

**AGRONOMIC TRAITS ASSESSMENT AND GROWTH AND YIELD RESPONSES OF  
SELECTED SPIDER PLANT (*Cleome gynandra* L.) ACCESSIONS TO WATER STRESS**

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**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE  
AWARD OF THE DEGREE OF MASTER OF SCIENCE IN AGRONOMY**

**DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION  
FACULTY OF AGRICULTURE  
UNIVERSITY OF NAIROBI**

**2020**

## DECLARATION

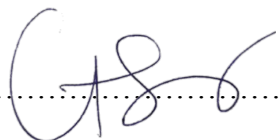
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## **DEDICATION**

To my family for their continued support in my studies.

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## **LIST OF ABBREVIATIONS AND ACRONYMS**

ALVs	African Leafy Vegetables
ANOVA	Analysis of Variance
CAVS	College of Agriculture and Veterinary Sciences
FAO	Food and Agriculture Organization of the United Nations
FC	Field Capacity
FS	Field Station
GBK	Gene Bank of Kenya
GDP	Gross Domestic Product
HCD	Horticultural Crops Directorate
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KALRO	Kenya Agricultural and Livestock Research Organization
RCBD	Randomized Complete Block Design
MoA	Ministry of Agriculture
MT	Metric tonnes
NARI	National Agricultural Research Institute
OA	Osmotic Adjustment
SPAD	Soil Plant Analysis Development
SSA	Sub Saharan Africa
WHO	World Health Organization

## GENERAL ABSTRACT

African leafy vegetables (ALVs) are vegetables that are locally consumed and whose edible parts include leaves, young shoots and flowers. They have a crucial role in enhancing food security, nutrition, biodiversity, income and sustainable development in Kenya. Spider plant (*Cleome gynandra* L.) is one of the ALVs with a great potential for improving food security and income among rural and urban resource-poor communities. However, its productivity is low partly due to lack of suitable varieties, poor soil fertility, drought stress and poor agronomic practices. Currently, there is scanty information on its potential for vegetable and seed production and adaptability to water stress. Therefore, the objectives of this study were: (i) to evaluate the agronomic traits of selected spider plant accessions; and (ii) to determine the effect of water stress on growth and yield of selected spider plant accessions. In the first objective, a study was conducted at Kabete in the field and greenhouse and on-farm in Migori County to assess agronomic traits of 40 selected spider plant accessions using a randomized complete block design with three replications. In the second objective, 14 selected Kenyan spider plant accessions were grown under soils at 40%, 60%, 80% and 100% field capacity (FC) conditions in a greenhouse at Kabete between June 2018 and March 2019. In both experiments, data was collected on plant growth, physiological and yield attributes and subjected to analysis of variance using GenStat 15<sup>th</sup> edition at 5% probability level. Number of days to emergence and emergence level varied from 4 (accessions GBK-045436) to 12.7 (accessions GBK-032302 and GBK-031992) and 23.1% (accession Baringo) to 59% (Commercial variety), respectively. Number of leaves per plant and seed yield per plant varied from 23.2 (accession Mombasa) to 121.7 (accession GBK-028563) and 0.3 g (accession Mombasa) to 16.8 g (accession GBK-045456), respectively. Plant height ranged from 16.0 cm (accession Mombasa) to 107.1 cm (accession GBK-045436), while 100 seed weight varied from 60 mg (accession Mombasa) to 170 mg (accession GBK-031994). Number of leaves per plant were proportional to number of primary branches ( $R^2 = 0.81$ ,  $P \leq 0.01$ ) and plant height ( $R^2 = 0.87$ ,  $P \leq 0.01$ ). Water stress reduced plant height by 9.9%, 26.2%, and 38.5%, and leaf yield by 25.7%, 55.1%, and 74.2% at 80%, 60% and 40% field capacity, respectively. Pod number per spider plant reduced by 17.0%, 47.9%, 61.5% and seed yield per spider plant by 43.9%, 77.9% and 90.6% at 80%, 60% and 40% FC, respectively. Chlorophyll content reduced by 11.3%, 26.7%, 38.2% at 80%, 60%, 40% FC, respectively. Results indicate that there exist significant genotypic differences among the

evaluated spider plant landraces and the commercial variety in adaptation to drought. The responses to drought in most of the physiological, growth and yield parameters were dependent on the accessions. Genotypes that expressed superior agronomic traits for yield such as accessions GBK-032210, GBK-040449, GBK-031991 Kakamega and GBK-045456, point to the existence of exploitable drought tolerance genes in spider plant landraces that can be utilized in breeding programmes for drought adaptability aimed at improving spider plant growth and yield.

## CHAPTER 1: INTRODUCTION

### 1.1 Background information

Horticulture is the fastest growing sector of agriculture in Kenya contributing to alleviation of poverty and nutritional security, and generating huge employment opportunities along the food chain (Kebede and Bokelmann, 2017). According to the Horticultural Crops Directorate of Kenya, domestic value of horticulture production in 2017 amounted to Kenyan shillings (KES) 236.45 billion compared to KES 213.11 billion in 2016 reflecting an increase of 11 % from 2016. Cultivation area increased by 7 % from 546, 936 Ha to 584,597 Ha with a total production of 8.589 million metric tonnes (MT) in 2017 compared to 7.89 MT in 2016. Vegetables accounted for approximately 36% of total horticultural production during 2016- 2017 period (HCDA, 2017) (Table 1). During the period under review vegetable exports increased from 78,790,023 MT in 2016 to 87,240,279 MT in 2017 representing 11 percent increase. The value also increased from KES 23.36 billion to KES 24.06 billion in 2017 representing 3 percent increase.

**Table 1: Summary of performance of horticultural products per category in 2016 and 2017**

Crop	YEAR 2016			YEAR 2017			% Total Value
	Area (Ha)	Volume (MT )	Value (KES) (Bil.)	Area (Ha)	Volume (MT)	Value ( KES) (Bil.)	
Cut Flowers	13,265	133,658	70.8	13,265	159,961	82.2	34.8
Exotic Vegetables	283,615	4,145,900	72.2	295,089	4,404,171	75.5	32.0
Fruits	163,624	3,039,773	53.2	185,211	3,396,582	60.7	25.7
Indigenous Vegetables	63,314	229,492	6.8	66,879	265,267	8.0	3.4
Summer flowers	8,257	194,284	3.5	8,267	198,358	3.5	1.5
Aromatic plants	12,383	124,642	5.8	12,359	129,253	5.2	2.2
Asian Vegetables	1,980	19,043	0.6	3,067	32,292	0.9	0.4
Medicinal plants	498	3,989	0.1	460	3,492	0.1	0.1
<b>Total</b>	<b>546,936</b>	<b>7,890,781</b>	<b>213.1</b>	<b>584,597</b>	<b>8,589,376</b>	<b>236.2</b>	<b>100.0</b>

Source: HCDA (2017) KES (Bil.) – Kenyan shillings in billions

The ALVs are vegetables that are locally consumed and their edible parts include leaves, young shoots and flowers (Abukutsa-Onyango, 2010). African leafy vegetables, also known as indigenous vegetables, are considered to be underutilized crops (Weinberger, 2007). The most commonly consumed indigenous vegetables in Sub-Saharan Africa are spider plant (*Cleome gynandra* L.), cowpea (*Vigna unguiculata* L.), amaranthus (*Amaranthus* species), African nightshade (*Solanum* species), African kale (*Brassica cavinata* L.), African eggplant (*Solanum aethiopicum* L.), and jute



mallow (*Corchorus solitorins* L.) (Aura, 2011). Africa is the center of origin of these edible indigenous vegetables that play a vital role in Africa's food and nutritional security (Aura, 2011). Cultivation, commercialization and consumption of indigenous vegetables is currently taking root in Africa and gaining popularity among the locals. These ALVs not only improve nutrition, but also contribute to increased income, as well as restoration and conservation of agricultural biodiversity (Kebede and Bokelmann, 2017). African leafy vegetables have many potential benefits. They have the potential to alleviate extreme poverty and hunger as they are cheaper to produce in terms of inputs and management (Kebede and Bokelmann, 2017). They are also rich in vitamins, minerals, phytochemicals and anti-oxidant properties. Increased consumption of ALVs positively impacts health, nutrition and economic wellbeing of the consumer and producer (Abukutsa, 2010; Makokha and Ombwara, 2005). Despite the potential benefits of indigenous vegetables, the preference for exotic vegetables is still high due to lack of appreciation of indigenous vegetables (Abukutsa-Onyango, 2010), rural-urban migration, limited scientific information about African indigenous vegetable cultivars and species, inadequate seed quality, low seed yields, short shelf-life, technical issues, climate change, environmental degradation, negative attitudes and policy issues (Shei, 2008; Abukutsa-Onyango, 2012).

In the recent past, there has been an increased role of indigenous vegetables in horticulture. The preference for the indigenous vegetable popularly known as African leafy vegetables (ALVs) has been on the increase because of increased awareness on the health and nutritional benefits. According to HCDA (2017), during 2017 the area under these vegetables increased by 6 percent from 63,314 ha in 2016 to 66,879 ha in 2017. The yields and value increased from 229,492 tonnes in 2016 to 265,267 tonnes in 2017 and KES 6.83 billion in 2016 to KES 8.01 billion in 2017 representing a 16% and 17% increase, respectively. In this category of vegetables, cowpea contributed 38.97% followed by African Nightshade and spider plant that contributed 23.75% and 12.41%, respectively (Table 2). *Cleome* belongs to the genus of the family Cleomaceae (formerly Capparaceae). It is a major group of angiosperms and comprises many species found in tropical and sub-tropical regions of the globe. The family encompasses flowering plants in the order Brassicales that comprises more than 764 species that belong to 12 genera. Among these genera, *Cleome* is the largest with approximately 601 species of ecological, ethnobotanical, medicinal and nutritional importance (Ravichandra *et al.*, 2014). Spider plant (*Cleome gynandra* L.) is the most widely used *Cleome* plant species as a leafy vegetable. Its closer relative species namely, *C. monophylla*, *C. hirta* and *C. hasslerian*, are also occasionally used as vegetables (Hart and Vorster, 2006).

**Table 1.2: Production of indigenous vegetables for the year 2016-2017**

Crop	Year 2016			Year 2017			% total value
	Area (Ha)	Volume (MT )	Value (KES Bil.)	Area (Ha)	Volume (MT)	Value (KES Bil.)	
Cowpea	50,357	124,957	2.94	52,199	135,116	3.12	38.97
African night shade	4,285	38,757	1.61	4,615	43,794	1.90	23.75
Spider plants	2,854	15,128	0.58	3,285	24,055	0.99	12.41
Pumpkin fruit	1,164	16,349	0.51	1,394	20,698	0.58	7.19
Leaf amaranthus	1,867	15,760	0.48	2,053	17,979	0.58	7.18
Slender	403	4,052	0.19	641	7,104	0.23	2.85
Jute mallow	842	5,384	0.16	937	5,829	0.19	2.36
Pumpkin leaves	711	5,553	0.13	821	6,546	0.15	1.82
Grain amaranth	500	1,594	0.11	487	1,474	0.14	1.71
Vine spine	103	1,520	0.07	208	2,268	0.09	1.14
Tunguja	160	150	0.04	168	160	0.04	0.55
Malabor	20	65	0.002	23	72	0.002	0.03
Stinging nettle	46	98	0.002	46	107	0.002	0.03
<b>Total</b>	<b>63,314</b>	<b>229,492</b>	<b>6.83</b>	<b>66,879</b>	<b>265,267</b>	<b>8.01</b>	<b>100.0</b>

Source, HCDA (2017) KES Bil.- Kenyan shillings in billions

The genus *Cleome* is undergoing constant advancement and a number of its species are showing progressive change from C<sub>3</sub> photosynthesis to C<sub>4</sub> photosynthesis. These developmental changes are indistinguishable from Brassicaceae individuals such as *Arabidopsis thaliana* and currently a number of species of spider plant are described as C<sub>4</sub> plants (Kori *et al.*, 2009).

Spider plant is widely used as a local vegetable in sub Saharan Africa (FAO, 2010). It is a tropical plant with common names including spider flower, cat whiskers, spider plant of Africa, spider wisp and African cabbage (Mishra *et al.*, 2011). Different African communities have given *C. gynandra* different local names including saget (Kalenjin), chinsaga (Kisii), *a lot dek* (Luo) and saga (Swahili) (Onyango *et al.*, 2016). Spider plant has both food and medicinal value. It is rich in micronutrients and vitamins and crucial in relieving hunger, poverty and malnutrition (Jansen Van Rensburg *et al.*, 2004; Van den Heever and Venter, 2007). The evaluation of spider plant for nutrient content shows that it contains high calcium, magnesium, iron, zinc, vitamins A, C and E, proteins and high beta-carotene content (Jinazali *et al.*, 2017; Ekpong, 2009; Mahyao *et al.*, 2008). Spider crop yields in Kenya are relatively low and this impedes its commercial production. Estimated spider plant yield using locally available resources varies from 1.0 to 5.3 t ha<sup>-1</sup> (Abukutsa-Onyango, 2003; HCDA, 2017) compared to the potential yield of 20.5 to 30 t ha<sup>-1</sup> (Abukutsa-Onyango, 2003). The low spider

crop yields could be attributed to the low soil fertility, low soil moisture, poor farming techniques and lack of quality seed (Vorster and Jansen Van Rensburg, 2005).

Low consumption and marketability of landrace cultivars is associated with their bitter taste and pubescence. The status of this spider plant as a weed, volunteer and a wild crop has led to the misconception that spider plant is a vegetable for the poor (Abukutsa-Onyango, 2010). There is limited information about the agronomic trait variations in spider plant and possibility for enhancement of the crop through selection, domestication and breeding. Little is known about its adaptability to drought, even though it is grown in different environments.

