas due to pre-treatment

Treatments	**Iron (mg/100g)**	**Zinc (mg/100g)**	**Protein (%)**	**Total sugars (mg/100g)**	**Vitamin A (µg/100g)**	**Vitamin C (mg/100g)**
Fresh + Deep frozen (T1) [R]	4.7a	2.5bc	23.0b	4.0b	331.6b	27.7b
Blanched +Deep Frozed (T3) [S]	3.8a	1.5a	21.5a	3.3a	263.4a	15.8a
Dehydrated + Room storage[T]	7.2b	2.8d	23.3b	4.3b	337.2b	26.9b
Blanched+ Dehydration + Room (T4) [U]	6.8b	2.4b	22.0a	3.5a	278.4a	24.4b
Stored in Pods + Room storage (T5) [V]	5.1a	2.6c	23.1b	4.3b	304.1ab	24.4b
Mean	**5.54**	**2.36**	**22.56**	**3.86**	**302.94**	**23.81**
SEM	0.35	0.03	0.17	0.1	9.55	1.39
SED	0.5	0.05	0.25	0.15	13.51	1.97
LSD>0.05	1.05***	0.100***	0.52***	0.309***	28.64***	4.17***
CV%	14.1	3.2	1.7	6	7.1	13.1

[R] *Samples (wet mass) were non-blanched then deep-frozen storage at $^{-}18^{o}C$ (T1).*

[S] *Samples steam blanched at $72^{o}C$ for 4 mins, then deep-frozen storage at $^{-}18^{o}C$. (T3)*

[T] *Oven-dried samples at $65^{o}C$ for 8 hours, then stored under room condition (T2).*

[U] *Samples (wet mass) were blanched then oven-dried at $65^{o}C$ for 8 hours and stored deep-frozen at $^{-}18^{o}C$ (T4).*

[V] *Un-threshed pods (podded, wet mass) stored at room temperature of 20-25°C (T5).*

Different letters within columns for iron, zinc, protein, total sugars, vitamin A and vitamin C indicate significant ($P<0.05$) differences among treatments.

Table 44: Percent change in mineral and proximate composition in fresh green vegetable pigeon peas

Pre-Treatments	**Iron (mg/100g)**	**Zinc (mg/100g)**	**Protein (%)**	**Total Sugars (mg/100g)**	**Vitamin A (µg/100g)**	**Vitamin C (mg/100g)**
Fresh (Unblanched): Base	4.7	2.5	23.0	4.0	331.6	27.7
			% Change			
Fresh Blanched	- 18.8	- 18.0	- 6.4	- 17.8	- 20.6	- 43.0
Blanched + Dehydrated	2.2	3.0	- 19.8	- 8.5	- 8.4	- 12.4
Fresh + Dehydrated	9.6	7.8	- 20.5	- 18.5	- 25.5	- 28.2
Stored in Pod	7.8	5.7	- 4.1	7.3	- 8.3	- 11.7
Blanching + Dehydration	(16.54)	(14.95)	(26.19)	(26.29)	(29.01)	(55.35)

Fresh vegetable pigeon peas have the capacity to supply about 10% of the daily intake requirement of zinc micronutrient. Blanching of the sample reduced the concentration by 18%, from 2.53 to 2.1 mg/100g. Our results are consistent with that previously reported in African leafy vegetables by Vorster *et al*., (2002), who noted reduction in Zinc concentration after blanching. When dehydration was done on fresh sample, the concentration increased by 7.8%, from 2.53 mg/100g to 2.7 mg/100g, due to reduction in moisture content that led to increased zinc concentration (Table 44). When blanched samples were then dehydrated, the Zn concentration reduced by 15% after dehydration. This could be due to reduction in moisture levels. Peas in pods recorded Zinc concentration of 2.7 mg/100g, which differed with fresh threshed sample, by 5.7% (Table 44). Threshing of peas from the pods and initial washing before being analysis may have reduced the Zinc concentration in threshed sample, compared to the sample in pods, which lost Zinc only at the time of analysis.

5.3.5 Effect of storage on green vegetable pigeon pea zinc (Zn)

Zinc concentration was determined at 0-, 14-, 22- and 60-days post pre-treatment. There was significant difference in zinc concentration in all the storage duration (p<0.001) (Table 45). Significant interaction between duration and pre-treatment of the sample was also significant (p<0.001), indicating that pre-treatment and storage interact to influence the final Zinc concentration after 60 days of storage.

Table 45: Effects of storage duration on average zinc levels in vegetable pigeon peas subjected to pre-treatment.

Treatment^R	0 Days	14 Days	22 Days	60 Days	% Change
Fresh Blanched + Deep Freezer	2.07e	1.92c	1.90c	1.88d	- 9.35
Fresh + Deep freezer	2.53d	2.50c	2.49c	2.27 ad	- 10.21
Blanched + Dehydrated + Room	2.15c	2.14c	2.12d	2.09d	- 2.79
Fresh + Dehydrated + Room	2.73c	2.69 c	2.65a	2.60d	- 4.62
Stored in Pod + Room (Control)	2.67d	2.65 cd	2.52c	2.42c	- 9.43

^{R}*Data represent average zinc content for treatments and storage parameters. Different small letters within columns for 0, 14, 22 and 60 days indicate significant (p<0.001) differences in protein content in vegetable pigeon peas.*

The study noted a reduction in Zinc concentration during storage, with the highest, 10.21% for fresh peas stored in the room at room temperature, followed by blanched peas stored in a deep freezer by 9.43% after 60 days of storage. Blanched followed by dehydration of fresh sample and storage in a room condition recorded the lowest loss of 2.79%. When the sample is blanched and subsequently dehydrated, further leaching during storage is reduced. The fresh-blanched sample stored in a deep freezer recorded a 9.35% loss in Iron concentration after 60 days of storage, due to leaching during thawing and subsequent preparation during preparation for analysis/ The study noted that dehydration of fresh sample and blanching the sample first then dehydration, led to reduced loss in Zinc concentration during the 60 days of storage.

5.3.6 Effect of pre-treatment on protein (%) concentration

The concentration of protein (%) in green vegetable pigeon peas was determined before the pre-treatment and after the pre-treatment. There was a significant difference among the pre-treatment (P>0.001) for % protein content (Table 40). The base concentration before pre-treatment was 23%. Singh et al., (2018) reported protein concentration of 19.8mg/100g in pigeon peas at green stage. The difference in protein content in this research compared to others could be due to seasonal and varietal differences as also concluded by Ceyhan et al., (2012), when they assessed protein concentration in different pigeon pea genotypes.

The study noted that Blanching of the sample reduced the protein concentration from 23% to 21.5%, representing a 6.4% reduction (Table 44). A reduction in protein concentration from blanching was probably due to the loss of water-soluble nitrogen-containing compounds in vegetable pigeon peas because of heat treatment. Similar reduction in protein concentration of 10 - 20% have been observed in chickpea (*Cicer arientinum*), pigeon pea and climbing bean (Phaseolus vulgaris) due to steaming, as documented by Sood et al., (2002). When the fresh samples were dehydrated, the % protein concentration reduced from 23.0% to 18.3% representing a 20.5% reduction. When dehydration was done on blanched sample, the % protein concentration reduced by 26.2% compared with the fresh sample, from 18.3%. The peas that were in the pods recorded a difference of 4% in protein concentration, compared to the fresh sample of 23%, after analysis, due to washing before analysis, leading to reduction.

5.3.7 Effect of storage on protein (%) profile

Percent protein concentration analysis was undertaken at 0-, 14-, 22- and 60-days post pre-treatment. There was significant difference in protein concentration in all the storage duration

($p<0.001$) (Table 42). Significant interaction between duration and pre-treatment of the sample was also significant ($p<0.001$), indicating that pre-treatment and storage interact to influence the final protein concentration after 60 days of storage.

Table 46: Effects of storage duration on mean protein levels in vegetable pigeon peas subjected to pre-treatment at post-harvest.

Treatment^R	0 Days	14 Days	22 Days	60 Days	% Change
Fresh Blanched + Deep Freezer	21.53b	21.05b	20.68c	20.67ba	- 3.99
Fresh + Deep freezer	22.99a	22.67cd	21.83cd	19.80cd	- 13.88
Blanched + Dehydrated + Room	16.97a	16.40ab	16.21ab	16.19ab	- 4.60
Fresh + Dehydrated + Room	18.27c	16.70a	16.50ab	16.48ab	- 9.80
Stored in Pod + Room	22.05cb	21.92d	21.08 e	19.54d	- 11.38

^{R}*Data represent average protein content for treatments and storage parameters. Different small letters within columns for 0, 14, 22 and 60 days indicate significant ($p<0.001$) differences in protein content in vegetable pigeon peas.*

The study noted reduction in protein concentration during storage among all the pre-treatment after 60 days of storage (Table 44). Threshed fresh peas stored in a deep freezer recorded the highest reduction of 13.88%, due to double heating of the sample during thawing and analysis. Those stored in pods lost 11.38% of protein, after 60 Days, due to exposure to high temperatures and loss of moisture under room condition in which they were stored, leading to denaturation of protein. The difference between shelled sample stored in a deep freezer and peas stored in pods under room condition was due to double heating of the sample stored in a deep freezer at thawing and analysis. Fresh blanched and stored in a deep freezer recorded the lowest loss of 3.99%, as blanching ceases further protein loss during storage. Samples that were dehydrated and stored in room condition also recorded a lower loss of 9.8%. The study noted that blanching of fresh peas, and subsequent dehydration and storage under room conditions, reduces reduction in protein concentration by 4.6% during the 60 days of sample storage.