## **1.2 Problem statement**

There is continuous collection and cultivation of spider plant accessions in various parts of Kenya by farmers and gene bank curators, but the agronomic traits and adaptability to water stress of most of these accessions have not been systematically documented (K'Opondo *et al.*, 2009; Masuka and Mazarura, 2012). Utilizing locally available growth resources, farmers obtain spider plant yield of 1.0 to 5.3 t ha<sup>-1</sup> compared to a yield potential of 20-30 t ha<sup>-1</sup> (Abukutsa-Onyango, 2003, HCDA, 2017). The low yield is partly attributed to drought stress and use of low yielding varieties, (Masinde and Agong, 2011). Production of spider plant in Kenya is mainly rain-fed leading to exposure of the crop to varying degrees of drought due to low, erratic and unreliable rainfall which is exacerbated by climate change. Drought results to reduced plant growth and yield of spider plant. Phenotyping for drought tolerance under controlled conditions can be used to prescreen spider plant genotypes for further verification in the field. The developmental stages at which these stresses occur, their duration, and their severity are also key factors for tolerance/resistance evaluation. It is therefore necessary to evaluate the spider plant accessions currently being used by farmers and those preserved in the gene bank for adaptation to drought. Limited documentation of agronomic traits of existing spider plant accessions impedes selection and development of elite varieties. This translates to lack of high yielding varieties of spider plant in the market. Evaluation of existing genotypes aims at identifying spider plant genotypes with desirable traits pertinent for vegetable and seed production and good adaptability to drought.

## **1.3 Justification**

Previous studies have shown that *C. gynandra* grows best when adequately supplied with water especially in those areas experiencing short periods of adequate rainfall. Generally, spider plant can

tolerate some minimal degree of water stress, but when the periods of drying are prolonged, flowering and plant senescence are accelerated and leaf yield and quality are reduced (Mnzava and Chigumira, 2004; Schippers, 2000). Due to high leaf area and rate of development, spider plant exhibits a high transpiration rate (Rajendruru *et al.*, 1996). This predisposes it to weakening in the plant's water status leading to reduced leaf area development, plant growth and yield. There is therefore a need to identify spider plant accessions that are highly adapted to water stress. However, there is limited information about the adaptive responses of a wide range of spider plant genotypes to drought. Previous research on spider plant agronomic trait diversity and adaptability to water stress focused on a few genotypes (Onyango *et al.*, 2016; Masinde *et al.*, 2005; Wasonga *et al.*, 2015). The focus is selection and growing of spider plant accessions that possess good qualities with great potential to positively impact on food security. Wild varieties also contain important genes that can be exploited in genetic improvement of cultivated spider plant accessions. The findings from this study will inform farmers to select high yielding genotypes with better adaptability to drought. This may lead to increase of spider plant yield from 5.3 t ha<sup>-1</sup> in 2017 (HCDA, 2017) to the potential yield of up to 30 t ha<sup>-1</sup> (Abukutsa-Onyango, 2003). Genotypes adapted to drought will contribute to resilience of small-holder farmers to the adverse effect of climate change. Findings will guide gene bank curators to identify accessions with desirable traits, monitor their genetic stability and integrity while screening for duplicate accessions so as to minimize resource wastage and management cost (Collonnier *et al.*, 2001).

#### **1.4 Objectives**

The main objective of the study was to improve spider plant productivity through stress adapted spider plant genotypes with good agronomic traits. The specific objectives were:

- (i) To assess the agronomic traits of selected spider plant accessions.
- (ii) To determine the effect of water stress on growth and yield of selected spider plant accessions.

#### **1.5 Hypotheses**

- (i) Spider plant accessions vary in agronomic traits.
- (ii) Response to water stress varies with spider plant accessions.

## CHAPTER 2: LITERATURE REVIEW

### 2.1 Botany and ecology of spider plant

Spider plant (*Cleome gynandra* L.) belongs to kingdom plantae, division Angiosperm, class Dicotyledonae, order capparidales, family cleomaceae, genus *Cleome* and species *gynandra* (Ravichandra *et al.*, 2014). The Capparaceae family is composed of Capparoideae, mainly woody, and Cleomoideae, mainly herbaceous (Omondi *et al.*, 2017). Spider plant is native to Asia, Middle East, Africa and South America (Anhazhagi *et al.*, 2009). This plant is used as a vegetable mainly in the tropics and is an annual herb (Fox and Young, 1982). Spider plant is a relative to Brassiceae (Hall *et al.*, 2005). It is erect, branched and tap rooted. The plant varies in height between 0.55 m and 1.55 m depending on the growing environment. It has alternating, palmately compounded leaves made of 3 to 7 leaflets. Glandular hairs cover leaves and stems and stem pigmentation varies, can be green, pink and purple. The terminal inflorescence is defined by distinct small white flowers, with relatively pink and lilac flower colour. Spider plant with a purple stem is more nutritious and insect resistant although more susceptible to diseases than a green stemmed spider plant (Raju *et al.*, 2016). Its stems and petioles are relatively sticky with glandular hairs but rarely glabrous. Spider plant inflorescence is characterized by a terminal raceme elongating into a fruit. It has a spindle-shaped fruit that contains a green capsule that assumes a yellow color when it has ripened and dehiscences easily when it is dry. It has circular, grey to black seeds that resemble the shells of a snail and contains brittle, curled embryos covered with a brittle seed coat (Ochuodho, 2005). Spider plant is reported to mainly flower at night after achieving the minimum number of palmately compounded leaves. It has small silique fruits (Van Wyk and Gericke, 2000). Spider plant flowers 4 to 6 weeks after germinating and it takes three to four months for fruit development and maturation (Mnzava, 1997).

Spider plant is both self and cross-pollinating (Mnzava and Chigumira, 2007). The ability to self-pollinate results to uniformity in population species for most characters (Raju *et al.*, 2016). Pollination instruments facilitating outcrossing in spider plant include wind, honey bees and spiders. The plant has fertile pollens and experiences regular meiosis under ideal conditions (Chweya and Mnzava, 1997). Spider plant has varying diploid counts with  $2n=20$  being the most common in relation to  $2n=18$ , 20, 30, 32, 32, 34, and 36 (Schippers, 2000; Mnzava and Chigumira, 2004). The plant produces hybrids when it is crossed with its close relatives. Environmentally controlled traits are targeted for genetic improvements (Omondi, 1990). Agronomic traits in spider plant are

quantitatively controlled. The vegetative yield of the plant can be increased by manipulating components of yield. However, there is poor heritability estimates for morphological characters leading to low expected selection advantage due to genetic uniformity (Ayiecho and Omondi, 1992). Spider plant exhibits negative photoblastic leading to poor germination (Chweya and Mnzava, 1997). Hard seed coats, immature embryos and induced seed dormancy contribute to poor germination of spider plant seeds. In a period of six months after harvest, germination percentage of 25% at 31° C was reported (Bohringer *et al.*, 1999). Seeds take four to six days to germinate (Chweya and Mnzava, 1997). Treating seeds with 0.2 % gibberrellic acid enhances germination in addition to dark conditions or alternating temperatures of 20°-30°C (Ochuodho and Modi, 2007; Wasonga *et al.*, 2015). Being a C<sub>4</sub> plant, spider plant assimilates carbon (IV) oxide through a C<sub>4</sub>-pathway (Fankhauser and Aubry, 2017).

Spider plant originated from the tropics of Africa and South Asia. It has spread across tropical and subtropical regions (Feodorova *et al.*, 2010). Recent research suggests that spider plant has a worldwide distribution. In Kenya, spider plant is mainly grown across Coast, Eastern, Western and Rift valley. Migori, Kericho, Kisii, Siaya and Nyamira are the key areas growing the plant (HCDA, 2017). The eating behaviour of some communities renders the vegetable available or unavailable in the area. The distribution is determined by its consumption rate among the communities and other benefits attached to it including medicinal, nutritional and cultural values (Adhikari *et al.*, 2017).

Spider plant grows well from low to medium altitude in semi-arid, sub-humid and humid climates. It requires optimal temperatures of 18°C to 25°C combined with high light intensity since it is sensitive to cold. Well-drained and medium textured soils, with optimal pH of 5.5 to 7.0, are suitable for spider plant production. It can tolerate some degree of water stress but early flowering and senescencing can be hastened by long periods of drought. The plant still performs well in areas with short periods of useful rains. Water stress reduces leaf quality and yield and the plant cannot withstand flooding (Chweya and Mnzava, 1997).

## **2.2 Importance of spider plant**

Spider plant contains phytochemicals that are essential in human health and nutrition and protects the body against cardiovascular diseases, some forms of cancer and other degenerative diseases (Mishra *et al.*, 2011). Spider plant methanol extract has a good total antioxidant potential

that deter and rummage free oxygen radicals giving the body protection against degenerative and infectious diseases (Muchuweti *et al.*, 2007). Numerous studies have reported a wide range of medicinal benefits of spider plant such as alleviating migraine and reducing vomiting, cases of pneumonia, aching of septic ears, ailments of the stomach, rheumatism and tumor activity. Sap of crushed spider plant leaves and roots eases childbirth and treats stomachache, constipation and thread-worm infection. Seeds and roots have anti-helminthic properties (Iwu, 2014; Sogbohossou *et al.*, 2018). Nutrient analysis shows that spider plant is rich in iron, magnesium, calcium, zinc, vitamins, proteins and beta-carotene (Mahyao *et al.*, 2008). Being rich in micronutrients and vitamins, spider plant can be used to deal with malnutrition and lifestyle diseases in Africa (WHO, 2005).

In some African countries, spider plant is uprooted while still young and marketed in urban and rural centres mostly by women hence accounting for source income especially in rural area where there is limited formal employment (Munene *et al.*, 2018; Onyango *et al.*, 2016). Area under production of spider plant increased by 15% from 2,854 hectares in 2016 to 3,285 hectares in 2017. In 2017, spider plant production was 24,055 MT recording a value of KES 990 million (HCDA, 2017).

### **2.3 Assessment of agronomic traits in plants**

Agronomic trait assessment involves easily visible, heritable and expressed traits across the production environments. Genetically, assessing agronomic traits refers to process of detecting variations due to modifications in deoxyribonucleic acid arrangements (de Vincente *et al.*, 2005). There are four main classifications of traits: morphological, botanical, agronomic and chemical traits. Assessment of traits may start during exploration and collection, and continue in the laboratory before or after multiplication (Perrino and Monti, 1991). Various remarks can be made after assessment of agronomic traits of varied plant genotypes. Plants with the identified traits have to be preserved, availed and accessed by breeders, bank curators and the germplasm accumulators (Huaman *et al.*, 1997). Trait assessment information has many applications including plant material collection and checking their authenticity; differentiating distinct homonyms and identifying replicates (UPOV, 2004); identifying and selecting species, clones and cultivars with a desirable combination of traits; classifying species, clones, cultivars or varieties and detecting groups with correlated characteristics that may contain immediate practical value or may give a hint to genetic relationships among accessions; and identifying variations within a collection (Saad and Idris, 2001).

Characterization of traits aids bank curators not to fill up spaces in the genebank by storing duplicate materials (Lungu, 1990). The environment where the crop is to be grown or was grown is also appraised during trait assessment, and recognizing the major limiting factors to crop performance.

In assessing agronomic traits, performance of characters is emphasized as it is essential in the use of the germplasm (Idris and Saad, 2001). Agronomic traits assessed may vary according to species, and qualitative and quantitative traits (K'Opondo *et al.*, 2009). In an effort to develop a crop cultivar one starts with appreciating genetic diversity and characterizing the diversity of genes and the extent of association. Generally, it is easier and cheaper to evaluate some qualitative traits as they do not require complex and sophisticated experiments and equipment (Van Beuningen and Busch, 1997). Morphological and agronomic traits assessment entails primary and secondary evaluation. Primary analysis involves recording easily seen characters recorded at varying stages of plant growth and development such as surface area of the leaf, size of the leaf and the colour of the leaves. Secondary characterization involves more complex morphological traits that are of agronomic significance including resistance of the plant to diseases, setting of fruits in the plants, yield potential of the plant and plant's biochemical properties (Ayad *et al.*, 1995).

It is important to study the diversity of spider plant germplasm before and after breeding to establish the uniqueness and distinctiveness of the genotypes and phenotype composition so as to protect the rights of the breeder. Quantitative (morpho-agronomics) and qualitative traits are always measured in each accession in order to conserve, evaluate and utilize genetic resources (Franco *et al.*, 2001).

Identification of crop germplasm based on agro-morphological characteristics is often subject to variations caused by changes in the environmental conditions. It requires extensive trials to adequately describe the morphological traits of germplasm (Lin and Binns, 1994) thus, acceptable contrast must involve uniformity of site and season. Germplasm identification can also significantly vary among traits when the number of collections is large and when the germplasm converges on a few of the most desirable characters (Cooke and Reeves, 1998). During morphological characterization the germplasm has to be vegetatively produced each season and this involves a high risk of exchange and mixing of lots that results to great variations among traits. Few comprehensive studies have reported on agronomic trait variation.



Masuka and Mazarura (2012) characterized four spider plant genotypes using nine morpho-agronomic traits. The study revealed that the morphs differed in most of the traits evaluated on qualitative and quantitative traits. The Kenyan morph was smaller with purple stem pigmentation, profusely pubescent and recorded high podding rate than the Zimbabwean morphs which were green stemmed and exhibited glabrous pubescence. This study also showed variations among the four spider plant morphs in growth and yield parameters. The study recommended further field studies for characterization trials using more accessions, grown at multiple sites.

K'Opondo (2011) morphologically characterized four spider plant types. The results of the study revealed that the genotypes were different for three variables out of the seven scored. These were plant structure, stem pubescence, leaflet shape and leaflet apices. In the case of variable counts, genotypes differed for three out of the five counted. For variable measurements, genotypes showed differences for three out of the five measured, and the variables were plant height, petiole length and fruit breadth. In characterizing the four genotypes, it was noted that overlaps in morphological characteristics occurred as expected. Despite these overlaps, significant differences were observed indicating that apart from stem and petiole colours, other agronomic traits of importance also differed. The study recommended further testing of the four genotypes including more collections but under field trials in view of variety release and for use in breeding programmes.

For effective determination of suitable entities for informing future breeding programmes, analysis of relationships between morpho-agronomic data of genotypes serves a source of such useful information. For intensive and accurate study of relationships among genotypes, it is necessary to combine morphological and molecular information as phenotypic distinctness is only connected to specific genes or coding regions while molecular markers have the ability to cover the entire genome that's including coding and non-coding regions (Burstin and Charcosset, 1997).

#### **2.4 Agronomic traits of spider plant accessions grown in Kenya**

Spider plant genotypes differ significantly in the number of days taken from planting to seedling emergence. Number of days to emergence has been reported to range from 4 days to 10 days, with genotypes obtained from the Genebank of Kenya taking longer (8-10 days) to emerge compared to the commercial spider plant Saga (Munene et al., 2018; Onyango *et al.*, 2016). Munene et al. observed that the lowest and highest number of primary branches was 4 and 12 respectively among the spider accessions studied (Munene *et al.*, 2018).

The number of days to flowering varies significantly among genotypes. For example, Saga took 35 days from planting to flowering compared to farmers' spider plant landraces that took approximately 40 days to flowering (Munene et al., 2018). The leaf formation varies significantly between genotypes. Eight out of 20 genebank genotypes evaluated developed between 11 and 13 leaves per plant in six weeks, which is comparable to that of the commercial variety Saga (Onyango et al., 2016). This implies that the genotypes with higher cumulative leaf number than Saga could be candidates for promotion for vegetable production. Leaves are the primary sites of photosynthesis in crop plants (Nobel, 2009).

The number of days to pod formation also varies significantly among genotypes. In a study carried out by Onyango et al. (2016) days to Pod formation varied between 38 and 48 days for most genebank accessions. The beginning of pod formation in spider plant significantly leads to loss of leaves with minimal production of new ones. The pods become an extra sink into which photosynthates are transported and may limit the production of new leaves (Onyango et al., 2016). Significant variations in genotypes for the number of seeds per pod have been reported. In genebank accessions, number of seeds per pod varied from 12 seeds to 170 seeds (Onyango et al., 2016). The number of seeds in a pod can vary widely among plant species and individual plants within a species (Stephenson, 1984).

Genebank accessions produce the heaviest seeds (0.157 g) (Onyango et al., 2016). The 100-seed weight is one of the most important criteria in seed quality determination. It determines embryo size and seed storage for germination and emergence (Moshatati and Gharineh, 2012). High 100-seed weight increases germination percent and seedling emergence (Cordazzo, 2002). Thus, seed weight has a large effect on seed germination, seed vigor, seedling establishment and yield production. For commercial purposes, genotypes with a high 100-seed weight will be preferred by farmers as seeds are sold by weight. For vegetable production, a high 100-seed weight is important in ensuring high germination percentages, hence high plant population resulting in high leaf yield per unit area (Onyango et al., 2016).

## **2.4 Effects of water stress on plant growth and development**

### **2.4.1 General overview**

Water stress is lack of enough moisture in the soil that has a potential to decrease crop yield and profitability by altering plant growth and development, and inducing deterring effects on plant

physiological and biochemical processes (Anjum *et al.*, 2017). Episodes of drought are on the increase with unpredictable intensity and duration. Water stress impacts on plants and alters important processes of growth and development, including germination, plant height, stem diameter, number of leaves, leaf area, dry matter production and partitioning, flower and fruit production, and maturity. Nonetheless, plants show some morphological and physiological changes to cope with drought stress by lowering water loss, enhancing water uptake and maintaining tissue water status. Some plants complete their life cycle early before the onset of drought to escape water deficit conditions. Identification of effects of drought stress on morphological attributes and morphological changes in response to drought can be promising for selection and breeding of drought resistant genotypes (Anjum *et al.*, 2017).

Spider plant experiences water stress either when the water supply to roots gets to be troublesome or when the transpiration rate turns out to be high (Masinde *et al.*, 2005). It relies on water for its survival. The plant basically requires water for photosynthesis, uptake and translocation of nutrients, maintaining turgidity of the cells and lowering canopy temperature (Farooq *et al.*, 2009). Being an integral part of a plant, water plays a crucial role in the initiation of growth and subsequent maintenance of developmental processes throughout the plant's life. Division and development of cells are important processes that determine the growth and development of spider plants. Spider plant growth and development is active in meristematic regions that prompt primary and secondary growth (Taiz and Zeiger, 2006). Water stress alters the cell growth, development and metabolism in these regions (Jaleel *et al.*, 2009). Studies have reported that enlargement or growth of the cell can be affected by slight water deficit even before photosynthesis or respiration (Alves and Setter, 2004). Water stress is characterized by a decline in cell water status, turgor and aggregate water capability of plant bringing about stomatal closure, wilting, and decrease in cell growth and development. Extreme water stress might bring about cessation of photosynthesis, aggravation of metabolism, loss of turgidity and lastly cell death (Bohnert and Jensen, 1996). The harmful impacts of drought stress on overall plant growth and development procedures are of different nature, and can impact germination, seedling emergence, leaf, root, tiller and stem growth and development, dry matter production, floral initiation, panicle development, pollination, fertilization, seed development, seed yield, and seed quality (Jaleel *et al.*, 2007).

#### **2.4.2 Effects of water stress on plant height and stem diameter**

Plant height is an important agronomic parameter reflecting the vegetative growth behaviour of spider plant in response to the applied growth resources and stressed conditions (Anjum *et al.*, 2016 a; Wang *et al.*, 2016). A number of studies on various plants have demonstrated substantial reduction in plant height because of drought stress. Plant height suppression by water stress is majorly associated to lessened expansion and elongation of cells (Manivannan *et al.*, 2007; Jaleel *et al.*, 2009). Stem diameter shrinks due to alterations in cell turgidity in spider plants facing water stress. Water potential of soil and leaf basically accelerates change in stem diameter (Masinde *et al.*, 2005). Masinde *et al.* (2005) reported that maximum stem diameter and leaf area were recorded in well-watered conditions, which gradually reduced with increasing water stress.

#### **2.4.3 Effect of drought stress on number of leaves and leaf expansion**

Reduction in number of leaves per plant, and narrowing of individual leaf size are associated with reduction in soil water potential (Anjum *et al.*, 2011). Parameters influencing expansion of leaves like maintenance of leaf turgor and accumulation of assimilates were modified due to drought stress in *Cleome gynandra* (L.) (Masinde *et al.*, 2005). Leaf shedding due to water stress lowers water use but increases yield loss (Schuppler *et al.*, 1998). The immediate impact of any abiotic stress is reduced leaf size (Anjum *et al.*, 2016 b). Higher photosynthetic rates are absolutely associated with an enhanced leaf expansion rate (He and Li, 2009). Water stress prompts reduced cell development and cell division that in the long run results in reduced leaf size by lessening mature cell size (Alves and Setter, 2004). Leaf growth and development is more sensitive to water stress than root growth and development. Water use efficiency of the crop is also improved by the leaf area of the plant. The potential leaf size, phenology, stem morphology and leaf emergence determine leaf area and any effects of water stress on these parameters would certainly change leaf area (Anjum *et al.*, 2017). Phenotypic plasticity can play a role in the persistence of individuals under changing climate conditions (Nicotra *et al.*, 2010) but the extent of phenotypic plasticity can be limited by ecological and evolutionary constraints (Valladares *et al.*, 2007). Leaf plasticity is an important strategy of plants maintaining control over water-use under water stress. Reduction in cell expansion, diminished cell division, dead of apical parts of a leaf, senescing and curling of leaves under water stress lessen the leaf area significantly (Reddy *et al.*, 2003; 2004).

Reduction in expansion of leaf area under water stress results to a net decrease in transpiration surface. This leaf area reduction mechanism is characterized by fewer and smaller cells

produced by leaf meristems (Tardieu *et al.*, 2000). Slight water stress results to reduction in leaf number, leaf expansion rate and final size of the leaf while severe water stress causes diminished elongation of the leaf and stops leaf development. In the long run, severe water stress stops the production of new leaves influencing the total leaf size. Leaf senescence could be accelerated due to continued drought stress and increased rate of dead leaf tissues bringing about leaf abscission (De Souza *et al.*, 1997).

#### **2.4.4 Effects of water stress on plant phenological stages**

The impacts of drought stress rely on the span, severity and phenological stage at which the drought occurs. One of the most typical unfavorable impacts of water stress on plant phenological stages is development and transition from one developmental stage to another in plants. Flowering time makes up marked developmental changes in plants which initiates after termination of the vegetative phase. Moderate drought diminishes the length of time from flowering to anthesis to escape drought; however, it might be increased under severe water stress (Prasad *et al.*, 2008). Significant seed yield is reduced when plants face drought stress during seed filling and development periods (Pervez *et al.*, 2009). Among various plant developmental processes that are affected by drought the most important ones are the plant source sink relationship, leaf senescence and plant phenological development that ultimately affect the various growth processes and plant productivity (Jordan *et al.*, 2012).

Reduced germination and poor stand establishment are early markers of drought stress. Drought stress contributes to absence of water which is the key to start the germination (Harris *et al.*, 2002). Water uptake and its imbibition are dependant predominantly on the soil water availability and soil water potential. Drought stress delays imbibition process and in this way brings about diminished seedling emergence rates and at last prompts decreased seedling emergence percent and seedling vigour (Liu *et al.*, 2015). Desclaux *et al.*, (2000) delineated that germination and seedling establishment stages are most vulnerable to drought stress. Grain filling duration is the time from seed set to the physiological maturity. It is well known that seed yield is reduced if plants encounter by drought stress during seed development. The evident impact is shortening of seed filling period which lessens the final seed size (Pervez *et al.*, 2009).

## CHAPTER THREE: ASSESSMENT OF AGRONOMIC TRAITS OF SELECTED SPIDER (*Cleome gynandra* L.) PLANT ACCESSIONS

### 3.1 Abstract

Spider plant (*Cleome gynandra* L.) is an indigenous vegetable with great potential to improve food and nutritional security as well as incomes among resource-poor communities in Africa. However, there is limited information on the potential of the existing spider plant genotypes for vegetable and seed production. Knowledge of the agronomic traits and performance of the existing spider plant genotypes is crucial in the efforts to select superior types for crop improvement programmes. A study was conducted to assess the agronomic traits of selected spider plant accessions pertinent for seed and vegetable production. In this study, 40 spider plant accessions were evaluated for agronomic traits on-station at Kabete field station (University of Nairobi) and on-farm at Nyabokarange village, in Bukira North location, Kuria West Sub-County (Migori County) in a randomized complete block design with three replications. Forty (40) spider plant accessions, 16 local landraces, one commercial variety and 23 genebank accessions. Genebank accessions were sourced from Muguga Genetic Resource Institute. Farmers' accessions were collected from markets in the regions where the vegetable is grown in the country. The commercial variety was sourced from Simlaw seed company in Nairobi. Data was collected on days to seedling emergence, percent seedling emergence, plant height, number of leaves per plant, days to 50% flowering, number of pods per plant, number of seeds per pod, weight of 100 seeds and seed yield per plant and subjected to analysis of variance using GenStat 15<sup>th</sup> edition at 5% probability level. Number of days to seedling emergence and seedling emergence varied significantly from 4 (accession GBK-045436) to 12.7 (accessions GBK-045436 and GBK-031992) and 23 % (accession Baringo) to 68% (accession Awendo), respectively. Number of leaves per plant varied significantly from 22.3 (accession Mombasa) to 125.7 (accession GBK-032253R) while plant height ranged from 16.0 cm (accession Mombasa) to 107.1 cm (accession GBK-045436). Number of pods per plant ranged from 12.3 (accession Mombasa) to 180.3 (accession GBK-031850). Seed yield per plant ranged from 0.3 g (accession Mombasa) to 24.9 g (accession GBK-045456). Number of leaves per plant was proportional to the number of primary branches ( $R^2 = 0.62$ ) and plant height ( $R^2 = 0.82$ ). Fourth five percent of the evaluated spider plant accessions were taller than the commercial variety (saga) in the field experiment while in the greenhouse experiment seven accessions including Kuria (100.3 cm), Nyamira (103.0 cm) and GBK-045436 (107.1 cm) were taller than the commercial variety (saga).

Eight and 18 accessions recorded a higher leaf number than the commercial variety in the greenhouse and field experiment respectively. In the field and greenhouse experiment, 30 and 26 accessions respectively flowered earlier than the commercial variety. Seventy seven and a half percent of the spider plant accessions evaluated recorded a higher number of seeds per pod than the commercial variety (saga). Accessions Homabay (160.0 mg), GBK-045436 (160.0 mg), GBK-032210 (160.0 mg) and GBK-031994 (170.0 mg) recorded a higher 100 seed weight than the commercial variety (saga). About 82.5 % of the evaluated accessions in the field recorded a higher seed yield than the commercial variety (saga) while in the field experiment six accessions recorded a higher seed yield than commercial variety. Results have demonstrated that there exist significant genotypic variations among the evaluated spider plant accessions. Spider plant landraces generally performed better than the commercial variety (saga). Genotypes GBK-031991, Kakamega, GBK-045456, GBK-032302 and Migori expressed superior agronomic traits and can thus be recommended for cultivation by farmers and used in developing new varieties of spider plant.

**Key words:** genebank, genotypes, indigenous vegetable, seed yield,

### 3.2 Introduction

Spider plant (*Cleome gynandra* L.) is widely used as a local vegetable in sub-Saharan Africa (Chadha, 2003). It occurs in semi-arid, subhumid and humid climates where it grows in cultivated or fallow fields and alongside roads. Although found in semi-arid conditions, it is adapted to moist soils alongside rivers, irrigation canals and ditches. Spider plant tolerates many soil types provided they are deep, well drained and with a pH range of 5.5 to 7 (Chweya and Mnzava, 1997). It can grow and reproduce under salt stress but cannot tolerate flooding (Mwai *et al.*, 2004). Spider plant is rich in micronutrients and vitamins and crucial in relieving hunger, poverty and malnutrition in Africa (Omondi *et al.*, 2017). Young leaves and stems of *C. gynandra* are cooked and eaten as a vegetable either alone or in stews (Sogbohossou *et al.*, 2018). Leaves, stems and roots are widely used in traditional medicine (Mnzava and Chigumira, 2004; Iwu, 2014; Sogbohossou *et al.*, 2018; Chinsebu, 2016).