5.3.8 Effect of pre-treatment total sugars (mg/100g) profile

The concentration of total sugar (mg/100g) in green vegetable pigeon peas was determined before and after the pre-treatment. There was a significant difference among the pre-treatment ($P>0.001$) for Total sugar concentration post pre-treatments (Table 40). The base concentration before pre-treatment was 4.0 mg/100g. Blanching of the sample reduced the concentration from 4.0 to 3.3 mg/100g, representing a 17.8%. Dehydration of the fresh sample reduced the concentration by

18.5%, from 4.0 mg/100g to 3.3 mg/100g. When the blanched sample were further dehydrated, the total sugar concentration further reduced from 3.3 mg/100g to 2.9 mg/100g, representing a 10.3% reduction. When the fresh pea sample undergo both blanching and dehydration, the total sugar concentration reduces by 26.3% (Table 44). This was because of double heat treatment during blanching and dehydration. The total sugar concentration in peas in pods was 4.3 mg/100g compared to 4.0 mg/100g of the fresh threshed sample, a difference of 7.3%. Threshing of peas from the pods and initial washing before analysis may have reduced the total sugar concentration in threshed sample, compared to the sample in pods.

5.3.9 Effect of storage on total sugars (mg/100g) profile

Total sugar concentration analysis was undertaken at 0-, 14-, 22- and 60-days post pre-treatment. There was significant difference in total sugar concentration in all the storage duration ($p<0.001$) (Table 41). Significant interaction between duration and pre-treatment of the sample was also significant ($p<0.001$), indicating that pre-treatment and storage interact to influence the final total sugar concentration after 60 days of storage. The study noted reduction in total sugars concentration during storage among all the pretreatment after 60 days of storage. The threshed fresh peas samples, stored in a deep freezer recorded the highest loss of 10.99% (Table 47).

Table 47: Effects of storage duration on mean total sugars levels in vegetable pigeon peas subjected to pre-treatment at post-harvest.

Treatment^R	0 Days	14 Days	22 Days	60 Days	% Change
Fresh Blanched + Deep Freezer	3.28a	3.14c	3.06d	3.06d	- 5.55
Fresh + Deep freezer	3.99a	3.74c	3.62c	3.56d	- 10.99
Blanched + Dehydrated + Room	2.94a	2.80bc	2.69c	2.68c	- 8.97
Fresh + Dehydrated + Room	3.26a	3.22b	3.18c	3.05 d	- 6.33
Stored in Pod + Room	4.29a	4.15b	4.03c	3.86c	- 9.94

^{R}Data represent average total sugar content for treatments and storage parameters. Different small letters within columns for 0, 14, 22 and 60 days indicate significant ($p<0.001$) differences in protein content in vegetable pigeon peas.

This could have been due to double heating of the sample during thawing and sample analysis. Storage of peas in pods under room conditions led to 9.94% reduction in total sugar due to exposure to high room temperatures, loss of moisture during storage and loss during sample preparation. Vegetable pigeon peas samples which were freshly blanched then stored in the deep freezer, recorded the lowest loss in total sugars after 60 days of storage of 5.55%, while those which were dehydrated and stored under room conditions, lost 6.33% of the total sugars during the 60 days of storage. This study noted that blanching of fresh peas and subsequently storing in a deep freezer, reduces loss in total sugars during storage.

5.3.10 Effect of pre-treatment on green vegetable pigeon pea vitamin C content (mg/100g)

The concentration of Vitamin C (mg/100g) in green vegetable pigeon peas was determined before and after pre-treatment. There was a significant difference among the pre-treatment (P>0.001) for vitamin C concentration after pre-treatments (Table 40). The base concentration before pre-treatment and storage at 0 day was 27.7 mg/100g. Lin and Brewer, (2005) reported 29 mg/100g Pigeon pea. The differences in vitamin C concentration in these studies could be due to varietal, location and climate differences. Blanching of the sample reduced the concentration from 27.7 to 15.8 mg/100g, representing a 43.0 % reduction. Dehydration of the fresh sample reduced vitamin C concentration reduced by 28% from 27.7 mg/100g to 26.9 mg/100g. The increased temperature during dehydration led to oxidation and degradation of vitamin C, given its low heat stability, (Nwakaudu et al., 2015). Dehydration of blanched sample reduced the vitamin C concentration by 22%% from 15.8 mg/100g post blanching to 12.4 mg/100g post dehydration. When both blanching and dehydration are done on fresh green pigeon peas, the vitamin C concentration reduces by 55%, from 27.7 mg/100g to 12.4 mg/100g. The peas that were in the pods recorded a difference of 11.7% in vitamin C concentration, 24.4 mg/100 grams from the base of 27.7 mg/100g. The storage of peas in pods under room conditions exposed the peas to high temperatures, that affected Vitamin C. Further reduction was noted during sample preparation for analysis.

5.3.11 Effect of storage on green vegetable pigeon pea on vitamin C (mg/100g)

Vitamin C concentration analysis was undertaken at 0-, 14-, 22- and 60-days after pre-treatment. There was significant difference in Vitamin C concentration in all the storage duration (p<0.001) (Table 41). Significant interaction between duration and pre-treatment of the sample was also significant (p<0.001), indicating that pre-treatment and storage interact to influence the final Vitamin A concentration after 60 days of storage. The study noted significant reduction in Vitamin C concentration by 53.80% when fresh samples were stored in deep freezer for 60 days. This was due to double heat treatment of the samples during thawing and sample preparation (Table 48). Storing of peas in pods under room conditions led to 36.71% reduction in Vitamin C after 60 days of storage. Blanching of the sample and subsequent dehydration recorded the lowest loss of vitamin C by 12.55%, compared to when the fresh samples were blanched, then subsequent storage in a deep freezer, which recorded a 17.93% reduction in concentration.

Table 48: Effects of storage duration on mean vitamin C levels in vegetable pigeon peas subjected to pre-treatment at post-harvest.

Treatment^R	0 Days	14 Days	22 Days	60 Days	% Change
Fresh Blanched + Deep Freezer	15.8e	13.78b	13.60c	13.55c	- 14.08
Fresh + Deep freezer	27.7d	15.84 cd	12.89c	12.78d	- 53.80
Blanched + Dehydrated + Room	12.4c	11.08b	10.98b	10.80b	- 12.55
Fresh + Dehydrated + Room	19.9c	17.52 d	17.18cd	16.30e	- 17.93
Stored in Pod + Room	24.4d	15.98cd	15.74d	15.45c	- 36.71

^{R}Data represent average vitamin C content for treatments and storage parameters. Different small letters within columns for 0, 14, 22 and 60 days indicate significant (p<0.001) differences in protein content in vegetable pigeon peas.

5.3.12 Effect of pre-treatment on green vegetable pigeon pea vitamin A content (µg/100g)

The concentration of vitamin A (µg/100g) in green vegetable pigeon peas was determined before and after the pre-treatment. There was a significant difference among the pre-treatment (P>0.001) for vitamin A concentration. The study noted a base concentration before pre-treatment was 331.6 µg/100g (Table 44). Blanching of the sample reduced the concentration by 20.6%, from 331.6 to 263.4 µg/100g. When dehydration was done on fresh sample vitamin A concentration reduced by 25.5% from 331.6 µg/100g to 247.2 µg/100g, while when both blanching and dehydration was done on fresh peas, the vitamin A concentration reduced by 29%, from 331.6 (µg/100g) to 235.4 (µg/100g). The peas that were in the pods recorded a difference of 8.3% in vitamin A concentration, compared to the fresh threshed sample of 331.6 µg/100g.

5.3.13 Effect of Storage on green vegetable pigeon pea vitamin A (µg/100g)

Vitamin A concentration was determined at 0-, 14-, 22- and 60-days post pre-treatment. There was significant difference in Vitamin A concentration in all the storage duration (p<0.001) (Table 41). Significant interaction between duration and pre-treatment of the sample was also significant (p<0.001), indicating that pre-treatment and storage interact to influence the final Vitamin A concentration after 60 days of storage. The study noted significant reduction in Vitamin A concentration by 28.72% when the samples were stored in deep freezer for 60 days. This was due to double heat treatment of the samples during thawing and sample analysis (Table 49). Storing of peas in pods under room conditions led to 21.55% reduction in Vitamin A after 60 days of storage. Blanching of the sample and subsequent storage in a deep freezer recorded the lowest loss of vitamin A by 7.10%, compared to blanching of fresh sample and subsequent dehydration.

Table 49: Effects of storage on vitamin A concentration in vegetable pigeon peas

Treatment^R	**0 Days**	**14 Days**	**22 Days**	**60 Days**	**% Change**
Fresh Blanched + Deep Freezer	263.4 a	250.23cd	245.44c	244.70c	- 7.10
Fresh + Deep freezer	331.6a	317.67b	268.90c	236.35cd	- 28.72
Blanched + Dehydrated + Room	235.4b	228.57c	223.05d	217.08e	- 7.78
Fresh + Dehydrated + Room	247.2b	232.27b	222.50d	222.40d	- 10.03
Stored in Pod + Room	304.1a	286.28b	250.56c	238.56e	- 21.55

^{R}Data represent average Vitamin A content for treatments and storage parameters. Different small letters within columns for 0, 14, 22 and 60 days indicate significant ($p<0.001$) differences in vitamin A content in vegetable pigeon peas.

5.3.14 Rehydration (RC) and swelling (SC) coefficient.

Pre-treated green vegetable pigeon peas were evaluated for rehydration (RC) and swelling coefficient (SC) after 22 days of storage. The study noted that both RC and SC of the green vegetable pigeon peas were substantially affected by pre-treatments (Table 50). Swelling coefficient (SC) ranged from 105% for podded to 120% for dehydrated sample, while Rehydration coefficient (RC) ranged from 132% for podded to 274% for blanched + Dehydrated sample.

Table 50: Effects of pre-treatment on rehydration (%) and swelling coefficient (%) after 22 days of storage

Pre-Treatment^R	Rehydration coefficient (RR) (%)	Swelling coefficient (SC) (%)	Moisture Content (MC) (%)
Blanched + Dehydrated + Room	273.6	115	15
Fresh + Dehydrated + Room	226.2	120	13
Fresh Blanched + Deep Freezer	151.3	110	48
Fresh + Deep freezer	151.4	112	37
Stored in Pod + Room	132.2	105	11

^{R}Data represent average of rehydration (%) and swelling coefficient (%).

The data indicated that the dehydrated samples recorded a higher RC and SC compared to non-dehydrated sample, possibly due to diversity in composition and compactness of the cell wall structure and seed coat permeability. Tripathi *et al.*, (2012) made similar observation in chickpeas, and dehydration increases seed coat permeability. Moussou *et al*., (2019) noted that legumes with a higher hydration capacity require less cooking time, affecting consumer preference for the seeds.