The estimated yield of vegetables using locally available resources varies from 1 to 5.3 t/ha compared to the potential yield of 20 to 30 t/ha (Abukutsa-Onyango, 2003; HCDA, 2017). The low spider plant yield is attributed mainly to low soil fertility, low soil moisture, poor farming techniques and lack of improved varieties. In addition, the status of the spider plant as a weed, volunteer and a

wild crop has led to the misconception that spider plant is a vegetable for the poor (Vorster and Van Rensburg, 2005).

Spider plant seed germination is influenced by physiological maturity of the seeds (Ochuodho *et al.*, 2005). Genotypes that take a long time to germinate may result in a poor final plant stand and hence reveal low leaf yields per unit area (Nennich, 2000). The number of plants established from a given weight of seed depends on the size of seeds and percent of those seeds that are viable and can grow into established plants (Anderson, 1986). A high seed germination percent is a prerequisite for successful commercial vegetable production (Liu *et al.*, 2012).

The start of flowering marks the end of the vegetative stage and the reproductive stage sets in with reduced leaf production (Nonnecke, 1986). The main obstacle to spider plant production as a vegetable is that most of the genotypes currently being used by the farmers tend to flower very early and give low leaf yields. Leaves are the primary sites of photosynthesis in crop plants (Nobel, 2009). Therefore, one might assume that the greater the number of leaves in a field, the better interception of sunlight and higher the yield (Silver tooth, 1999). The beginning of pod formation in spider plant significantly leads to loss of leaves with minimal production of new leaves. Therefore, spider plant genotypes in which pod formation sets in early are not suitable for vegetable production if it results in senescence of the leaves. The shorter period taken to pod formation might also not be a good indicator of a genotype that should be used for seed production since this may mean a low total leaf yield and hence limited photosynthetic capacity and hence reduced photosynthates necessary for seed formation (Onyango *et al.*, 2016). The primary components of seed yield in spider plants are number of pods per plant and seed weight. Seed yield is a complex character with polygenic inheritance having positive or negative effects on yield component traits (Azhar and Naeem, 2008). Esmail *et al.* (1994) has shown that characteristics such as number of pods per plant and seed yield per plant can be used for selecting genotypes for seed production. One hundred seed weight is one of the most important criteria in seed quality determination. It determines embryo size and seed storage for germination and emergence (Moshatati and Gharineh, 2012). High 100-seed weight increases germination percent and seedling emergence (Cordazzo, 2002). Thus, seed weight has a large effect on seed germination, seed vigor, seedling establishment and yield production. For commercial purposes, spider plant genotypes with a high 100-seed weight will be preferred by farmers as seeds are sold by weight. For vegetable production, a high 100-seed weight is important in ensuring high germination percentages, hence high plant population resulting in high leaf yield per unit area. The



above outlined traits can be improved in the commercial variety (Saga) to boost its productivity for vegetables and seeds.

In the recent past, spider plant has received increased interest from researchers due to its potential to alleviate malnutrition, enhance food security and generate income among resource poor rural farmers. The most recent studies on spider plant include a roadmap to breeding spider plant by Sogbohossou *et al.*, (2018). The study discusses genomic-assisted breeding of orphaned leafy vegetables in detail with emphasis on improvement of leaf yield, phytonutrient content, resistance to abiotic and biotic stresses and post-harvest management in spider plant. Omondi *et al.* (2017) reported high genetic variation in 30 spider plant genotypes evaluated in the study. This study revealed chromosome numbers of  $2n = 34$  in root tip metaphase cells from one entry. Gonye *et al.*, (2017) evaluated field performance of spider plant and reported increase in growth, yield and micronutrient content with organic and inorganic fertilizer application.

Most of the aforementioned research activities have not comprehensively evaluated the agronomic traits of spider plant germplasm preserved in the Kenyan genebank and farmers' currently cultivated landraces and commercial variety being sold by seed companies. Therefore, there is limited information on the agronomic trait variations of the existing spider plant germplasm preserved in the gene bank and in farmers' fields. The information is necessary for enhancement of crops through selection, domestication and breeding of spider plant. Agronomic trait assessment of the spider plant accessions aims at identifying desirable agronomic traits which can inform future spider plant improvement programmes. Therefore, the objective of this study was to assess agronomic traits of selected spider plant accessions pertinent for seed and vegetable production.

### **3.3 Materials and Methods**

#### **3.3.1 Experimental site**

A glasshouse experiment was carried out in a greenhouse at Kabete field station and field trials were carried out at Kabete field station (UoN) in Nairobi County and at Nyabokarange village in Bukira North location, Kuria West sub-County (Migori County). Kabete field station lies at a latitude of  $1^{\circ}14'S$  and longitude of  $36^{\circ}44'E$  and at an altitude of about 1940 m above the sea level (a.s.l). The agro-ecological zone of the area is upper midland zone three (UM3) (Muturi *et al.*, 2012). The average temperature varies from  $16^{\circ}C$  to  $23^{\circ}C$  (Meteorological department, 2017), receiving long rains in early March to late June and short rains from early October to late December, with an

average rainfall of 1000 mm annually. Soils are deep, well drained, dark reddish-brown clay soil, pH range from 5.2-7.2 in top soil and 5.2-7.7 in sub soil (Michieka, 1978). The study was carried out between August 2018 and January 2019.

Kuria West Sub County is bound between 1° 4' 0" south of the equator and longitudes 34°28'0" east of the prime meridian, and 1524 meters above the sea level. Agro-ecological of Kuria west sub county lower midland zone three (LM3). The commonly grown crops are maize, finger millet, beans, and cassava. The sub county experiences two seasons of rain per annum. Long rains set in from early March spreading to late June. Seasons of short rains starts from October to December recording 950 mm to 1500 mm rainfall annually (Nyamohanga, 2017; Sombroek, 1982). The study was carried out between September 2018 and February 2019 during the short rains. Nyaboakarange village of Kuria West sub county was selected based on the fact it lies at lower midland zone three (LM3) in comparison to Kabete field station that lies at upper midland zone three (UM3). This provided a relatively uniform base of comparison on the agronomic performance of the selected spider plant accessions.

In both sites, soils were sampled at 30 cm depth prior to planting and analyzed for soil pH and nutrients at University of Nairobi's Soil Chemistry Laboratory (Table 3.1). Weather data were collected in both sites during the experimental period (Table 3.2 and Table 3.3).

**Table 3.1: Soil chemical characteristics of the experimental sites at Kabete Field Station and Nyabokarange village in Kuria west Sub County.**

<b>Parameters</b>	<b>Kabete</b>	<b>Nyabokarange</b>	<b>Critical level</b>
Soil Ph	6.2	6.7	<5.0
Total Nitrogen (g kg <sup>-1</sup> )	3.0	1.0	<3.0
Total Organic Carbon (g kg <sup>-1</sup> )	19.0	8.0	<0.5
Calcium (cmol <sub>c</sub> kg <sup>-1</sup> )	2.4	2.2	<1.0
Magnesium (cmol <sub>c</sub> kg <sup>-1</sup> )	0.7	1.0	<0.4
Potassium (cmol <sub>c</sub> kg <sup>-1</sup> )	1.2	0.8	<0.8
Manganese (cmol <sub>c</sub> kg <sup>-1</sup> )	65.9	80.2	<2.3
Iron (mg kg <sup>-1</sup> )	55.0	65.8	<30.0
Zinc (mg kg <sup>-1</sup> )	8.5	7.5	<25.0
Copper (mg kg <sup>-1</sup> )	1.1	1.0	<4.0
Phosphorus (mg kg <sup>-1</sup> )	24.1	21.7	<0.3

**Table 3.2: Weather conditions at Kabete field station between June 2018 and March 2019 cropping season**

Month	Temperature (°C)		Rainfall (mm)	Relative humidity (%)	Evaporation (mm)
	Mean Max	Mean Min	Total	Mean	Total
June	19.5	12.9	270.3	67.2	60.2
July	18.8	12.0	27.3	66.2	68.3
August	20.3	11.7	1.1	59.9	82.0
September	25.0	12.7	8.3	46.5	124.1
October	23.0	14.0	65.5	57.6	131.4
November	27.1	15.1	110.4	54.7	N/A
December	21.6	14.5	95.9	58.8	N/A
January	23.6	13.6	9.8	40.1	154.3
February	26.0	14.2	3.5	38.9	174.5
March	27.5	15.7	2.9	30.6	230.4

Source: Kenya Meteorological Department, Kabete Agro-met Station (May 2019). N/A- not available

**Table 3.3: Weather conditions at Nyabokarange village in Kuria west sub-county (Migori County) between November 2018 and February 2019 cropping season**

Month	Temperature (°C)		Rainfall (mm)	Relative humidity (%)	Evaporation (mm)
	Mean Max	Mean Min	Total	Mean	Total
November	26.2	15.8	144.7	56.9	109.7
December	25.2	15.7	161.8	61.5	92.3
January	27.2	16.5	21.6	43.2	113.3
February	28.9	16.7	26.1	40.4	111.1

Source: Kenya Meteorological Department, Head Quarters Met station (May 2019). Max-maximum, Min-minimum

### **3.3.2 Treatments, experimental design and crop husbandry**

#### **Planting materials**

Fourty (40) spider plant accessions were evaluated in the study. These accessions comprised 16 local landraces sourced from markets in the regions where the vegetable is grown in the country. These regions included Western, Rift Valley, Nyanza and Coast. One commercial variety was sourced from Simlaw Seed Company in Nairobi and 23 genebank accessions were sourced from Muguga Genetic Resource Institute (Table 3.4).

**Table 3.4: List of spider plant accessions evaluated in the study.**

Entry	Accessions	Species	Source*	Region
1	Awendo	<i>C. gynandra</i>	Awendo	Nyanza
2	Baringo	<i>C. gynandra</i>	Baringo	Rift Valley
3	Bungoma	<i>C. gynandra</i>	Bungoma	Western
4	Eldoret	<i>C. gynandra</i>	Eldoret	Rift Valley
5	GBK-028542	<i>C. gynandra</i>	Elgeyo Marakwet	Rift Valley
6	GBK-028554	<i>C. gynandra</i>	Siaya	Nyanza
7	GBK-028563	<i>C. gynandra</i>	Elgeyo Marakwet	Rift Valley
8	GBK-031833	<i>C. gynandra</i>	Bungoma	Western
9	GBK-031837	<i>C. gynandra</i>	Bungoma	Western
10	GBK-031850	<i>C. gynandra</i>	Kakamega	Western
11	GBK-031866	<i>C. gynandra</i>	Kakamega	Western
12	GBK-031968	<i>C. gynandra</i>	Kakamega	Western
13	GBK-031991	<i>C. gynandra</i>	Busia	Western
14	GBK-031992	<i>C. gynandra</i>	Busia	Western
15	GBK-031993	<i>C. gynandra</i>	Busia	Western
16	GBK-031994	<i>C. gynandra</i>	Busia	Western
17	GBK-031996	<i>C. gynandra</i>	Busia	Western
18	GBK-031997	<i>C. gynandra</i>	Busia	Western
19	GBK-031998	<i>C. gynandra</i>	Busia	Western
20	GBK-032210	<i>C. gynandra</i>	Makueni	Eastern
21	GBK-032229	<i>C. gynandra</i>	West pokot	Rift Valley
22	GBK-032253	<i>C. gynandra</i>	West pokot	Rift Valley
23	GBK-032253R	<i>C. gynandra</i>	West pokot	Rift Valley
24	GBK-032302	<i>C. gynandra</i>	Mbale	Western
25	GBK-045426	<i>C. gynandra</i>	Vihiga	Western
26	GBK-045436	<i>C. gynandra</i>	Kisumu	Nyanza
27	GBK-045456	<i>C. gynandra</i>	Central Kiambu	Central
28	Homabay	<i>C. gynandra</i>	Homabay	Nyanza
29	Kakamega	<i>C. gynandra</i>	Kakamega	Western
30	Kericho	<i>C. gynandra</i>	Kericho	Rift Valley
31	Kisii 1	<i>C. gynandra</i>	Elgeyo Marakwet	Nyanza
32	Kisii 2	<i>C. gynandra</i>	Elgeyo Marakwet	Nyanza
33	Kuria	<i>C. gynandra</i>	Kuria	Nyanza
34	Marakwet	<i>C. gynandra</i>	Marakwet	Rift Valley
35	Migori	<i>C. gynandra</i>	Migori	Nyanza
36	Mombasa	<i>C. gynandra</i>	Mombasa	Coast
37	Nakuru	<i>C. gynandra</i>	Nakuru	Rift Valley
38	Nandi	<i>C. gynandra</i>	Nandi	Rift Valley
39	Nyamira	<i>C. gynandra</i>	Nyamira	Nyanza
40	Commercial	<i>C. gynandra</i>	Commercial	Simlaw

GBK-GeneBank of Kenya, *C.gynandra*- *Cleome gynandra*, source\*-where seed was obtained

## **Greenhouse experiments**

Fourty (40) accessions of spider plant were evaluated in pots in a greenhouse using a randomized complete block design with three replications. Randomized complete block design (RCBD) was adopted due to shading caused by neighboring trees and other greenhouses in the morning and the evening. The greenhouse experiments were carried out two times (June 2018 to November 2018 and September 2018 to January 2019). Soil used for potting was collected within Kabete field station close to the field experiment site hence; soil characteristic used in potting was similar to that of the field experiment. Two parts of the soil were mixed with one part of sand and one part of cattle manure (2:1:1) before potting. The pots used were 36.5 cm long x 18.5 cm wide. The 40 pots per replication were each filled with 7 kg of air-dried soil mixture and di-ammonium phosphate (DAP) fertilizer (18:46:0) applied at 3.15 g/pot just before sowing. Four seeds were sown in each pot and adequately watered. Thinning was done at 14 days after seedling emergence and repeated after 21 days leaving two plants per pot. Seedlings were top dressed at 30 cm seedling height with calcium ammonium nitrate (CAN) (26%N) at a rate of 5.1 g/pot. The plants were watered three times each week and sprayed with Karate® (active ingredient lambda cylothrin) at the rate of 20 g /20 litres at five days after emergence, vegetative phase and before flowering to control aphids and whiteflies.