There is possibility that dehydration temperature of 65°C for 8 hours and storage conditions, didn't affect the Testa's structure and chemical composition of the sample, leading to improved rehydration and swelling capacity of dried vegetable pigeon peas, leading to improved water absorption capacity. Similar conclusion was made by Kilonzi *et al.,* (2017) on beans, and Shete *et al.,* (2015) on dried green pea products. High hydration has potential to improve cookability, as reported by Shimelis and Rakshit (2005) who observed that legumes with higher hydration and swelling coefficients require less cooking time.

5.4 Conclusion and recommendation

The green vegetable pigeon pea nutritional characteristics, based on Iron (Fe), Zinc (Zn), protein, total sugars, vitamin A and Vitamin C, before and after pre-treatments was determined and subsequently after 14, 22 and 60 days of storage. The little differences could be due variation in genotypes, edaphic and climatic factors. The study has noted that blanching of green vegetable pigeon peas reduces the nutrient profile of green vegetable pigeon peas, with significant reduction observed on Vitamin C. When dehydration was done on blanched sample, the nutrient loss was minimal after 60 days of storage, compared to the fresh unblanched samples stored in a deep freezer at below 18 degrees. Vitamin C concentration and retention are mainly influenced by high temperature and oxygen concentration, therefore any change in concentration is an indicator for either improvement or reduction in product quality.

The study noted that the high temperature of 23-25°C in the room, leads to reduction in moisture content (%), which affects most of the nutrients, except Zinc and Iron, which appreciates marginally. Dehydration led to slight improvement in iron and Zinc content, which was associated with reduction in moisture, leading to increased mineral concentration. Compared to other pre-treatments, storing peas in pods reported less loss in most nutrients, with greatest loss on Vitamin C, after 60 days. Dehydrated samples, especially those that were blanched before dehydration was done, recorded a higher dehydration and swelling coefficients, making them easier for reconstitution pre or during cooking. Therefore, the study noted that dehydration of green vegetable pigeon peas does not affect the seed Testa, and therefore seed coat water permeability.

The study observed that all samples recorded reduction in nutrients during storage, with significant loss being vitamin A and C. Blanching of fresh peas and subsequent dehydration recorded the lowest mean nutrient reduction of 7.4% after 60 days of storage, with Zinc being the least lost by 2.8%, followed by 4.6% in protein, 7.5% in Iron, 7.8% in Vitamin A, 8.9% in Total sugars and 12.6% in vitamin C. The second lowest loss in nutrients was noted when the green vegetable pigeon peas was blanched and kept in a deep freezer with a mean nutrient loss of 7.7%, after 60 days of storage, with a lowest reduction of 3.99% being realized in proteins, followed by 5.55% in total sugars, 7.10% in Vitamin A and 14.08% in vitamin C. The loss during storage was mainly due to temperature, especially for those stored in the room, during thawing especially those from the deep freezer and leaching when all the samples are being prepared for analysis. Fresh peas which were stored in a deep freezer, lost the highest amounts of nutrients, of 21.2% due to leaching and subsequent thawing when being prepared for analysis. When blanched and subsequently dehydrated, moisture content is reduced to 13%, which reduces chances of leaching during storage, except during sample preparation.

This study has been able to contribute towards increasing the shelf life of green vegetable pigeon peas, which has been a challenge to most households in the Eastern region. The innovation of (a) blanching and storing the peas in a deep freezer and (b) blanching, dehydration and storing the peas at room temperature, and their ability to maintain nutrients during storage, has capacity to improve food security in Kenya. More evidence needs to be documented when solar drying is done (dehydration in this study was done using an oven at 65^{o}C for 8 hours), coupled with development of standard operating procedure both for the rural and urban consumers.

CHAPTER SIX: CONSUMER PREFERENCE AND ACCEPTABILITY OF PROCESSED AND STORED GREEN VEGETABLE PIGEON PEAS

ABSTRACT

Consumer preference and acceptability of pre-treatment green vegetable pigeon peas, stored for 22, under different conditions was determined by a team of semi-trained panelists based on 7 – point hedonic scale. Four green vegetable pigeon pea genotypes of medium duration: ICEAP 00554, ICEAP 00557, MZ 2/9 and KAT 60/8, planted in a randomized block design, at Kiboko research station in Makueni county, were harvested and thoroughly mixed to generate a sample for further analysis. The five (5) pre-treatments, T1- Threshed fresh sample stored in a deep freezer at $^{-}18^{0}$C; T2: Threshed fresh sample, dehydrated then stored under room conditions; T3: Threshed fresh sample, blanched then stored in a deep freezer at $^{-}18^{0}$C; T4: Threshed fresh sample, blanched, dehydrated then stores under room condition; T5: Peas stored in pods, were assessed. There were significant differences among the panellists ($P<0.05$) on appearance, color, Odor/Smell, and seed tenderness, while they generally agreed on taste and overall preference ($P>0.05$). The average sensory score among the panelists on physical appearance of samples stored in pods was 6.3, indicating high acceptability, while blanched samples had an average of 6.0 rating. The podded, blanched + oven dried recorded an average of 5.6, 6.6, and 6.1 scores, respectively on seed tenderness. The highest moisture reduction of 43% was noted in samples stored in pods and kept under room condition while the lowest reduction of 6% was noted on blanched sample stored in a deep freeze at negative 18^{o}C. A positive relationship ($P\leq0.001$) between appearance and color ($r=0.71$) and tenderness ($r=0.42$) was noted, while the odor/Smell was positively related with taste ($r=0.463$) and overall acceptance ($r=0.532$). Peas stored in pods were the most preferred and acceptable pre-treatment and storage of green vegetable pigeon peas due to color, taste and physical appearance, followed with the peas that were blanched and store in a deep freezer. Those blanched and dehydrated also rated highly on taste but not in tenderness. Assessment of these pre-treatment under solar drier need to be done, coupled with development of standard operating procedure for blanching and dehydration of green vegetable pigeon peas for increased shelf-life.

Keywords: ***Panelist, Hedonic scale, storage, sensory, acceptance.***

6.1 Introduction

Pigeon pea is a popular legume in the dryland regions of Kenya, produced by majority of the households and is ranked third in acreage after beans and cowpeas. The region is characterized by high levels of food insecurity and malnutrition (Salome, 2016), due to lack of and access to diversified diets. Due to its high nutritive value, green vegetable pigeon peas, when consumed, green, has potential in reducing malnutrition in the region. Households in the Eastern region of Kenya shell them (Shiferaw *et al.,* 2008), when harvested as green peas, based on the household and marketing needs. When shelled, the peas are exposed to extreme temperature regimes, reducing their shelf life. Majority of the households store the peas in pods (without shelling), for about 3-5 days (Shiferaw *et al.,* 2008) before consumption or delivery to the market. The pods protect the peas from harsh temperatures increasing their shelf life. There are several pretreatment methods that have potential to increase the green vegetable pigeon peas apart from storing in pods.

There is scanty information on the effect of these pre-treatment and storage on consumer preference and acceptability of green vegetable pigeon peas. Czaikosk *et al.*, (2012) observed that soyabeans quality changes when stored under cold storage, while Tosun and Yücecan (2008) observed reduction in vitamin C by 52% due to pre-treatment and freezing of Soya beans. Removal of water from food through dehydration has been recommended as one of the methods of increasing the shelf life, through reduction in moisture levels (Morris *et al*., 2004). Consumer preference and acceptability has been used to assess products for commercialization. Panelist involved in sensory evaluation have always rated highly cooked peas with great appearance and taste, while physical characteristics of the peas have always contributed to how panelists rate the appearance (Mkanda, 2007). Pea Testa color has been observed by Ojwang *et al*., (2016a) to influence green vegetable pigeon pea consumers' acceptance. They noted that dark colored green vegetable pigeon pea genotypes were not preferred and accepted by consumers as they are used to cream colored peas. Storage of peas in pods, blanching (Pervin et al 2017), dehydration and refrigeration methods are being applied in most households in effort to increase the shelf life in other related products. There is limited information on the effect of these pre-treatments on the consumer preference and acceptability in green vegetable pigeon pea product.

6.2 Materials and method

6.2.1 Material description

Medium duration genotypes were planted in a randomized block design at Kiboko research station, in Makueni County. These genotypes included ICEAP 00557 and ICEAP 00554 were originally from Tanzania, flowering in 90 days and mature in 160 days, KAT 60/8, developed at Katumani in Kenya, flowers in 120 days, and final plant height is about 130cm, have a spreading growth habit and MZ 2/9, which originally was selected from Mozambique germplasm and is an early flowering genotype. With exception of MZ 2/9, which was speckled brown, the other genotypes peas were green to light green in seed color. The seeds of the respective genotypes were sourced from ICRISAT Kiboko.

6.2.2 Sample harvest and transportation

Fresh Pigeon pea pods were harvested when they had achieved thirty-two (32 days) days post flowering based on recommendation by Singh *et al*., (1984) who suggested that peas need to be harvested 26-32 days after flowering, to benefit from maximum nutrient composition. Pods from different plots were harvested, thoroughly mixed, with some being threshed before delivery to the laboratory for sensory evaluation. Households in the Eastern region normally mix the genotypes during harvesting especially for green vegetable pigeon peas. Our practice, therefore, was to replicate farmer practice of not harvesting and cooking genotypes separately but as one mixture. The difference occurs when dealing with dry grains when producers harvest based on seed sizes, which is dictated by the market. The peas in pods and shelled were immediately threshed and transported to the lab, 250 Km in Nairobi in a cool box, at $4^{o}C$, based on previous recommendation (Onyango and Silim, 2000).

6.2.3 Pre-treatment of the green vegetable pigeon peas

The harvested vegetable Pigeon pea samples were divided into five treatments as explained below and arranged in a completely randomized design with 3 replications. After treatments, samples were stored for 22 days prior to sensory assessment. The treatment descriptions were as follows:

T1: Fresh peas: Pods were shelled, and peas, placed in polythene bags (Zip Bags) and air was removed by pressing to remove air and kept within the laboratory. The sample was stored under room temperature for 22 days at temperatures between 20-25^{o}C.