## **Field experiment**

Assessments were performed on 40 spider plant accessions using a randomized complete block design with three replications. The experimental field was tilled and harrowed to a fine tilth using a tractor. The experimental plot size was 21 m × 28.6 m. Plots and blocks were each separated by 1 m path. Hand sowing was done for each accession in four rows at the rate of five seeds per row (20 plants in a plot) with inter-row spacing of 30 cm and intra-row spacing of 30 cm. Diammonium phosphate (DAP) fertilizer (18:46:00) was applied at a rate of 100 kg/ha and thoroughly mixed with the soil before sowing seeds. Top dressing with CAN (26%N) was done after the first weeding in the third week after emergence at a rate of 65 kg N/ha. Spider plant seedlings were sprayed with an organophosphate insecticide lambdacyhalothrin-250EC (Twiga Chemical Industries, Nairobi, Kenya) at the rate of 5 ml/ 20 litres after emergence and before flowering to control cutworms and aphids. Weeds were controlled through hand-weeding. The experiment was carried out from November 2018 to February 2019 during the short rain season.

### **3.5 Data collection**

Agronomic traits data was collected on number of days to 50% seedling emergence, seedling emergence percentage, number of days to 50% flowering, plant height (cm), number of pods per plant, number of leaves per plant, number of seeds per pod, 100-seed weight and seed yield. In the field three plants were randomly selected and tagged for data collection while in the greenhouse one plant was tagged in each pot for data collection.

#### **3.5.1 Growth components of spider plant**

Number of days from sowing to seedling emergence was determined by recording the number of days when 50% of the seedlings had emerged. Percent emergence was determined by counting the number of seedlings that emerged divided by the total number of seeds sown and multiplied by 100%. Number of days to flowering was determined by counting the number of days from sowing to when 50% of the plants had flowered. Number of days to podding was determined by counting the number of days from sowing to when 50% of the plants had podded. Plant height was measured after 50% flowering from the base of the plant to the tip of the main stem using a meter rule. The number of primary branches was determined by counting the main branches from the tagged plants after 50% flowering.

#### **3.5.2 Yield and yield components of spider plant**

Number of leaves per plant was determined by counting fully expanded edible leaves at the vegetative stage. Number of pods per plant was determined by counting the number of mature pods in a plant. Seed yield per plant was determined by weighing seeds from tagged plants that had been sun-dried to about 13 % moisture level. Numbers of seeds per pod were determined by randomly picking three pods from the harvested portion of each accession and counting the number of seeds in them. The weight of 100 seeds was determined by counting 100 sun-dried seeds and weighing them using an analytical scale with precision of 0.001.

### **3.6 Data analysis**

Analysis of variance (ANOVA) for the quantitative data was performed using GenStat 15<sup>th</sup> edition (Payne et al., 2011) at 5% level of significance. Mean separation for treatment effects that were significant was done by Fisher's protected least significant difference (LSD) test. Variability within each quantitative trait was calculated using statistical measures of mean. Correlation analyses were performed in GenStat to estimate quantitative relationships among the traits.

## **3.7 Results**

### **3.7.1 Number of days to seedling emergence among spider plant accessions**

Spider plant accession varied significantly ( $P \leq 0.05$ ) in number of days to seedling emergence in both greenhouse and field experiments (Table 3.5 and Table 3.6). In the field experiment, location and location  $\times$  spider plant interaction had significant effect on the number of days to seedling emergence. Seedling emergence in accessions Eldoret, GBK-028554, Marakwet and Mombasa took significant longer days to emerge in Kabete field station than in Nyabokarange village in Kuria west Sub County. In contrast, accessions GBK-032302, GBK-045436 and Migori took significantly longer days to emerge in Nyabokarange village at Kuria west Sub County than in Kabete field station. In the greenhouse, average number of days to seedling emergence ranged from 4 (accessions Nandi, GBK-045436 and Kisii) to 12 (accessions GBK-028554, GBK-031833 and GBK-031968) while the average number of days to seedling emergence for the field experiment ranged from 6.8 (accession Kuria) to 12.7 (accessions GBK-031992, GBK-032302). Greenhouse grown accessions had an average of 8.1 days from sowing to emergence compared to an average of 9.4 days to emergence recorded in the field grown accessions. In the field experiment, accessions grown in Kabete field station recorded a significantly higher mean of 9.7 days to seedling emergence than Nyabokarange village grown accessions with a mean of 9.1 days to seedling emergence (Table 3.5). About 75% of field grown accessions recorded an average of above 7 days to seedling emergence while 40% of the greenhouse grown accessions emerged in 7 days. Farmers' accessions had an average of 9 days from sowing to emergence compared to 10 days after emergence of gene bank accessions for field grown accessions. Commercial variety (saga) recorded an average of 8.2 days to seedling emergence in the field and 6.3 days in the greenhouse.

### **3.7.2 Seedling emergence percentage among spider plant accessions**

Spider plant accessions varied significantly at  $P \leq 0.05$  in seedling emergence for field grown accessions (Table 3.5 and Table 3.6). In the field experiment, location  $\times$  spider plant accession interaction had significant effects on seedling emergence but location main effects on this parameter were not significant. However no significant variation was recorded for greenhouse grown accessions. Accessions, Awendo and Marakwet had significantly higher percent seedling emergence in Kabete field station than in Nyabokarange village but there were no differences among all other accessions. Seedling emergence in the greenhouse ranged from 23.1% (accession Baringo) to 59%

(commercial variety-saga) while in the field experiment seedling emergence varied from 31% (accession Mombasa) to 58.6% (accession Awendo). Field grown accessions recorded average seedling emergence of 42.9 % compared to 41.8 % for greenhouse grown accessions. Awendo and Baringo accessions had a higher seedling emergence than the commercial variety in the field experiments. Farmers' accessions recorded an average seedling emergence of 45.6 % compared to 40.4 % for gene bank accessions in the field experiment. In the greenhouse, genebank accessions recorded an average seedling emergence of 42 % while the farmers' accessions had an average of 40.4 %. Accessions Kuria (53.8 %) and commercial variety (saga) (59 %) recorded a seedling emergence of above 50 % in the greenhouse while in the field experiment accessions Kakamega (54.4 %), Kericho (51 %), Awendo (58.6 %), Baringo (56 %), Bungoma (53.4 %) and commercial variety (55.9 %) recorded seedling emergence of more than 50 %. In the field, Kabete field station grown accessions recorded a mean 42.3 % seedling emergence compared to 43.4 % in Nyabokarange village grown accessions (Table 3.5).

### **3.7.3 Number of primary branches per spider plant**

Spider plant accessions varied significantly at  $P \leq 0.05$  among spider plant accessions in number of primary branches per plant, for greenhouse and field experiment (Table 3.5 and Table 3.6). Location  $\times$  spider plant accession interaction had significant effects on number of primary branches per spider plant but location main effects on this parameter were not significant. Accessions Awendo and Kuria recorded a significantly higher number of primary branches in Nyabokarange village than in Kabete field station. In contrast, accession Mombasa recorded a significantly higher number of primary branches in Kabete than in Kuria but there were no differences among all other accessions. Number of primary branches per plant varied from 7 (accession GBK-031997) to 12.7 (accession GBK-031991) in the field grown accessions and 5.7 (accession Mombasa) to 12.7 (accession Eldoret) in the greenhouse grown accessions. There was no significant difference in the average number of primary branches for field grown accessions at Kabete field station and Nyabokarange village. Genebank accessions recorded an average of 10.4 primary branches per plant while the farmers' accessions recorded an average of 9.4 primary branches per plant. In the greenhouse, genebank accessions recorded a mean of 10.2 primary branches per plant while farmers' accessions recorded a mean of 9.6 primary branches per plant.



**Table 3.5: Days to seedling emergence, percent seedling emergence, primary branches and plant height of 40 spider plant accessions grown in the field at Kabete and Nyabokarange**

Accession	DTE			EM%			NPB			PH		
	Kabete	Nyabo	Mean	Kabete	Nyabo	Mean	Kabete	Nyabo	Mean	Kabete	Nyabo	Mean
Awendo	7.3	8.0	7.7	49.2	68.0	58.6	6.0	9.0	7.5	44.3	55.3	49.8
Baringo	7.3	7.0	7.2	49.2	62.7	56.0	7.0	8.3	7.7	54.3	47.0	50.7
Bungoma	8.0	7.7	7.8	46.7	60.0	53.4	8.3	9.0	8.7	63.3	54.0	58.7
Eldoret	11.7	7.3	9.5	38.3	53.3	45.8	11.3	11.3	11.3	81.0	72.0	76.5
GBK-028542	10.7	8.7	9.7	41.7	42.7	42.2	11.0	11.3	11.2	77.7	73.3	75.5
GBK-028554	12.0	9.0	10.5	38.3	36.0	37.2	9.0	10.7	9.8	68.7	60.0	64.3
GBK-028563	9.0	7.7	8.3	45.0	32.0	38.5	9.7	9.3	9.5	69.0	52.3	60.7
GBK-031833	9.7	7.7	8.7	43.3	46.7	45.0	9.0	8.0	8.5	66.7	47.3	57.0
GBK-031837	9.0	9.3	9.2	45.0	45.3	45.2	10.0	9.3	9.7	76.3	50.7	63.5
GBK-031850	10.0	9.0	9.5	42.5	42.7	42.6	10.3	10.3	10.3	83.7	59.0	71.3
GBK-031866	10.7	11.7	11.2	40.8	45.3	43.1	11.0	10.3	10.7	82.0	58.3	70.2
GBK-031968	11.7	9.7	10.7	38.3	40.0	39.2	10.7	12.7	11.7	80.7	109.7	95.2
GBK-031991	11.7	11.3	11.5	38.3	29.3	33.8	13.3	12.0	12.7	100.7	101.0	100.8
GBK-031992	12.0	13.3	12.7	37.5	34.7	36.1	11.0	13.0	12.0	86.3	89.0	87.7
GBK-031993	9.7	9.0	9.3	43.3	45.3	44.3	9.3	9.7	9.5	69.0	68.3	68.7
GBK-031994	10.7	11.0	10.8	40.8	36.0	38.4	10.7	9.7	10.2	84.7	68.7	76.7
GBK-031996	8.7	6.7	7.7	45.8	32.0	38.9	7.7	8.0	7.8	60.7	52.0	56.3
GBK-031997	7.0	7.3	7.2	50.0	41.3	45.7	7.0	7.0	7.0	53.3	45.7	49.5
GBK-031998	10.0	8.3	9.2	42.5	37.3	39.9	10.0	9.7	9.8	76.3	64.7	70.5
GBK-032210	11.0	10.0	10.5	40.0	32.0	36.0	11.0	11.0	11.0	82.7	75.7	79.2
GBK-032229	10.7	10.7	10.7	40.8	41.3	41.1	11.3	10.0	10.7	84.7	69.3	77.0
GBK-032253	11.0	11.0	11.0	40.0	49.3	44.7	13.0	11.0	12.0	103.7	75.0	89.3
GBK-032253R	10.3	10.3	10.3	41.7	29.3	35.5	12.7	11.7	12.2	100.0	82.0	91.0
GBK-032302	11.3	14.0	12.7	39.2	54.7	47.0	12.0	12.3	12.2	101.3	81.7	91.5
GBK-045426	10.0	9.0	9.5	42.5	28.0	35.3	8.7	9.7	9.2	65.0	80.7	72.8
GBK-045436	11.0	13.3	12.2	40.0	33.3	36.7	11.0	11.3	11.2	86.0	72.7	79.3
GBK-045456	11.0	9.3	10.2	40.0	45.3	42.7	12.0	10.7	11.3	91.0	76.0	83.5
Homabay	10.0	9.0	9.5	42.5	57.3	49.9	10.7	9.7	10.2	80.3	81.7	81.0
Kakamega	8.3	9.0	8.7	50.0	58.7	54.4	11.7	10.7	11.2	91.7	75.0	83.3
Kericho	7.0	8.0	7.5	50.0	52.0	51.0	9.7	8.3	9.0	74.0	52.0	63.0
Kisii 1	8.0	6.7	7.3	35.8	37.3	36.6	10.7	12.3	11.5	74.0	82.3	78.2
Kisii 2	7.7	6.7	7.2	40.8	44.0	42.4	9.7	11.0	10.3	78.0	70.7	74.3
Kuria	6.3	7.3	6.8	41.7	53.3	47.5	8.0	10.7	9.3	62.0	72.0	67.0
Marakwet	11.7	7.0	9.3	35.0	53.3	44.2	8.7	9.3	9.0	66.7	60.7	63.7
Migori	6.3	9.3	7.8	33.3	42.7	38.0	9.7	8.0	8.8	79.3	53.7	66.5
Mombasa	12.3	8.7	10.5	36.7	25.3	31.0	9.0	5.0	7.0	17.7	16.3	17.0
Nakuru	10.0	9.0	9.5	42.5	38.7	40.6	8.3	9.3	8.8	62.0	67.7	64.8
Nandi	10.3	10.3	10.3	40.8	26.7	33.8	8.7	10.7	9.7	65.0	65.7	65.3
Nyamira	8.7	8.7	8.7	45.8	48.0	46.9	11.7	9.7	10.7	92.0	106.0	99.0
Commercial (saga)	9.0	7.3	8.2	55.8	56.0	55.9	11.7	9.7	10.7	84.3	61.3	72.8
<b>Mean</b>	<b>9.7</b>	<b>9.1</b>	<b>9.4</b>	<b>42.3</b>	<b>43.4</b>	<b>42.9</b>	<b>10.1</b>	<b>10.0</b>	<b>10.1</b>	<b>75.5</b>	<b>67.7</b>	
<b>P-Value (A)</b>	<b>&lt;.001</b>			<b>&lt;.001</b>			<b>&lt;.001</b>			<b>&lt;.001</b>		
<b>P-Value (L)</b>	<b>&lt;.001</b>			<b>0.07</b>			<b>0.8</b>			<b>&lt;.001</b>		
<b>P-Value (A×L)</b>	<b>&lt;.001</b>			<b>&lt;.001</b>			<b>0.04</b>			<b>&lt;.001</b>		
<b>LSD<sub>≤0.05</sub> (A)</b>	<b>1.5**</b>			<b>5.6**</b>			<b>1.7**</b>			<b>8.1**</b>		
<b>LSD<sub>≤0.05</sub> (L)</b>	<b>0.3**</b>			<b>NS</b>			<b>NS</b>			<b>1.8**</b>		
<b>LSD<sub>≤0.05</sub> (A×L)</b>	<b>2.1**</b>			<b>7.9**</b>			<b>2.4*</b>			<b>11.4**</b>		
<b>CV%</b>	<b>13.9</b>			<b>11.4</b>			<b>14.7</b>			<b>9.9</b>		

DTE-Days to emergence, EM% -Seedling emergence percentage, NPB-Number of primary branches per plant, PH-Plant height; \*\* highly significant at P<0.05 level, \* significant at P<0.05 level, NS-not significant; A-Accession, L-Location. Nyabo-Nyabokarange village in Kuria west Sub County.