T2: Fresh + Oven-dried pre-treatment: 500 grams of fresh shelled peas were oven dried at 65^{o}C for 8 hours, then stored at room temperature for 22 days, thereafter, prepared for sensory analysis.

T3: Fresh peas blanching: Two Kilograms of shelled peas were steam blanched at 72^{o}C for 2 min, immediately submerged in cold water then drained. Immediately after blanching, the sample were stored in a deep freezer at $^{-}$18^{0}C for 22 days.

T4: Blanched + Oven-dried pre-treatment: The shelled peas were blanched, then oven dried at 65^{o}C for 8 hours. Immediately after oven-drying, the sample were stored in the laboratory under room temperature for 22 days.

T5: Peas stored in pods (Un-threshed): This represented the traditional way household store peas. The peas in pods were spread on an aluminum tray and kept on the table inside the laboratory, for a period of 22 days. During sample preparation, a few pods that would generate 100 grams of fresh peas were shelled for sensory evaluation.

Moisture content of pigeon peas: Moisture content after 22 days of storage was determined based on AOAC method specifications, by using oven drying (AOAC, 2000). A 3g of sample was weighed in clean, dried crucible [W_1]. The content was placed in a crucible and dried in an oven at 100^{o}C for 12 hrs until a constant weight was obtained. The crucible plus content was cooled in a desiccator for 30 mins and weighed again [W_2]. The percent moisture content was calculated at 0, 22 and 60 days of oven drying by the following formula:

$$\text{Percent moisture [wet weight basis]} = \frac{[\text{W1} - \text{W2}]}{[\text{Weight of Sample}]} \times 100\%$$

Where: W_1=initial weight of crucible + sample; and

W_2=final weight of crucible + Sample

6.2.4 Panellist selection and training

The sensory assessment, based on the 7-point hedonic scale, was used to evaluate consumer preference and acceptability of green vegetable pigeon peas pre-treated through different methods and stored for 22 days, under different conditions. Panelists were made up of seven (7) final year students from the Department of Food Science and Nutrition, University of Nairobi. They were native of lower Eastern region of Kenya, who have been exposed to vegetable green Pigeon pea and had consumed the product in the past 12 months. A questionnaire was used to evaluate individual reaction to quantify the sensory attributes as follows: 1=very highly unfavorable, 2 = highly unfavorable, 3 = moderately unfavorable, 4 = neither favorable nor unfavorable, 5 = moderately favorable, 6 = highly favorable, and 7 = very highly favorable (Mkanda *et al.,* 2007). The characteristics evaluated were based on appearance, color, taste, aroma (flavor), seed tenderness and overall acceptance. Preliminary screening was done based on knowledge of the desired sensory attributes of vegetable pigeon peas, with the selected panelists, in a focus group discussion a day before the actual testing. The panelists underwent a detailed training on the sensory attributes of vegetable Pigeon pea and the use of appropriate descriptive terms.

6.2.5 Sample preparation.

The samples, after storage for 22 days, post pre-treatment, a sample of 200 grams were taken from each of the 5 treatments. The deep-frozen storage samples were thawed for 20 mins, before cooking. Those stored in pods were threshed and weighed (200g), then prepared for cooking. All the samples were fully cooked to a status of normal softness, based on the household procedure and consumer expectation of what is regarded as a cooked product (Ojwang et al, 2016a). Efforts to reduce potential biases were made by using the serving plates that were not transferring any aroma or flavor to the product, and efforts to get all samples served at the same temperature and in equal amounts of 50 grams each was done. The samples were codded using three randomly selected numbers, to avoid biasness. The testing was done in the sensory testing room at the department of Food Science and Nutrition, University of Nairobi, free from strong winds with enough lighting.

6.2.6 Statistical analysis of data

The effect of pre-treatment and storage duration were evaluated by performing a two-way ANOVA analysis at 5% level of significance, based on statistical analysis procedure outlined in GENSTAT 16th edition. The mean values of treatment of each parameter were further compared by using the least significant difference (LSD) test at ($P<0.05$) level of probability, using Turkey's method (Ott, 1988).

6.3 Results and discussions

6.3.1 Effect of pre-treatment and storage on moisture content (%)

The moisture content on dry weight basis was determined at day 0, after 22 days and 60 days of storage. The base moisture levels for the fresh peas (T1) and blanched then stored in a deep freezer was 57%, compared to 56% after 22 days of storage (Table 51). The fresh dehydrated and those that were blanched then dehydrated recorded a base moisture content of 13%, increasing to 14% after 22 days of storage.

Table 51: Variation in moisture content (MC) % of pre-treated green vegetable pigeon peas at 22 days of storage

Treatment	0 Day (% MC)	22 Days (% MC)
T1: Fresh and deep frozen[R]	57c	56a
T2: Fresh and dehydrated[T]	13a	14b
T3: Fresh Blanched and deep frozen[S]	57a	56a
T4: Fresh, Blanched and dehydrated[U]	13a	14b
T5: Fresh stored in pods at Room[V]	54a	13b

[R] Samples (wet mass) were non-blanched then deep-frozen storage at $^{-}18^{o}C$ (T1).
[S] Samples steam blanched at $72^{o}C$ for 4 mins, then deep-frozen storage at $^{-}18^{o}C$. (T3)
[T] Oven-dried samples at $65^{o}C$ for 8 hours, then stored under room condition (T2).
[U] Samples (wet mass) were blanched then oven-dried at $65^{o}C$ for 8 hours and stored room condition (T4).
[V] Un-threshed pods (podded, wet mass) stored at room temperature of 20-25°C (T5).

Peas stored in pods recorded a higher moisture content of 54%, which reduced to 13% after 22 days of storage. Moisture loss from samples stored under frozen conditions ($^{-}18C$) may have been due to formation of ice crystals on the surface of peas, which may sublime into gaseous state leading to water loss when freezer is open, as explained by Araujo *et al* (2017), who observed that when dried galega kale which were not packed in water vapor and oxygen proof materials, like in this situation, moisture was lost as a consequent of increases in storage temperature during freezer door opening. The 1% gain in moisture level for products stored in room condition after dehydration could be due to absorption of moisture from the atmosphere during storage.

6.3.2 Effect of pre-treatment and storage on green vegetable pigeon pea physical appearance

Sensory evaluation for physical appearance was done on un-cooked vegetable pigeon peas, which were pre-treated and stored for 22 days. There was significant difference (P<0.01) in appearance among pre-treatments based on the panelist score (Table 52).

Table 52: Analysis of variance on the sensory characteristics of post-harvest vegetable Pigeon pea at 22 days post-treatment.

Sources of variation	D.f. [a]	Appearance[b]	Color[b]	Odor/ smell[b]	Flavor/ taste[e]	Tenderness[c]	Overall acceptance[c]
Treatment	4	4.83**	7.04**	4.81*	4.53ns	5.54*	1.24ns
Tester	6	4.11ns	5.19ns	2.65ns	4.46ns	2.96ns	2.96ns
Residual	24	0.99	0.98	1.73	2.78	1.68	1.92
LSD $_{(0.05)}$	-	1.10**	1.09**	1.45*	1.84ns	1.43*	1.53ns
CV (%)	-	18.7	19.4	25	34.1	24.8	27.6

[a] *Degrees of freedom for the Anova tests.*

[b] *Visual appeal for seed appearance, color and aroma of vegetable pigeon pea seed as evaluated by randomly selected and trained sensory evaluation panels. Assessment was conducted using hedonic scale of 1-7 where 1= highly unfavorable [dislike] and 7=highly favorable [likable] for a particular attribute.*

[c] *Evaluation of taste and tenderness after normal cooking of vegetable pigeon pea and its overall acceptability by a trained panel based on hedonic scale of 1-7 where 1= highly unfavorable [dislike] and 7=highly favorable scale (likable).*

** = significant at P<0.05; ** = significant at P<0.01; ns = non-significant at P<0.05 based on Turkey's Test.*

The panelists scores ranged from 6.3 (high likeability) for peas stored in pods to 4.4 (neither liked nor disliked) for fresh peas that were dehydrated and stored under room condition (Table 53). While blanched + dehydrated and fresh dehydrated recorded a sensory score of 4.4 and 4.6, respectively; those stored in pods, blanched then stored in a deep freezer and those that were fresh and deep frozen recorded a higher sensory value for physical appearance. The score for appearance was mainly influenced by pea colour, as the sample with higher score for colour, such as fresh, podded (6.6), also scored highly for appearance (6.3). Dehydration of the green vegetable pigeon peas reduced the green coloration and seed size, resulting in lower sensory score. The seed size defines the consumer preference, and the most preferred seed size in Indian market is 10–14 g/100 seeds (Varshney et al., 2017). Physical observation of the dehydrated products reduced the pea size, because of moisture loss, producing wrinkled peas, leading to lower scores on physical appearance. This study therefore has noted that the visual appearance based on color and size, influences the selection, preference, and choices among the green vegetable pigeon peas consumers. Storage of peas in pods and in deep freezer maintained the physical appearance, leading to consumer preferences.

Table 53: Average sensory characteristic scores of pre-treated vegetables pigeon pea after 22 days of storage

Sample Treatment[a]	Appearance[b]	Colour[b]	Aroma[b]	Taste[c]	Tenderness[c]	Overall Acceptance[c]
Fresh and deep frozen	5.4abc	5.6bc	4.0a	3.7a	5.6ab	4.6a
Fresh and dehydrated	4.4a	4.0a	5.1ab	5.6a	4.1a	4.9a
Fresh Blanched and deep frozen	6.0bc	4.7ab	5.1ab	4.7a	5.9a	5.0a
Fresh, Blanched, and dehydrated + Room	4.6ab	4.6ab	6.1b	4.7a	4.4a	5.0a
Fresh stored in pods at Room	6.3c	6.6c	5.9ab	5.7a	6.1a	5.7a
Mean	5.34	5.09	5.26	4.89	5.23	5.03
SEM	0.38	0.37	0.49	0.53	0.49	0.53
SED	0.53	0.53	0.7	0.89	0.69	0.74
$LSD_{>0.05}$	1.10**	1.09***	1.45*	1.84^{NS}	1.43*	1.53^{NS}
CV	18.7	19.4	25	34.1	24.8	27.6

[a] *Post-harvest treatment of pigeon pea.*

[b] *Visual appeal for seed appearance, color and aroma of vegetable pigeon pea seed as evaluated by a randomly selected and trained sensory evaluation panels. Assessment was conducted using hedonic scale of 1-7 where 1= highly unfavorable [dislike] and 7=highly favorable scale.*

[c] *Evaluation of taste and tenderness after normal cooking of vegetable pigeon pea and its overall acceptability by a trained panel based on hedonic scale of 1-7 where 1= highly unfavorable [dislike] and 7=highly favorable scale (likable).*

6.3.3 Effect of pre-treatment and storage on green vegetable pigeon pea color

Sensory evaluation for pea color was done on un-cooked vegetable pigeon peas, which were pre-treated and stored for 22 days. The study noted a significant difference (*$P<0.001$*) in pea color among the pre-treatments (Table 52) of vegetable pigeon peas. The average sensory score rated by the panelists for seed color ranged from 4.0, for dehydrated fresh products, to 6.6 for peas stored in pods. Panelist awarded samples that were freshly blanched (4.7), freshly blanched then dehydrated (4.6); and fresh dehydrated (4.0), which were below the average of 5.09 (Table 53). The samples stored in pods had a high sensory score (6.6), followed by fresh deep-frozen (5.6) for seed color. Deep-frozen samples maintained their initial greenness color, while dehydration affected the green coloration, leading to lower sensory scores, probably due to adversely effect on the pea chlorophyll content resulting into brownish color, which are not popular with the consumers. Lower sensory scores of 4.7 scores were recorded for fresh blanched samples. This could be due to destruction of chlorophyll content of vegetable pigeon peas by high temperature

(72^0C) due to steam blanching treatment. Nguyen *et al*. (2012) reported that chlorophyll content in peas was reduced gradually as the blanching temperature and time increased.

The green color of vegetable pigeon peas is widely considered as an appropriate marker for monitoring physical appearance changes during processing and storage (Goncalves *et al.*, 2011). The thermal processing led to loss of the vivid green chlorophyll color, resulting in olive brown color, characteristic of pheophytin. This is ultimately perceived by consumers as a loss of quality. Some of the color changes in food products results from enzymatic reactions and the release of organic acids from disrupted tissue (Martins and Silva, 2002). In the sensory evaluation of broccoli, it was noted that the vegetable color was the most important characteristic influencing consumer choice Goncalves *et al.* (2011). This study therefore observes that the green coloration of the vegetable pigeon peas plays a significant role in consumer selection and preference. Change in color due to dehydration and high temperature blanching are detrimental on the coloration of the peas, leading to reduced preference and potential rejection.

6.3.4 Effect of pre-treatment and storage on green vegetable pigeon pea taste

Sensory evaluation for pea taste was done on cooked vegetable pigeon peas, which were pre-treated and stored for 22 days. The study noted lack of significant difference ($P>0.05$) in pea taste among the pre-treatments (Table 52) of vegetable pigeon peas, indicating that pre-treatment of the product and storage for 22 days, do not affect the taste of the final product, and therefore does not impact on palatability of green vegetable pigeon peas. The panelist score on taste ranged from 3.7 for fresh peas stored in a deep freezer to 5.7 for peas stored in pods (Table 53). The leaching of nutrients during thawing and preparation could have had a change in taste of the products. Though not significant, these results show that dehydration of the peas changes the taste of peas leading to increased consumer preference and acceptance. Discussion with the panelists indicated that fresh dehydrated and fresh blanched + dehydrated peas, which scored 4.7 respectively, produced taste that is different from the normal taste they are used to. This study therefore noted that even though different pre-treatment of peas does not change the taste, those stored in pods were more preferred and accepted by consumers.

6.3.5 Effect of pre-treatment and storage on green vegetable pigeon pea tenderness

Sensory evaluation for pea tenderness was done on cooked vegetable pigeon peas, which were pre-treated and stored for 22 days. The study noted a significant difference ($P<0.05$) in pea tenderness among the pre-treatments (Table 52) of vegetable pigeon peas. The panelists gave a score ranging from 4.1 for fresh dehydrated products to 6.1 for peas stored in pods after 22 days of storage. Comparatively, the samples that were dehydrated scored very low on tenderness of 4.1 compared to those stored pods (6.1), fresh blanched and deep frozen (5.9), Fresh and deep-frozen (5.6) and fresh blanched and dehydrated (4.4) (Table 53). The low tenderness score observed in this study among the dehydrated samples, could be due to poor textural quality resulting from dehydration. This has been mainly due to product exposure to high temperatures in the presence of air during the drying process (Eze and Akubor, 2012). This has been shown to interfere with the cooking quality of vegetable seeds (Sharma *et al.*, 2006). Similar observations have been made in a study reported by Shams and Shouk, (1999), who noted that when green peas are dehydrated at 60 watts in a microwave, panelists gave them a lower score, due to the hard texture.

6.3.6 Effect of pre-treatment and storage on green vegetable pigeon pea aroma

Sensory evaluation for pea Aroma was done on cooked vegetable pigeon peas, which were pre-treated and stored for 22 days. The study noted a significant difference ($P<0.05$) in pea Aroma among the pre-treatments (Table 52) of vegetable pigeon peas, indicating the importance of aroma as a selection criterion for pre-treated green vegetable pigeon peas for consumer preferences and acceptance. The sensory scores for aroma ranged from 4.0, for fresh deep-frozen sample to 6.1, for blanched and dehydrated products, with an overall mean value of 5.3 (Table 53). While the scores for fresh peas stored in a deep freezer had significantly ($P<0.05$) lower scores, 4.0 than the average, peas stored in pods and fresh dehydrated sample were slightly above the average score value of 5.3. This study noted that fresh peas that were blanched and dehydrated improved the aroma of the product, followed by those storage in pods and finally fresh peas which were blanched and stored in a deep freezer, in that order. Aroma is an integral part of taste and general indicator of food preference and is an important parameter for acceptability of formulated foods (Mkanda, 2007). Blanching and dehydration of green vegetable pigeon peas improved the aroma of cooked vegetable pigeon pea. Foods of various constituents when subjected to heat treatment (blanched, oven-dried) may produce a wide spectrum of aroma, resulting from degradation of sugar and amino acids and their interactions (Amaefule and Onwudike, 2000; Morris *et al*., 2004). Dehydration therefore produced a characteristic sweet smell aroma that is preferred and acceptable to consumers.

6.3.7 Effect of pre-treatment and storage on green vegetable pigeon pea overall acceptance

Sensory evaluation for overall acceptance was done on cooked and un-cooked vegetable pigeon peas, which were pre-treated and stored for 22 days. There was no significant difference among the pre-treatments ($P>0.05$) for overall acceptance (Table 52), indicating that pre-treatment of the green vegetable and storage for 22 days, does not affect the overall acceptance by the consumers. The trained panellists score on overall acceptance ranged from 4.6 for deep-frozen to 5.7 for peas stored in pods (Table 53). The overall acceptability score, 5.7, was higher (though not significant) among the peas stored in pods for 22 days, indicating high overall preference. These results indicates that though colour, tenderness, appearance, and aroma are the main factors influencing acceptance and preference among the consumers for pre-treated and stored green vegetable pigeon peas, consumers don’t mind cooking them for consumption.

6.3.8 Relationships between different sensory characteristics in green vegetable pigeon peas.

The study observed a positive correlation between appearance, colour, and tenderness ($P<0.001$) (table 64). Consumers are used to see the greenness in green vegetable pigeon peas based on its physical appearance.

Table 54: Pairwise correlation coefficient for mean sensory characteristics of pre-treated and store green vegetable pigeon peas.

Parameters	Appearance	Color	Odor/ Smell	Overall Acceptance	Taste
Appearance	-				
Product Color	0.706***	-			
Odor-Smell	-0.0109^{NS}	0.0694^{NS}	-		
Overall Acceptance	0.3556^{NS}	0.579***	0.532***	-	
Product Taste	0.3096^{NS}	0.3634^{NS}	0.463***	0.734***	-
Tenderness/Softness	0.422***	0.429***	0.3356^{NS}	0.458***	0.3663^{NS}

** =significant at P≤0.05; ** = significant at P≤0.01. *** = significant at P≤0.001.*

Green vegetable Pigeon pea coloration is green and therefore, any change in colour confuses the consumers. Any pre-treatment that interferes with the colour of the product may not be acceptable.

On tenderness, oven dried products were found to be hard and gritty, and sometimes changed the physical appearance of the product, leading to reduced preference and acceptance. Colour was also positively and significantly related to overall acceptance and tenderness, indicating that selection of genotypes that meet consumer expectation need to consider the colour of the pigeon pea Testa. Dehydration contributes to poor textural quality in dried samples, which reduces tenderness leading to gritty feel during chewing. The practice also affects the greenness of the peas because of chlorophyll breakdown at high temperature. Positive and significant ($P<0.05$) association was also noted between Odor/Smell and taste ($r=0.734$) and tenderness ($r=0.458$). Consumers do consider taste as an important parameter when evaluating sensory characteristics of food for acceptance (Muhimbula *et al.,* 2011) and therefore forms an important parameter in selecting genotypes for production among the household utilization.