### **3.7.4 Plant height among spider plant accessions**

Spider plant accessions varied significantly at  $P \leq 0.05$  in plant height for greenhouse and field experiment (Table 3.5 and Table 3.6). In the field experiment, location and location  $\times$  spider plant interaction had significant effects on plant height per spider plant. Accessions GBK-028563, GBK-031833, GBK-031837, GBK-031850, GBK-031866, GBK-031994, GBK-032229, GBK-032253, GBK-032253R, GBK-032302, GBK-045436, GBK045456, Kakamega, Kericho, and Migori recorded significantly taller plants in Kabete field station than in Nyabokarange village. However, accessions GBK-031968, GBK-045426 and Nyamira recorded significantly taller plants in Nyabokarange village than in Kabete field station. Plant height varied from 16 cm (accession Mombasa) to 107.1 cm (accession GBK-045436) in the greenhouse and 17.0 cm (Mombasa) to 100.8 cm (GBK-031991) in the field experiment. Field grown accessions recorded an average plant height of 71.6 cm compared to 70.75 cm in the greenhouse. Commercial variety (saga) recorded a height of 72.8 cm. However, 45% of the evaluated spider plant accessions were taller than the commercial variety (saga) in the field experiment. Field grown accessions at Kabete field station recorded an average plant height of 75.5 cm compared to 67.7 cm in Nyabokarange village grown accessions (Table 3.3). In the greenhouse experiment, commercial variety (saga) recorded a height of 83.3 cm. Seven accessions including Kuria (100.3 cm), Nyamira (103.0 cm) and GBK-045436 (107.1 cm) were taller than the commercial variety (saga). In the field and greenhouse, commercial variety (saga) recorded 10.7 and 12.3 primary branches per plant respectively.

### **3.7.5 Number of leaves per plant among spider plant accessions**

Spider plant accessions varied significantly at  $P \leq 0.05$  in number of leaves per plant in greenhouse and field experiments (Table 3.5 and Table 3.6). In the field experiment, location and location  $\times$  spider plant interaction had significant effects on the number of leaves per spider plant. Accessions Awendo, GBK-028554, GBK-031968, Kisii 1, Kuria, Nakuru and Nyamira recorded a significantly higher number of leaves per spider plant in Nyabokarange village than in Kabete field station. However, accessions GBK-028563, GBK-031833, GBK031866, GBK-031991, GBK-031994, GBK-032253, GBK-032253R, GBK-045456, Homabay, Kericho, and Migori recorded a significantly higher number of leaves per spider plant in Kabete field station than in Nyabokarange village. Number of leaves per plant varied from 23.2 (accession Mombasa) to 115.7 (accession GBK-032253R) in the field and 49.3 (accession Mombasa) to 121.7 (accession GBK-028563) in the greenhouse.

**Table 3.6: Means of quantitative trait means of 40 spider plant accessions grown in the greenhouse at Kabete field station**

<b>Accession</b>	<b>DTE</b>	<b>EM%</b>	<b>NPB</b>	<b>PH</b>	<b>NLP</b>	<b>DTF</b>	<b>NPP</b>	<b>NSP</b>	<b>100sd(g)</b>	<b>SYP</b>
Awendo	8.0	46.2	11.0	74.3	85.7	42.3	53.0	69.7	110.0	4.0
Baringo	5.0	23.1	12.5	82.0	98.3	35.3	60.7	98.0	120.0	7.0
Bungoma	6.0	43.6	12.7	92.0	102.3	36.3	66.3	79.0	130.0	6.9
Eldoret	8.0	28.2	10.7	76.7	86.0	42.7	56.0	88.7	120.0	6.0
GBK-028542	10.3	25.6	11.0	74.0	87.3	42.7	51.0	79.7	120.0	4.7
GBK-028554	8.3	38.5	11.7	78.3	94.0	40.0	60.7	76.7	120.0	5.6
GBK-028563	12.3	43.6	12.0	21.0	121.7	51.7	37.7	34.0	90.0	1.2
GBK-031833	11.3	38.5	9.0	56.0	79.7	43.7	44.0	55.7	90.0	2.2
GBK-031837	12.7	38.5	7.7	52.3	82.7	47.3	41.0	141.3	120.0	6.8
GBK-031850	9.3	46.2	11.0	74.3	101.3	41.3	44.0	180.3	110.0	8.5
GBK-031866	10.3	48.7	11.3	40.0	93.3	46.0	33.3	161.3	100.0	5.4
GBK-031968	9.3	41.0	8.7	54.7	82.7	46.0	38.3	125.3	120.0	5.9
GBK-031991	12.7	43.6	12.0	44.0	112.0	50.3	36.3	85.0	100.0	3.3
GBK-031992	8.3	41.0	10.0	68.6	82.7	42.3	51.0	79.3	120.0	5.0
GBK-031993	8.3	41.0	10.0	73.3	80.7	43.2	40.0	61.7	130.0	3.3
GBK-031994	10.0	46.2	9.0	63.7	72.7	46.0	43.0	79.0	170.0	5.8
GBK-031996	10.7	48.7	7.7	56.0	64.7	47.3	40.7	32.7	120.0	1.6
GBK-031997	10.3	43.6	12.0	56.3	109.7	45.6	46.7	31.3	130.0	1.9
GBK-031998	9.0	46.2	9.2	61.0	99.3	43.3	47.3	128.0	140.0	8.3
GBK-032210	8.7	48.7	11.3	76.0	104.3	41.0	54.7	95.7	160.0	8.6
GBK-032229	8.3	38.5	10.3	70.3	76.3	41.7	51.3	178.7	130.0	12.3
GBK-032253	7.0	33.3	11.3	76.3	86.3	37.7	54.3	92.7	150.0	7.6
GBK-032253R	6.7	33.3	12.3	83.3	96.3	38.3	60.3	76.7	150.0	7.0
GBK-032302	8.3	41.0	11.7	82.0	108.0	41.3	53.0	99.0	150.0	7.7
GBK-045426	7.0	41.0	11.7	84.7	102.7	38.5	61.0	149.0	150.0	13.4
GBK-045436	4.7	51.3	6.7	107.1	59.0	33.3	69.7	152.3	160.0	16.8
GBK-045456	5.0	48.7	7.3	98.7	57.7	34.7	69.7	164.0	150.0	16.8
Homabay	8.3	38.5	11.3	76.3	87.3	43.3	55.0	108.3	160.0	9.5
Kakamega	5.3	43.6	7.3	91.3	67.0	34.7	64.7	105.7	150.0	10.5
Kericho	10.3	41.0	9.0	59.7	71.3	43.0	44.7	100.0	130.0	6.0
Kisii 1	7.3	46.2	12.3	82.0	94.0	39.0	60.7	109.3	150.0	10.0
Kisii 2	7.3	38.5	10.3	70.0	80.7	39.0	62.0	109.7	150.0	10.3
Kuria	4.7	53.8	8.0	100.3	67.3	34.0	70.7	113.7	150.0	12.1
Marakwet	8.3	38.5	7.0	44.3	57.0	47.0	35.0	77.0	130.0	3.5
Migori	6.0	43.6	12.0	82.0	97.0	38.3	60.7	134.0	140.0	11.4
Mombasa	5.0	30.8	5.7	16.0	49.3	34.0	31.7	14.0	60.0	0.3
Nakuru	6.3	46.2	7.3	82.3	80.7	34.7	59.3	134.0	130.0	10.5
Nandi	9.3	38.5	9.3	62.3	75.0	43.3	42.7	59.0	140.0	3.7
Nyamira	4.3	46.2	7.7	103.0	65.7	29.7	69.3	97.7	140.0	9.8
Commercial (saga)	6.3	59.0	12.3	83.3	99.0	36.7	62.3	136.3	140.0	11.6
<b>Mean</b>	<b>8.1</b>	<b>41.8</b>	<b>10</b>	<b>70.8</b>	<b>85.5</b>	<b>40.9</b>	<b>52.1</b>	<b>99.8</b>	<b>130</b>	<b>7.3</b>
<b>P-Value</b>	<b>&lt;.001</b>	<b>0.256</b>	<b>&lt;.001</b>	<b>&lt;.001</b>	<b>&lt;.001</b>	<b>&lt;.001</b>	<b>&lt;.001</b>	<b>&lt;.001</b>	<b>&lt;.001</b>	<b>&lt;.001</b>
<b>LSD<sub>0.05</sub></b>	<b>1.4**</b>	<b>NS</b>	<b>1.9**</b>	<b>6.9**</b>	<b>10.1**</b>	<b>2.7**</b>	<b>5.5**</b>	<b>9.3**</b>	<b>20.0**</b>	<b>2.3**</b>
<b>CV%</b>	<b>10.6</b>	<b>27.4</b>	<b>11.9</b>	<b>6</b>	<b>7.3</b>	<b>4</b>	<b>6.5</b>	<b>5.7</b>	<b>11.7</b>	<b>19.6</b>

DTE-Days to emergency, EM%-Seedling emergence percentage, NPB-Number of primary branches, PH-Plant height NLP-Number of leaves per plant, DTF-Days to flowering, NPP-Number of pods per plant, NSP-Number of seeds per Pod, % 100 sds-weight of 100 seeds. SYP-Seed yield per plant. \*\* Highly significant at P<0.05 level, \* significant at P<0.05 level NS-not significant,

Kabete field grown accessions had an average of 87.3 leaves per plant compared to 85 leaves per spider plant in Nyabokarange grown accessions. Commercial variety (saga) recorded 86.0 leaves per plant in the field experiment and 99.0 leaves per plant in the greenhouse. In the greenhouse farmers' accessions had an average of 79.0 leaves per plant while gene bank accessions had an average of 89.3 leaves per plant. In the field experiment, accessions GBK-045436 (98.3), GBK-045456 (98.5), GBK-032253 (101.2), GBK-032302 (105.5), GBK-031968 (106.2), GBK-031991 (109.5), GBK-031992 (109.7) and GBK-032253R (115.7) recorded the highest number of leaves per plant. In the greenhouse experiment, accessions GBK-031850 (101.3), Bungoma (102.3), GBK-045426 (102.7), GBK-032210 (104.3), GBK-032302 (108.0), GBK-031997 (109.7), GBK-031991 (112.0) and GBK-028563 (121.7) recorded the highest number of leaves per plant.

### **3.7.6 Number of days to 50% flowering among spider plant accessions**

Spider plant accessions varied significantly at  $P \leq 0.05$  in number of days to 50% flowering in both experiments (Table 3.9 and Table 3.10). Location  $\times$  spider plant accession interaction had no significant effects on number of days to 50% flowering but location main effects on this parameter were significant. Number of days to 50% flowering varied from 29.7 (Nyamira) to 51.7 (GBK-028563) in the greenhouse and 34.0 (Marakwet) to 45.0 (GBK-031991) in the field. Field grown accessions flowered at an average of 38.9 days compared to 40.9 days in greenhouse grown accessions. Accessions grown in the field at Kabete field station flowered at an average of 40 days compared to an average of 37.6 days in Nyabokarange grown accessions (Table 3.5, Table 3.9 and Table 3.10). Farmers' accessions flowered at an average of 38.5 days while the genebank accessions flowered at an average of 42.8 days in the greenhouse grown accessions. In the field experiment, farmers' accessions flowered at an average of 37.5 days while genebank accessions flowered at an average of 40.0 days. Accessions GBK-028563 (51.7 days) and GBK-031991 (42.8 days) took the longest time to flower in the greenhouse while accessions GBK-031991 (45 days) and GBK-032302 (44.8) took the longest time to flower in the field.

### **3.7.7 Number of pods per plant among spider plant accessions**

Spider plant accessions varied significantly at  $P \leq 0.05$  in number of pods in both experiments in number (Table 3.9 and Table 3.6). In the field experiment, location and location  $\times$  spider plant interaction had significant effects on number of pods per spider plant. Accessions Bungoma, Eldoret, GBK-028554, GBK-028563, GBK-031833, GBK-031837, GBK-031866, GBK-031992, GBK-031994, GBK-031997, GBK-032210, GBK-032253, GBK-032302, GBK-045426, GBK-045436,

GBK-045456, Homabay, Kericho, Marakwet, Migori, Mombasa, Nandi, Nyamira, and commercial variety (saga) recorded a significantly higher number of pods per plant in Kabete than in Kuria. In contrast, only accession GBK-032253R recorded a significantly higher number of pods in Nyabokarange village than in Kabete field station. Number of pods per plant varied from 19.7 (accession Mombasa) to 101.5 (accession Kakamega) and 31.7 (accession Mombasa) to 70.7 (accession Kuria) for greenhouse experiment. Field experiment recorded an average of 69.6 pods per plant compared to 52.1 pods in the greenhouse accessions (Table 3.7 and 3.8). Field grown accessions at Kabete field station recorded an average of 76.9 pods per plant compared to 62.4 pods per plant in Nyabokarange village grown accessions (Table 3.11 and Table 3.12). Commercial variety (saga) recorded an average of 63.8 pods per plant; however, 67.5% of the evaluated accessions in the field experiment recorded a higher number of pods per plant than the commercial variety (saga) while in the greenhouse commercial variety (saga) recorded an average of 62.3 pods per plant. In the greenhouse, genebank accessions had an average of 72.9 pods per plant while the farmers' accessions had an average of 65.2 pods per plant. In the field, farmers' accessions had an average of 55.8 pods per plant compared to 49.5 pods per plant for gene bank accessions.

### **3.7.8 Number of seeds per pod among spider plant accessions**

Spider plant accessions varied significantly at  $P \leq 0.05$  in number of seeds per pod in both experiments (Table 3.8 and 3.6). In the field experiment, location and location  $\times$  spider plant interaction had significant effects on number of seeds per pod. Accessions Baringo, Bungoma, Eldoret, GBK-028542, GBK-032253R, Kakamega, Kisii 1, Kisii 2, Kuria, and Nyamira recorded a significantly higher number of seeds per pod in Kuria than in Kabete, while all the other accessions recorded a significantly higher number of seeds in Kabete field station than in Nyabokarange village. Number of seeds per pod varied from 14.0 (accession Mombasa) to 180.3 (accession GBK-031850) in the greenhouse and 23.7 (accession GBK-028563) to 156.1 (accession Migori) in the field (Table 3.7 and Table 3.8). Field grown accessions recorded an average of 108.3 seeds per pod while greenhouse grown accessions had an average of 99.8 seeds per pod. Field grown accessions at Kabete field station recorded a mean of 122 seeds per pod compared to 94.5 seeds per pod in Nyabokarange village grown accessions (Table 3.9 and Table 3.10). In the greenhouse commercial variety (saga) recorded 136.3 seeds per pod which was below the number of seeds per pod for accessions GBK-045456 (164.0 seeds), GBK-032229 (178.7 seeds) and GBK-031850 (180.3seeds). In the field experiment, commercial variety (saga) recorded 93.8 seeds per pod.

**Table 3.7: Number of leaves, days to 50% flowering and number of pods per plant of 40 spider plant accessions grown in the field at Kabete field station and Nyabokarange in Kuria West**

Accession	NLP			DTF			NPP		
	Kabete	Nyabo	Mean	Kabete	Nyabo	Mean	Kabete	Nyabo	Mean
Awendo	54.3	81.7	68.0	37.0	34.3	35.7	48.7	53.0	50.8
Baringo	62.0	64.3	63.2	35.7	33.0	34.3	58.3	50.0	54.2
Bungoma	75.3	75.7	75.5	38.0	35.0	36.5	68.7	49.3	59.0
Eldoret	100.0	89.3	94.7	41.7	37.7	39.7	89.3	75.0	82.2
GBK-028542	94.3	92.3	93.3	41.0	36.7	38.8	77.0	67.7	72.3
GBK-028554	80.3	94.3	87.3	39.3	38.0	38.7	72.0	58.0	65.0
GBK-028563	89.3	75.3	82.3	40.0	34.0	37.0	77.0	50.3	63.7
GBK-031833	83.3	65.7	74.5	37.7	33.7	35.7	71.3	47.0	59.2
GBK-031837	87.0	76.0	81.5	40.3	36.3	38.3	73.3	54.3	63.8
GBK-031850	86.0	83.0	84.5	39.7	37.3	38.5	74.7	66.0	70.3
GBK-031866	101.7	84.3	93.0	41.7	38.7	40.2	83.7	64.7	74.2
GBK-031968	97.7	114.7	106.2	40.3	44.7	42.5	83.7	83.0	83.3
GBK-031991	117.3	101.7	109.5	46.0	44.0	45.0	104.0	72.3	88.2
GBK-031992	103.7	115.7	109.7	42.0	47.3	44.7	86.7	78.3	82.5
GBK-031993	79.7	81.3	80.5	42.0	35.0	38.5	70.3	68.0	69.2
GBK-031994	99.0	85.0	92.0	43.3	42.3	42.8	89.0	54.7	71.8
GBK-031996	75.0	65.7	70.3	36.7	32.3	34.5	59.7	63.7	61.7
GBK-031997	62.7	55.0	58.8	35.7	32.7	34.2	55.3	37.7	46.5
GBK-031998	87.7	85.3	86.5	40.7	37.7	39.2	73.3	63.7	68.5
GBK-032210	99.3	93.3	96.3	41.7	38.3	40.0	86.3	66.0	76.2
GBK-032229	98.3	86.3	92.3	41.7	37.3	39.5	84.3	78.0	81.2
GBK-032253	107.7	94.7	101.2	46.3	42.0	44.2	86.3	63.3	74.8
GBK-032253R	125.7	105.7	115.7	44.3	42.0	43.2	87.7	103.0	95.3
GBK-032302	108.3	102.7	105.5	43.3	46.3	44.8	101.0	70.7	85.8
GBK-045426	79.7	91.7	85.7	38.3	35.7	37.0	81.3	61.3	71.3
GBK-045436	99.7	97.0	98.3	42.0	41.3	41.7	88.3	62.3	75.3
GBK-045456	108.0	89.0	98.5	42.7	38.7	40.7	97.0	58.3	77.7
Homabay	96.7	75.3	86.0	42.0	35.7	38.8	79.3	62.0	70.7
Kakamega	108.0	96.0	102.0	44.3	41.7	43.0	104.3	98.7	101.5
Kericho	90.7	58.7	74.7	40.3	36.7	38.5	77.7	47.7	62.7
Kisii 1	91.7	115.7	103.7	46.0	42.3	44.2	85.0	83.0	84.0
Kisii 2	89.3	96.3	92.8	40.3	38.0	39.2	75.3	74.3	74.8
Kuria	71.3	92.3	81.8	34.0	34.3	34.2	64.7	65.0	64.8
Marakwet	78.7	75.3	77.0	35.7	32.3	34.0	66.7	54.3	60.5
Migori	87.3	60.0	73.7	36.3	33.7	35.0	78.7	49.3	64.0
Mombasa	24.0	22.3	23.2	38.0	35.0	36.5	27.0	12.3	19.7
Nakuru	69.7	78.0	73.8	38.3	35.0	36.7	61.7	55.0	58.3
Nandi	68.0	78.3	73.2	38.3	39.0	38.7	71.0	57.0	64.0
Nyamira	67.0	120.3	93.7	37.0	34.0	35.5	83.7	61.3	72.5
Commercial (saga)	85.7	86.3	86.0	38.0	35.7	36.8	71.7	56.0	63.8
<b>Mean</b>	<b>87.3</b>	<b>85.0</b>	<b>86.2</b>	<b>40.2</b>	<b>37.6</b>	<b>38.9</b>	<b>76.9</b>	<b>62.4</b>	
<b>P-Value (A)</b>	<b>&lt;.001</b>			<b>&lt;.001</b>			<b>&lt;.001</b>		
<b>P-Value (L)</b>	<b>0.03</b>			<b>&lt;.001</b>			<b>&lt;.001</b>		
<b>P-Value (A×L)</b>	<b>&lt;.001</b>			<b>0.26</b>			<b>&lt;.001</b>		
<b>LSD<sub>≤0.05</sub> (A)</b>	<b>8.8**</b>			<b>3.2**</b>			<b>7.5**</b>		
<b>LSD<sub>≤0.05</sub> (L)</b>	<b>2.0*</b>			<b>0.7**</b>			<b>1.7**</b>		
<b>LSD<sub>≤0.05</sub> (A×L)</b>	<b>12.4**</b>			<b>4.6ns</b>			<b>10.6**</b>		
<b>CV%</b>	<b>8.9</b>			<b>7.5</b>			<b>9.4</b>		

NLP-Number of leaves per plant, DTF-Days to flowering, NPP-Number of pods per plant, \*\* highly significant at P≤0.05 level, \* significant at P≤0.05 level ns-not significant, A-Accessions, L-Location, Nyabo-Nyabokarange village in kuria West Sub County

However, 77.5 % of the spider plant accessions evaluated recorded a higher number of seeds per pod than the commercial variety (saga). In the field experiments, accessions Nakuru (140.0), Baringo (142.6), Eldoret (145.7), GBK-031833 (149.8), Awendo (151.4), GBK-031997 (151.8) and Migori (156.1) recorded the highest number of seeds per pod.

### **3.7.9 100-seed weight per spider plant**

Spider plant accessions varied significantly at  $P \leq 0.05$  in 100-seed weight for both experiments. In the field experiment, location and location  $\times$  spider plant interaction had significant effects on the weight of 100 seeds per spider plant. Accessions GBK-028542, GBK-028554, GBK-031866, GBK-031968, GBK-031998, GBK-032253, GBK-032253R, GBK-032302, GBK-045436, GBK-045456, Homabay, Kisii 2, Kuria, Marakwet, and Migori recorded a significantly higher 100 seed weight in Kabete field station than in Nyabokarange village. Weight of 100 seeds varied from 66.7 mg (accession Mombasa) to 146.7 mg (accessions Kisii 2, GBK-045456 and GBK-031996) for field grown accessions, and 60 mg (accession Mombasa) to 170 mg (accession GBK-031994) for the greenhouse grown accessions. Field grown accessions at Kabete field station recorded an average of 136.3 mg compared to 123.3 mg in Nyabokarange village grown accessions (Table 3.8, Table 3.11 and Table 3.12). Spider plant accessions had an average 100 seed weight of 130 mg in both greenhouse and field experiment (Table 3.9 and Table 3.11). Commercial variety (saga) recorded an average 100 seed weight of 120 mg in the field and 140 mg in the greenhouse grown accessions. Accessions Homabay (160.0 mg), GBK-045436 (160.0 mg), GBK-032210 (160.0 mg) and GBK-031994 (170.0 mg) recorded a higher 100 seed weight than the commercial variety (saga).

### **3.7.10 Seed yield per plant**

Spider plant accessions varied significantly at  $P \leq 0.05$  in seed yield per plant in greenhouse and field experiments. In the field experiment, location and location  $\times$  spider plant interaction had significant effects on number of seeds per pod per spider plant. Except for accession Kakamega that recorded a significantly higher seed yield per spider plant in Nyabokarange village than in Kabete field station, all the other accessions recorded a significantly higher seed yield per plant in Kabete field station than in Nyabokarange village. Yield of seeds per plant varied from 0.3 g (accession Mombasa) to 16.8 g (accessions GBK-045436 and GBK-045456) in the greenhouse and 0.7 g (accession Mombasa) to 16.0 g (accession GBK-031991) in the field. The field experiment recorded an average seed yield of 10.2 g compared to 7.3 g in the greenhouse experiment (Table 3.9 and Table 3.10). Field grown accessions at Kabete field station recorded an average seed yield of 12.9 g compared to

7.5 g in Nyabokarange village grown accessions (Table 3.6 and Table 3.8). In the greenhouse experiment, commercial variety (saga) recorded a seed yield of 11.6 g which was below the seed yields of accessions Kuria (12.1 g), GBK-032229 (12.3 g), GBK-045426 (13.4 g), GBK-045456 (16.8 g), and GBK-045436 (16.8 g). About 82.5 % of the evaluated accessions in the field recorded a higher seed yield than the commercial variety (saga). Farmers' accessions recorded an average seed yield of 7.6 g per plant compared to 6.9 g for genebank accessions; however, genebank accessions recorded a higher seed yield per plant (10.3 g) than the farmers' accessions (10.1 g) in the field. In the field, accessions GBK-031991 (16.0 g), Eldoret (15.5 g), GBK-045456 (14.7 g), Migori (14.4 g), GBK-032229 (14.2 g), Kakamega (13.8 g), GBK-031968 (13.3 g), GBK-032302 (13.3 g), GBK-032210 (12.2 g) and Homabay (12.1 g) recorded the highest seed yield per plant compared to all other accessions evaluated in both sites.

### **3.8 Correlation of agronomic traits of spider plant accessions**

Agronomic traits of spider plant accessions showed significant positive and negative correlations (Table 3.11 and Table 3.12) in both greenhouse and field experiments. There were strong positive correlations between number of primary branches per plant and number of leaves per plant ( $r=0.81$  and  $r=0.78$ ) for greenhouse and field grown spider plant accessions respectively. Plant height and number of leaves positively correlated ( $r=0.90$  and  $r=0.80$ ) in the field and greenhouse respectively. Number of seeds per pod and seed yield had significant positive correlation ( $r=0.78$  and  $r=0.80$ ) for greenhouse and field experiments (Table 3.13 and Table 3.14). Days to flowering and number of pods per plant had significant a negative correlation in greenhouse grown accessions and a significant positive correlation in field grown accessions recorded a significant positive correlation (Table 3.11 and Table 3.12). Plant height and number of primary branches per plant had a significant positive correlation ( $r=0.76$ ) in field experiments and a non-significant positive correlation ( $r=0.12$ ) in greenhouse experiments. Number of days to seedling emergence and number of days to flowering ( $r=0.88$  and  $r=0.52$ ) had significant positive correlations for both greenhouse and field experiments. Number of days to seedling emergence and plant height registered significant negative correlation ( $r=-0.63$ ) in greenhouse grown accessions and non-significant negative correlation ( $r=-0.29$ ) in field grown accessions.