6.4 Conclusion and recommendation

The sensory evaluation of green vegetable pigeon pea, which were pre-treated and stored for 22 days revealed that appearance, colour, smell/Odor, and tenderness were the main sensory parameters that influenced consumers preference and acceptance. Dehydration of green vegetable pigeon peas at 65^{o}C for 8 hours improved the aroma of the peas, while at the same time reduced the tenderness and therefore the general appearance of the product. During dehydration, the green coloration and tenderness of the peas were affected as the peas were subjected to high temperature treatment in presence of air, leading to reduced tenderness as the Testa hardened. When green vegetable pigeon peas were blanched and subsequently stored in a deep freezer, the green coloration of the Testa is maintained, which is preferred by most consumers. Peas stored in pods and those freshly blanched and subsequently stored in a deep freezer, scored poorly on taste due to leaching of the mineral during thawing for cooking and storage in a deep freezer. Blanching of fresh peas and storing in a deep freezer recoded a higher sensory score on appearance, tenderness, and the seed color, due to low temperature storage that didn’t affect the Testa. Fresh peas which have been blanched and oven dried scored higher than those which were fresh and directly dehydrated on the smell/odor, tenderness, color, and appearance, indicating that blanching helps retain the color and freshness of the product before dehydration is done. The study noted that peas stored in pods for 22 days was the most preferred and accepted by the consumers, confirming that this practice is still relevant.

CHAPTER SEVEN: GENERAL DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

7.1 General discusions

Pigeon peas is an important crop among the households in the Eastern region of Kenya as a source of income, nutrition and food security. In the past decade, concerted efforts have been invested in identification and promotion of high yielding green vegetable pigeon pea genotypes for household consumption and market. Significant investment has been put on yield and yielding ability of these genotypes, with little efforts on their stability, adaptability across the main production agroecological zones and seasons, their response to moisture stress under different environment, potential effect of pre-treatments and duration of storage on nutrition characteristics and consumer preference and acceptance. This study has therefore been able to add to the body of scientific knowledge on these key issues, with the aim of improving livelihoods of the households in the Eastern region of Kenya.

Stability and adaptability of selected green vegetable pigeon peas genotypes has observed a high significant presence of GIE in plant height, duration to flower (DTF) and duration to mature (DTM), yield (Kg/ha), seed mass (10seed mass) and pods per plant (PPP) due to genetic differences, moisture regimes and temperature variation, emphasising the need for multi-location evaluation for adaptability and stability among the genotypes. Supplementing rainfall through irrigation at Kiboko and Kabete, led to delay in in genotype flowering and maturity due to prolonged vegetative growth period, leading to delayed flowering and maturity. The severity of the moisture stress during growth and development was noted when initiated during reproductive phase, with greatest effect being realized at flowering, when yields were reduced by 77% in the high tunnel and 43% in the open field at Kiboko. Water demand by green vegetable pigeon pea is more intense during flowering and podding phase and therefore, reduction in moisture levels leads to reduced leaf Relative water content (RWC). This confirms the potential negative impact of climate change, especially with increased temperatures and reduction in precipitation, on the growth and development of green vegetable pigeon peas, which potentially can expose the households in the Eastern region to severe food insecurity.

Storage of pre-treated green vegetable pigeon peas for 60 days led to reduction in nutrients with significant loss being vitamin A and C. Blanching was noted to reduces all the nutrient, with significant reduction observed on Vitamin C. Vitamin C concentration and retention are mainly influenced by high temperature and oxygen concentration, therefore any change in concentration is an indicator for either improvement or reduction in product quality. When dehydration was done on blanched sample, the nutrient loss was minimal after 60 days of storage, compared to the fresh unblanched samples stored in a deep freezer at below 18 degrees. Dehydration led to slight improvement in iron and Zinc content, which was associated with reduction in moisture.

The sensory evaluation revealed that appearance, colour, smell/Odor, and tenderness were the main parameters that influenced consumers' preference and acceptance. Dehydration of green vegetable pigeon peas at 65^{o}C for 8 hours improved the aroma of the peas, while at the same time reduced the tenderness and therefore the general appearance of the product. During dehydration, the green coloration and tenderness of the peas were affected due to breakdown of chlorophyll as the peas were subjected to high temperature treatment in presence of air, leading to reduced tenderness as the Testa hardened. Dehydration was associated with improved taste as a result of increased mineral, concentration, making them testier.

7.2 General conclusions

The significant difference among the genotypes for days to flower, maturity, Plant height, pods width, pod length, seeds per pod, yield, number of pods per plant, seed mass and shelling percent, showed great genetic diversity, and they can be of benefit in future selection either within the seasons or across the seasons. Supplementary irrigation and changes in temperature influenced the duration to flower and maturity, yield, and yield variables such as seed weight, confirming the potential impact of climate change. Lower temperatures accelerate early flowering and maturity, while supplementary irrigation to delay in flowering and maturity due to prolonged growth period. The study noted that KIONZA was the most ideal genotype due to its high mean yield across all the season, while Kambi ya Mawe, has both the discriminative ability and representativeness.

The study noted that when genotypes are faced with double challenge of increased moisture stress and high temperatures, duration to flowering and maturity is accelerated, with significant impact on yield. It was observed that genotype ICEAP 00557 and KAT 60/8 are tolerant to intermittent and terminal moisture stress due to their low values of DSI, low yield reduction rate and high drought tolerance efficiency. The study has also provided information for Irrigation scheduling during growth and development of green vegetable pigeon peas, with significant investment being during flowering and podding phases, as these are the most sensitive development stage that are affected by moisture stress.

Compared to other pre-treatments, storing peas in pods reported less loss in most nutrients, with greatest loss of Vitamin C, after 60 days. Dehydrated samples, especially those that were blanched before dehydration was done, recorded a higher dehydration and swelling coefficients, making them easier for reconstitution pre or during cooking. Therefore, the study noted that dehydration of green vegetable pigeon peas does not affect the seed Testa, and therefore seed coat water permeability. The nutrient loss during storage was mainly due to temperature, especially for those stored in the room, during thawing especially those from the deep freezer and leaching when all the samples are being prepared for analysis.

Sensory evaluation of the green vegetable pigeon peas observed that when the peas were blanched and subsequently stored in a deep freezer, the green coloration of the Testa is maintained, which is preferred by most consumers. Peas stored in pods and those freshly blanched and subsequently stored in a deep freezer, scored poorly on taste due to leaching of the mineral during thawing for cooking and storage in a deep freezer. Blanching of fresh peas and storing in a deep freezer recoded a higher sensory score on appearance, tenderness, and the seed color, due to low temperature storage that didn’t affect the Testa. Fresh peas which have been blanched and oven dried scored higher than those which were fresh and directly dehydrated on the smell/odor, tenderness, color, and appearance, indicating that blanching helps retain the color and freshness of the product before dehydration is done.

7.3 General recommendations

1. The trial at Kabete in March 2016 (S3) and October 2016 (S5) was to inform ICRISAT on its performance and possibility of evaluating green vegetable pigeon pea genotypes during off seasons in Eastern Kenya. This study recommends the location for testing unstable genotypes during preliminary selection.

2. Future research opportunities need to promote the stable, generally adapted and moisture stress tolerant genotypes MZ 2/9, KAT 60/8 and ICEAP 00557 through participatory on-farm demonstrations and trials for increased adoption among the pigeon pea producing households in the Eastern region of Kenya. Kambi ya Mawe should be considered as an ideal location for evaluating green vegetable pigeon peas in future and use KIONZA as the reference genotypes during evaluation.
3. Households and research institutions that supplement rainfall with irrigation should note that increasing irrigation frequency at flowering and podding phase will have a positive impact on yield, compared to frequent irrigation during vegetative phase. This study has been able to provide the basis for irrigation scheduling.
4. Two post-harvest management practices for green vegetable pigeon peas with potential to increase the shelf life has been proposed. (1) Promotion of blanching and subsequent dehydration of green vegetable pigeon peas, targeting the rural households. This therefore will need promotion of blanching and dehydration equipment coupled with development of the drying and blanching standard operating procedure (SOP) to achieve the correct sample specifications. (2) Promote blanching of fresh vegetable pigeon peas and subsequent storage in deep freezer, targeting the urban households, given their connectivity to the electricity grid.
5. The study noted that peas stored in pods for 22 days and Blanching and subsequently dehydration were the most preferred and accepted pre-treatment by the consumers, based on improved appearance, color and tenderness. Consumers need to be sensitized on these innovations for adoption both in the rural and urban areas. Training the rural households on best conditions under which storage of peas in pods, blanching and deep freezing will be important.

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APPENDICES

Appendix 1: Effect of moisture stress on yield and yield variables compared to the control (full irrigation/No-stress) under open field and high tunnel.

Variables	High tunnel			Open field		
	Moisture stress at Podding	Moisture stress at Flower	Stress (No Irrigation)	Moisture stress at Podding	Moisture stress at Flower	Stress (No Irrigation)
Yield (Kg/ha)	-40.4	-76.9	ND	-13.6	-43	-79.6
Pods per Plant (#)	-35.5	-71.5	ND	4.7	12.8	-67.8
Seed Mass (Grams)	-7.5	-16.1	ND	4.2	-0.8	-12.6
Harvest Index (HI)	-16.5	-3.7	ND	-19	-9.5	-39
Shelling %	-6.7	-14.5	ND	13.3	27.5	17.5
Plant Height (CM)	-13	-21.1	-49.5	-5.1	-9.5	-25.2
Days to Flower	-2.5	1	ND	5.2	3.8	62.7
Days to Harvest	-2.1	4.3	ND	9.4	6.7	57.5
Root Dry Wt (Grams)	-25.7	-45.1	-89.5	ND	ND	ND
Root Length (cm)	-7.6	-18.3	-46.9	ND	ND	ND
Biomass Dry (Grams)	-47.7	-53.3	-91.3	ND	ND	ND

Where: ND: No Data; Stress: No supplementary Irrigation

Appendix 2: Analysis of Variance table - Yield Stability analysis

Variate: %100_Seed_mass_G_100

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	71.94	35.97	2.73	
VAR_NAME	4	1797.96	449.49	34.06	<.001
ENVIRON	5	2327.29	465.46	35.27	<.001
VAR_NAME.ENVIRON	20	666.95	33.35	2.53	0.003
Residual	58	765.33	13.20		
Total	89	5629.46			

Variate: Days_to_50%_Flower

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	206.60	103.30	1.31	
VAR_NAME	4	42084.33	10521.08	133.55	<.001
ENVIRON	5	98091.97	19618.39	249.02	<.001
VAR_NAME.ENVIRON	20	22824.20	1141.21	14.49	<.001
Residual	58	4569.40	78.78		
Total	89	167776.50			

Variate: Days_to_Harvesting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	185.27	92.63	0.93	
VAR_NAME	4	49498.96	12374.74	124.68	<.001
ENVIRON	5	91387.73	18277.55	184.15	<.001
VAR_NAME.ENVIRON	20	25215.71	1260.79	12.70	<.001
Residual	58	5756.73	99.25		
Total	89	172044.40			

Variate: Grain_Yield_Kg_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1620.	810.	0.01	
VAR_NAME	4	3306164.	826541.	6.03	<.001
ENVIRON	5	18103375.	3620675.	26.40	<.001
VAR_NAME.ENVIRON	20	7162881.	358144.	2.61	0.002
Residual	58	7954643.	137149.		
Total	89	36528683.			

Variate: No_of_Pods

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	322.	161.	0.12	
VAR_NAME	4	22201.	5550.	4.06	0.006
ENVIRON	5	116771.	23354.	17.07	<.001
VAR_NAME.ENVIRON	20	72026.	3601.	2.63	0.002
Residual	58	79353.	1368.		
Total	89	290673.			

Variate: No_of_Pri_Branches

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	26.987	13.494	3.20	
VAR_NAME	4	20.338	5.084	1.21	0.318
ENVIRON	5	204.081	40.816	9.68	<.001
VAR_NAME.ENVIRON	20	53.862	2.693	0.64	0.866
Residual	58	244.557	4.216		
Total	89	549.825			

Variate: No_of_Recemes

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	252.9	126.4	1.12	
VAR_NAME	4	7786.9	1946.7	17.21	<.001
ENVIRON	5	14603.7	2920.7	25.82	<.001
VAR_NAME.ENVIRON	20	10733.6	536.7	4.74	<.001
Residual	58	6560.7	113.1		
Total	89	39937.8			

Variate: No_of_Sec_Branches

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1.969	0.984	0.32	
VAR_NAME	4	24.870	6.218	2.02	0.103
ENVIRON	5	319.613	63.923	20.78	<.001
VAR_NAME.ENVIRON	20	120.036	6.002	1.95	0.025
Residual	58	178.426	3.076		
Total	89	644.913			

Variate: Plant_height_CM

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	473.2	236.6	1.10	
VAR_NAME	4	36031.8	9007.9	41.90	<.001
ENVIRON	5	120302.7	24060.5	111.91	<.001
VAR_NAME.ENVIRON	20	34186.8	1709.3	7.95	<.001
Residual	58	12469.6	215.0		
Total	89	203464.0			

Variate: Pod_Length_CM

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.0375	0.0187	0.03	
VAR_NAME	4	8.0114	2.0029	3.22	0.019
ENVIRON	5	96.0816	19.2163	30.94	<.001
VAR_NAME.ENVIRON	20	15.4347	0.7717	1.24	0.255
Residual	58	36.0254	0.6211		
Total	89	155.5907			

Variate: Pod_width_CM

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.00518	0.00259	0.24	
VAR_NAME	4	0.14427	0.03607	3.28	0.017
ENVIRON	5	0.40443	0.08089	7.36	<.001
VAR_NAME.ENVIRON	20	0.23009	0.01150	1.05	0.428
Residual	58	0.63782	0.01100		
Total	89	1.42180			

Variate: Seed_per_pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.5958	0.2979	2.02	
VAR_NAME	4	4.7727	1.1932	8.10	<.001
ENVIRON	5	8.0141	1.6028	10.88	<.001
VAR_NAME.ENVIRON	20	3.7611	0.1881	1.28	0.232
Residual	58	8.5459	0.1473		
Total	89	25.6896			

Variate: Shell_%

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	211.7	105.9	0.97	
VAR_NAME	4	2413.9	603.5	5.51	<.001
ENVIRON	5	3700.1	740.0	6.76	<.001
VAR_NAME.ENVIRON	20	2619.3	131.0	1.20	0.291
Residual	58	6352.6	109.5		
Total	89	15297.6			

Appendix 3: Analysis of Variance table – Response to moisture stress - Open Field

Variate: %100_Seed_mass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	9.745	4.873	0.90	
Block. *Units* stratum					
VAR_NAME	3	339.773	113.258	21.00	<.001
Treatment	3	152.365	50.788	9.42	<.001
VAR_NAME.Treatment	9	147.072	16.341	3.03	0.011
Residual	30	161.761	5.392		
Total	47	810.717			

Variate: Days_to_Harvest

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	7.875	3.938	0.41	
Block. *Units* stratum					
VAR_NAME	3	2112.667	704.222	73.67	<.001
Treatment	3	57794.167	19264.722	2015.20	<.001
VAR_NAME.Treatment	9	330.500	36.722	3.84	0.003
Residual	30	286.792	9.560		
Total	47	60532.000			

Variate: Grain_Yield_Kg_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	649821.	324910.	2.00	
Block. *Units* stratum					
VAR_NAME	3	3021016.	1007005.	6.21	0.002
Treatment	3	17769051.	5923017.	36.54	<.001
VAR_NAME.Treatment	9	2844147.	316016.	1.95	0.082
Residual	30	4863020.	162101.		
Total	47	29147055.			

Variate: HI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	31.57	15.79	0.61	
Block. *Units* stratum					
VAR_NAME	3	91.01	30.34	1.16	0.340
Treatment	3	813.65	271.22	10.40	<.001
VAR_NAME.Treatment	9	183.19	20.35	0.78	0.636
Residual	30	782.31	26.08		
Total	47	1901.73			

Variate: No_of_Pods

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1604.	802.	0.76	
Block. *Units* stratum					
VAR_NAME	3	22763.	7588.	7.23	<.001
Treatment	3	220352.	73451.	69.97	<.001
VAR_NAME.Treatment	9	16520.	1836.	1.75	0.121
Residual	30	31492.	1050.		
Total	47	292731.			

Variate: No_of_Pri_Branches

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.1076	0.0538	0.44	
Block. *Units* stratum					
VAR_NAME	3	0.4535	0.1512	1.24	0.314
Treatment	3	1.0702	0.3567	2.92	0.050
VAR_NAME.Treatment	9	1.0988	0.1221	1.00	0.462
Residual	30	3.6674	0.1222		
Total	47	6.3974			

Variate: No_of_Sec_Branches

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.2004	0.1002	0.11	
Block. *Units* stratum					
VAR_NAME	3	4.3240	1.4413	1.65	0.200
Treatment	3	9.1106	3.0369	3.47	0.028
VAR_NAME.Treatment	9	3.9519	0.4391	0.50	0.862
Residual	30	26.2729	0.8758		
Total	47	43.8598			

Variate: Plant_height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	619.	309.	0.27	
Block. *Units* stratum					
VAR_NAME	3	11003.	3668.	3.23	0.036
Treatment	3	33879.	11293.	9.94	<.001
VAR_NAME.Treatment	9	28784.	3198.	2.82	0.016
Residual	30	34067.	1136.		
Total	47	108352.			

Variate: Pod_Length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.1017	0.0508	0.16	
Block. *Units* stratum					
VAR_NAME	3	4.7092	1.5697	4.99	0.006
Treatment	3	5.3425	1.7808	5.66	0.003
VAR_NAME.Treatment	9	2.6208	0.2912	0.92	0.518
Residual	30	9.4450	0.3148		
Total	47	22.2192			

Variate: Pod_width

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.000079	0.000040	0.02	
Block. *Units* stratum					
VAR_NAME	3	0.002773	0.000924	0.43	0.735
Treatment	3	0.010373	0.003458	1.60	0.211
VAR_NAME.Treatment	9	0.025152	0.002795	1.29	0.282
Residual	30	0.064921	0.002164		
Total	47	0.103298			

Variate: Seed_per_pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.3517	0.1758	1.27	
Block. *Units* stratum					
VAR_NAME	3	2.8958	0.9653	6.97	0.001
Treatment	3	1.6825	0.5608	4.05	0.016
VAR_NAME.Treatment	9	1.2542	0.1394	1.01	0.457
Residual	30	4.1550	0.1385		
Total	47	10.3392			

Variate: Shell_%

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	67.24	33.62	0.35	
Block. *Units* stratum					
VAR_NAME	3	285.65	95.22	0.99	0.411
Treatment	3	995.22	331.74	3.45	0.029
VAR_NAME.Treatment	9	840.23	93.36	0.97	0.483
Residual	30	2884.93	96.16		
Total	47	5073.27			

Variate: DSI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.2893	0.1446	0.77	
Block. *Units* stratum					
VAR_NAME	3	0.0055	0.0018	0.01	0.999
Treatment	2	0.0033	0.0016	0.01	0.991
VAR_NAME.Treatment	6	0.0077	0.0013	0.01	1.000
Residual	22	4.1513	0.1887		
Total	35	4.4572			

Variate: DTE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1281.2	640.6	2.26	
Block. *Units* stratum					
VAR_NAME	3	903.5	301.2	1.06	0.384
Treatment	2	20670.4	10335.2	36.53	<.001
VAR_NAME.Treatment	6	3166.7	527.8	1.87	0.132
Residual	22	6224.5	282.9		
Total	35	32246.4			

Appendix 4: Analysis of Variance table – Response to moisture stress – High tunnel

Variate: %100_Seed_mass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	7508.514	2502.838	901.45	<.001
Genotype_Name	3	1043.591	347.864	125.29	<.001
Treatment.Genotype_Name	9	412.608	45.845	16.51	<.001
Residual	32	88.847	2.776		
Total	47	9053.559			

Variate: Days_to_50%_Flower

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	33.50	16.75	1.05	
Block. *Units* stratum					
Genotype_Name	3	2625.42	875.14	54.72	<.001
Treatment	3	87398.25	29132.75	1821.43	<.001
Genotype_Name.Treatment	9	980.25	108.92	6.81	<.001
Residual	30	479.83	15.99		
Total	47	91517.25			

Variate: Days_to_Harvest

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	13.62	6.81	0.26	
Block. *Units* stratum					
Genotype_Name	3	2567.50	855.83	32.99	<.001
Treatment	3	150967.50	50322.50	1939.52	<.001
Genotype_Name.Treatment	9	1275.00	141.67	5.46	<.001
Residual	30	778.38	25.95		
Total	47	155602.00			

Variate: Final_Plant_height_0103

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	54.12	27.06	2.06	
Block. *Units* stratum					
Genotype_Name	3	1085.40	361.80	27.60	<.001
Treatment	3	17562.40	5854.13	446.64	<.001
Genotype_Name.Treatment	9	1745.19	193.91	14.79	<.001
Residual	30	393.21	13.11		
Total	47	20840.31			

Variate: Grain_Yield_Kg_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	13374.	6687.	0.36	
Block. *Units* stratum					
Genotype_Name	3	651255.	217085.	11.53	<.001
Treatment	3	15877654.	5292551.	281.05	<.001
Genotype_Name.Treatment	9	336237.	37360.	1.98	0.077
Residual	30	564940.	18831.		
Total	47	17443459.			

Variate: HI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	156.43	78.21	1.44	
Block. *Units* stratum					
Genotype_Name	3	4115.27	1371.76	25.34	<.001
Treatment	3	9010.68	3003.56	55.48	<.001
Genotype_Name.Treatment	9	4062.32	451.37	8.34	<.001
Residual	30	1624.07	54.14		
Total	47	18968.77			

Variate: No_of_Pods

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1.542	0.771	0.42	
Block. *Units* stratum					
Genotype_Name	3	309.667	103.222	56.86	<.001
Treatment	3	5583.333	1861.111	1025.25	<.001
Genotype_Name.Treatment	9	235.667	26.185	14.42	<.001
Residual	30	54.458	1.815		
Total	47	6184.667			

Variate: No_of_Pri_Branches

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	10.6667	5.3333	6.86	
Block. *Units* stratum					
Genotype_Name	3	37.5833	12.5278	16.11	<.001
Treatment	3	589.5833	196.5278	252.68	<.001
Genotype_Name.Treatment	9	60.7500	6.7500	8.68	<.001
Residual	30	23.3333	0.7778		
Total	47	721.9167			

Variate: No_of_Sec_Branches

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1.292	0.646	0.62	
Block. *Units* stratum					
Genotype_Name	3	2.833	0.944	0.90	0.451
Treatment	3	4.333	1.444	1.38	0.268
Genotype_Name.Treatment	9	7.833	0.870	0.83	0.592
Residual	30	31.375	1.046		
Total	47	47.667			

Variate: Pod_Length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1.8704	0.9352	1.70	
Block. *Units* stratum					
Genotype_Name	3	8.6190	2.8730	5.22	0.005
Treatment	3	494.2623	164.7541	299.14	<.001
Genotype_Name.Treatment	9	15.1952	1.6884	3.07	0.010
Residual	30	16.5229	0.5508		
Total	47	536.4698			

Variate: Pod_width

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.02625	0.01313	0.89	
Block. *Units* stratum					
Genotype_Name	3	0.24562	0.08187	5.58	0.004
Treatment	3	16.38563	5.46188	372.05	<.001
Genotype_Name.Treatment	9	0.17021	0.01891	1.29	0.284
Residual	30	0.44042	0.01468		
Total	47	17.26813			

Variate: Root_Dry_Weight_Gms

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	13.93	6.96	0.44	
Block. *Units* stratum					
Genotype_Name	3	587.97	195.99	12.30	<.001
Treatment	3	1352.68	450.89	28.31	<.001
Genotype_Name.Treatment	9	271.53	30.17	1.89	0.092
Residual	30	477.87	15.93		
Total	47	2703.98			

Variate: Root_Length_cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	331.91	165.95	4.54	
Block. *Units* stratum					
Genotype_Name	3	132.35	44.12	1.21	0.324
Treatment	3	2430.31	810.10	22.18	<.001
Genotype_Name.Treatment	9	636.80	70.76	1.94	0.084
Residual	30	1095.59	36.52		
Total	47	4626.95			

Variate: Seed_per_pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.7917	0.3958	1.13	
Block. *Units* stratum					
Genotype_Name	3	0.5000	0.1667	0.47	0.702
Treatment	3	186.8333	62.2778	177.23	<.001
Genotype_Name.Treatment	9	3.0000	0.3333	0.95	0.500
Residual	30	10.5417	0.3514		
Total	47	201.6667			

Variate: Shell_%

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	64.97	32.48	0.83	
Block. *Units* stratum					
Genotype_Name	3	132.38	44.13	1.13	0.353
Treatment	3	26504.83	8834.94	226.15	<.001
Genotype_Name.Treatment	9	795.42	88.38	2.26	0.045
Residual	30	1172.01	39.07		
Total	47	28669.60			

Variate: Stem_and_Branch_Dry_Wts_Gms

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	69.6	34.8	0.33	
Block. *Units* stratum					
Genotype_Name	3	2929.3	976.4	9.33	<.001
Treatment	3	21483.9	7161.3	68.42	<.001
Genotype_Name.Treatment	9	1275.7	141.7	1.35	0.252
Residual	30	3140.0	104.7		
Total	47	28898.5			

Variate: DSI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.18144	0.09072	0.91	
VAR_NAME	3	0.00493	0.00164	0.02	0.997
Treatment	1	0.00489	0.00489	0.05	0.828
VAR_NAME.Treatment	3	0.00351	0.00117	0.01	0.998
Residual	14	1.38871	0.09919		
Total	23	1.58348			

Variate: DTE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	483.4	241.7	1.36	
VAR_NAME	3	630.0	210.0	1.18	0.352
Treatment	1	8629.2	8629.2	48.59	<.001
VAR_NAME.Treatment	3	363.1	121.0	0.68	0.578
Residual	14	2486.1	177.6		
Total	23	12591.8			

Variate: Relative Water content at flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	8595.28	2865.09	67.77	<.001
Residual	8	338.23	42.28		
Total	11	8933.51			

Variate: Relative Water Content at podding

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	3924.59	1308.20	100.57	<.001
Residual	8	104.06	13.01		
Total	11	4028.65			

Variate: Relative Water Ccontent at Vegetative

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	890.3	296.8	2.51	0.133
Residual	8	946.1	118.3		
Total	11	1836.4			

Appendix 5: Analysis of variance table – Effect of processing on Nutrient composition

Variate: Dry matter

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	0.00	0.00		
TREATMENT	4	15050.00	3762.50		
DURATION	3	421.90	140.63		
TREATMENT.DURATION	12	1999.60	166.63		
Residual	19	0.00	0.00		
Total	39	17471.50			

Variate: Iron_mg_100g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	0.00000104	0.00000104	0.03	
TREATMENT	4	5.99011633	1.49752908	45159.25	<.001
DURATION	3	0.00246416	0.00082139	24.77	<.001
TREATMENT.DURATION	12	0.01114172	0.00092848	28.00	<.001
Residual	19	0.00063006	0.00003316		
Total	39	6.00435331			

Variate: Protein_%

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	8.471E-06	8.471E-06	0.60	
TREATMENT	4	2.208E+01	5.521E+00	3.931E+05	<.001
DURATION	3	4.020E+00	1.340E+00	95414.03	<.001
TREATMENT.DURATION	12	2.003E+00	1.669E-01	11886.88	<.001
Residual	19	2.668E-04	1.404E-05		
Total	39	2.811E+01			

Variate: Total_Sugars_mg_100g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	1.566E-04	1.566E-04	2.38	
TREATMENT	4	1.104E+01	2.761E+00	41952.93	<.001
DURATION	3	2.344E+00	7.813E-01	11873.09	<.001
TREATMENT.DURATION	12	5.444E-01	4.537E-02	689.47	<.001
Residual	19	1.250E-03	6.580E-05		
Total	39	1.393E+01			

Variate: Vitamin_A_ug_100g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	1.125E+00	1.125E+00	22.83	
TREATMENT	4	1.826E+05	4.566E+04	9.261E+05	<.001
DURATION	3	1.979E+04	6.596E+03	1.338E+05	<.001
TREATMENT.DURATION	12	6.092E+04	5.077E+03	1.030E+05	<.001
Residual	19	9.367E-01	4.930E-02		
Total	39	2.633E+05			

Variate: Vitamin_C_mg_100g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	0.3296	0.3296	0.61	
TREATMENT	4	2014.4038	503.6010	936.04	<.001
DURATION	3	121.3994	40.4665	75.21	<.001
TREATMENT.DURATION	12	264.5448	22.0454	40.98	<.001
Residual	19	10.2223	0.5380		
Total	39	2410.8999			

Variate: Zinc_mg_100g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	0.0000089	0.0000089	0.07	
TREATMENT	4	1.5953761	0.3988440	3130.76	<.001
DURATION	3	0.0011550	0.0003850	3.02	0.055
TREATMENT.DURATION	12	0.0186178	0.0015515	12.18	<.001
Residual	19	0.0024205	0.0001274		
Total	39	1.6175783			

Appendix 6: Analysis of variance table – Sensory characteristics

Variate: Appearance

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Tester stratum	6	24.6857	4.1143	4.13	
TrT_Name	4	19.3143	4.8286	4.85	0.005
Residual	24	23.8857	0.9952		
Total	34	67.8857			

Variate: Color

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Tester stratum	6	31.1429	5.1905	5.32	
TrT_Name	4	28.1714	7.0429	7.21	<.001
Residual	24	23.4286	0.9762		
Total	34	82.7429			

Variate: OdorSmell

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Tester stratum	6	15.886	2.648	1.53	
TrT_Name	4	19.257	4.814	2.78	0.050
Residual	24	41.543	1.731		
Total	34	76.686			

Variate: Overall Acceptance

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Tester stratum	6	17.771	2.962	1.54	
TrT_Name	4	4.971	1.243	0.65	0.636
Residual	24	46.229	1.926		
Total	34	68.971			

Variate: Taste

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Tester stratum	6	26.743	4.457	1.60	
TrT_Name	4	18.114	4.529	1.63	0.199
Residual	24	66.686	2.779		
Total	34	111.543			

Variate: Tenderness - Softness

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Tester stratum	6	17.771	2.962	1.77	
TrT_Name	4	22.171	5.543	3.31	0.027
Residual	24	40.229	1.676		
Total	34	80.171			