**Table 3.8: Number of seeds per pod, 100 seed weight and seed yield per plant of 40 Spider plant accessions grown in the field at Kabete field station and Nyabokarange village in Kuria West Sub County**

Accession	NSP			100-sw (mg)			SYP		
	Kabete	Nyabo	Mean	Kabete	Nyabo	Mean	Kabete	Nyabo	Mean
Awendo	164.7	138.0	151.4	136.7	133.3	135.0	11.0	9.7	10.4
Baringo	135.8	149.4	142.6	130.0	126.7	128.3	10.2	9.5	9.9
Bungoma	89.6	104.0	96.8	140.0	126.7	133.3	8.6	6.5	7.6
Eldoret	138.8	152.5	145.7	133.3	126.7	130.0	16.4	14.5	15.5
GBK-028542	79.0	147.5	113.3	140.0	110.0	125.0	8.4	10.9	9.7
GBK-028554	190.3	57.0	123.7	136.7	110.0	123.3	18.7	3.6	11.2
GBK-028563	28.4	18.9	23.7	120.0	116.7	118.3	2.7	1.1	1.9
GBK-031833	190.7	108.8	149.8	126.7	120.0	123.3	17.4	6.1	11.8
GBK-031837	156.9	56.5	106.7	130.0	116.7	123.3	15.0	3.6	9.3
GBK-031850	146.7	105.4	126.1	136.7	120.0	128.3	15.0	8.3	11.7
GBK-031866	78.0	93.7	85.9	156.7	126.7	141.7	10.2	7.7	9.0
GBK-031968	142.7	102.7	122.7	143.3	113.3	128.3	17.0	9.6	13.3
GBK-031991	137.0	117.5	127.3	146.7	130.0	138.3	20.9	11.1	16.0
GBK-031992	148.5	51.9	100.2	130.0	126.7	128.3	16.7	5.2	11.0
GBK-031993	93.0	48.8	70.9	133.3	116.7	125.0	8.7	3.9	6.3
GBK-031994	102.7	81.4	92.1	133.3	136.7	135.0	12.2	6.1	9.2
GBK-031996	136.7	89.2	113.0	146.7	146.7	146.7	12.0	8.4	10.2
GBK-031997	183.7	119.8	151.8	140.0	126.7	133.3	14.1	5.6	9.9
GBK-031998	104.3	97.0	100.7	143.3	116.7	130.0	11.0	7.2	9.1
GBK-032210	153.7	120.5	137.1	110.0	120.0	115.0	14.7	9.6	12.2
GBK-032229	142.3	119.2	130.8	130.0	136.7	133.3	15.6	12.8	14.2
GBK-032253	76.2	45.2	60.7	150.0	126.7	138.3	9.8	3.6	6.7
GBK-032253R	40.1	57.0	48.6	146.7	126.7	136.7	5.3	7.4	6.4
GBK-032302	140.0	67.6	103.8	146.7	120.0	133.3	20.7	5.8	13.3
GBK-045426	133.0	96.2	114.6	126.7	116.7	121.7	13.9	6.9	10.4
GBK-045436	139.5	52.7	96.1	143.3	120.0	131.7	17.7	4.0	10.9
GBK-045456	151.3	62.9	107.1	170.0	123.3	146.7	24.9	4.5	14.7
Homabay	175.8	86.8	131.3	120.0	140.0	130.0	16.6	7.5	12.1
Kakamega	68.3	126.3	97.3	136.7	143.3	140.0	9.7	17.9	13.8
Kericho	146.0	105.4	125.7	140.0	126.7	133.3	15.9	6.3	11.1
Kisii 1	95.0	104.8	99.9	133.3	130.0	131.7	10.9	11.4	11.2
Kisii 2	85.3	114.5	99.9	160.0	133.3	146.7	10.3	11.4	10.9
Kuria	82.3	116.3	99.3	150.0	103.3	126.7	7.9	7.9	7.9
Marakwet	81.0	62.8	71.9	150.0	126.7	138.3	8.0	4.3	6.2
Migori	173.3	138.8	156.1	150.0	120.0	135.0	20.5	8.3	14.4
Mombasa	54.5	36.4	45.5	73.3	60.0	66.7	1.1	0.3	0.7
Nakuru	140.7	139.3	140.0	123.3	140.0	131.7	10.7	10.6	10.7
Nandi	149.7	90.4	120.1	146.7	130.0	138.3	15.6	6.7	11.2
Nyamira	83.7	128.5	106.1	120.0	126.7	123.3	8.4	9.9	9.2
Commercial (saga)	119.1	68.5	93.8	123.3	113.3	118.3	10.5	4.3	7.4
<b>Mean</b>	<b>122.0</b>	<b>94.5</b>	<b>108.3</b>	<b>136.3</b>	<b>123.3</b>	<b>129.8</b>	<b>12.9</b>	<b>7.5</b>	
<b>P-Value (A)</b>	<b>&lt;.001</b>			<b>&lt;.001</b>			<b>&lt;.001</b>		
<b>P-Value (L)</b>	<b>&lt;.001</b>			<b>&lt;.001</b>			<b>&lt;.001</b>		
<b>P-Value (A×L)</b>	<b>&lt;.001</b>			<b>&lt;.001</b>			<b>&lt;.001</b>		
<b>LSD<sub>≤0.05</sub> (A)</b>	<b>6.1**</b>			<b>13.6**</b>			<b>1.7**</b>		
<b>LSD<sub>≤0.05</sub> (L)</b>	<b>1.4**</b>			<b>3.0**</b>			<b>0.4**</b>		
<b>LSD<sub>≤0.05</sub> (A×L)</b>	<b>8.7**</b>			<b>19.2**</b>			<b>2.4**</b>		
<b>CV%</b>	<b>5.0</b>			<b>9.2</b>			<b>14.6</b>		

NSP-Number of seeds per Pod, 100-sw-100-seed weight. SYP-Seed yield per plant. \*\* Highly significant at P≤0.05 level. Nyabo-Nyabokarange village in Kuria west Sub County

**Table 3.9: Quantitative trait measurements of 40 field grown spider plant accessions at Kabete field station and Nyabokarange village in Kuria west Sub County with their minimum and maximum values**

Variate	MIN	MEAN	MAX	SED	P-Value	LSD <sub>≤0.05</sub>
No. of days to 50% seedling emergence	5.0	9.4	15.0	1.1	<.001	2.1**
Emergence Percentage	20.0	42.9	68.0	4.0	<.001	7.9**
Number of primary branches	4.0	10.0	14.0	1.2	0.04	2.4*
Plant height (cm)	12.0	71.6	113.0	5.8	<.001	11.4**
Number of leaves per plant	18.0	86.2	136.0	12.0	<.001	12.4**
Number of days to 50 % flowering	30.0	38.9	49.0	2.3	0.264	NS
Number of pods per plant	10.0	69.6	108.0	5.4	<.001	10.6**
Number of seeds per pod	17.7	108.2	196.0	4.4	<.001	8.7**
100-seed weight (mg)	1.0	1.0	2.0	0.1	<.001	0.02**
Seed yield (g)	0.2	10.2	26.9	1.2	<.001	2.4**

\*\*=Highly significant, \*=Significant, NS=not significant, SED=Standard error of difference. P-probability. Data are means of three replications of three plants each for the 40 Spider plant accessions.

**Table 3.10: Quantitative trait measurements of 40 greenhouse grown spider plant accessions at Kabete field station with their minimum and maximum values**

Variate	MIN	MEAN	MAX	P-Value	SED	LSD <sub>≤0.05</sub>
Number of days to seedling emergence	4.0	8.1	14.0	<.001	0.7	1.4**
Emergence percentage	15.4	41.8	69.2	0.256	9.4	18.6ns
Number of primary branches per plant	5.0	10.0	14.0	<.001	1.0	1.9**
Plant height (cm)	14.0	70.8	112.0	<.001	3.5	6.9**
Number of leaves per plant	44.0	85.5	129.0	<.001	5.1	10.1**
Number of days to 50% flowering	29.0	40.9	52.0	<.001	1.3	2.7**
Number of pods per plant	29.0	52.1	74.0	<.001	2.8	5.5**
Number of seeds per pod	12.0	99.8	185.0	<.001	4.6	9.3**
100-seed weight (mg)	0.0	0.1	0.2	<.001	0.0	0.0
Seed yield (g) per plant	0.1	7.3	20.1	<.001	1.2	2.3**

\*\*=Highly significant, ns=not significant, SED=Standard error of difference. P-probability. Data are means of three replications of three plants each for the 40 Spider plant accessions.

**Table 3.11: Quantitative trait measurements of 40 field grown spider plant accessions at Kabete field station with their minimum and maximum values**

<b>Variate</b>	<b>MIN</b>	<b>MEAN</b>	<b>MAX</b>	<b>P-Value</b>	<b>SED</b>	<b>LSD<sub>≤0.05</sub></b>
Number of days to seedling emergence	5.0	9.7	14.0	<.001	1.1	2.2**
Emergence percentage	25.0	42.3	60.0	<.001	3.5	6.9**
Number of primary branches per plant	5.0	10.1	14.0	<.001	1.0	2.0**
Plant height (cm)	14.0	75.5	108.0	<.001	5.7	11.4**
Number of leaves per plant	18.0	87.3	136.0	<.001	6.6	13.0**
Number of days to 50% flowering	33.0	40.2	49.0	<.001	2.0	3.9**
Number of pods per plant	21.0	76.9	108.0	<.001	6.0	12.0**
Number of seeds per pod	24.0	122.0	196.0	<.001	4.7	9.4**
100-seed weight (mg)	60.0	136.3	180.0	<.001	0.0	0.02**
Seed yield (g) per plant	0.7	12.9	26.9	<.001	1.5	3.0**

\*\*=Highly significant, SED=Standard error of difference. P-probability. Data are means of three replications of three plants each for the 40 spider plant accessions.

**Table 3.12: Quantitative trait measurements of 40 field grown spider plant accessions at Nyabokarange village Kuria west Sub County with their minimum and maximum values**

<b>Variate</b>	<b>MIN</b>	<b>MEAN</b>	<b>MAX</b>	<b>P-Value</b>	<b>SED</b>	<b>LSD<sub>≤0.05</sub></b>
Number of days to seedling emergence	6.0	9.1	15.0	<.001	0.9	1.7**
Emergence percentage	20.0	43.4	68.0	<.001	4.1	8.2**
Number of primary branches per plant	4.0	10.0	14.0	<.001	1.4	2.7**
Plant height (cm)	12.0	67.7	113.0	<.001	5.9	11.8**
Number of leaves per plant	20.0	85.0	122.0	<.001	6.0	11.9**
Number of days to 50% flowering	30.0	37.6	49.0	<.001	2.6	5.2**
Number of pods per plant	10.0	62.4	108.0	<.001	4.7	9.4**
Number of seeds per pod	17.7	94.5	156.0	<.001	4.0	8.1**
100-seed weight (mg)	50.0	123.3	160.0	<.001	0.0	0.02**
Seed yield (g) per plant	0.17	7.5	19.2	<.001	0.9	1.7**

\*\*=Highly significant, SED=Standard error of difference. P-probability. Data are means of three replications of three plants each for the 40 Spider plant accessions.

**Table 3.13: Correlation coefficient table for the quantitative traits recorded for 40 accessions of spider plant grown in the greenhouse at Kabete field station. Number of observations:120**

	DTE	%SE	NPB	PH	NLP	DTF	NPP	NSP	100-sw	SYP
DTE	-									
%SE	-0.02	-								
NPB	0.13	-0.10	-							
PH	-0.63*	0.12	0.12	-						
NLP	0.32	0.00	0.81**	-0.07	-					
DTF	0.88	-0.03	0.11	-0.70	0.30	-				
NPP	-0.70**	0.09	0.17	0.90**	-0.02	-0.77**	-			
NSP	-0.22	0.18	0.02	0.44	0.02	-0.26	0.35	-		
100-sw	-0.31	0.11	0.16	0.64	-0.02	-0.30	0.56	0.30	-	
SYP	-0.56**	0.20	0.01	0.75**	-0.10	-0.61	0.77**	0.78**	0.63**	-

DTE-Days to seedling emergence, %SE-percent seedling emergence, NPB-Primary branches per plant, PH-Plant height (cm), NLP-Number of leaves per plant, DTF-Days to flowering, NPP-Number of pods per plant, NSP-Number of seeds per pod, SYP-Seed yield (g) per plant. 100 sw-100 seed weight (mg). \*\* Correlation at significant at  $P \leq 0.01$  level, \*correlation is significant at  $P \leq 0.05$  level

**Table 3.14: Correlation coefficient table for the quantitative traits recorded for 40 accessions of spider plant grown in the field at Kabete field station and Nyabokarange in Kuria west Sub County. Number of observations: 240**

	DTE	% SE	NPB	PH	NLP	DTF	NPP	NSP	100-sw	SYP
DTE	-									
% SE	-0.38	-								
NPB	0.38	-0.10	-							
PH	0.29	-0.09	0.76**	-						
NLP	0.29	-0.08	0.78**	0.87**	-					
DTF	0.52*	-0.21	0.77	0.63	0.65**	-				
NPP	0.28	-0.09	0.69**	0.80**	0.78**	0.67**	-			
NSP	-0.07	0.15	-0.10	0.10	0.01	-0.06	0.18	-		
100-sw	0.04	0.05	0.10	0.36	0.31	0.16	0.42	0.26	-	
SYP	0.13	-0.01	0.24	0.44	0.36	0.30	0.62**	0.80**	0.53**	-

DTE-Days to seedling emergence, %SE-percent seedling emergence, NPB-Primary branches per plant, PH-Plant height (cm), NLP-Number of leaves per plant, DTF-Days to flowering, NPP-Number of pods per plant, NSP-Number of seeds per pod, SYP-Seed yield (g) per plant, 100 sw-100-seed weight (mg). \*\* Correlation is significant at  $P \leq 0.01$  level, \*correlation is significant at  $P \leq 0.05$  level

### 3.9 Discussion

Spider plant accessions varied significantly in number of days to seedling emergence in both greenhouse and field experiments. Days to seedling emergence ranged from 4 (accessions Nandi, GBK-045436, Kisii) to 12.7 (accessions GBK-031992, GBK-032302). The observed genotypic variation may be attributed to possible differences in seed maturity level at harvest, seed processing

and seed dormancy. Ochuodho *et al.*, (2005) reported that spider plant seed germination is enhanced by physiologically mature seeds and proper seed processing and storage. Spider plant harvested when the pods are fully ripen and yellow exhibit high seedling emergence. Early harvesting results to seed dormancy and both early and late harvesting lead to poor quality seeds whose emergence tends to be low (Ekpong, 2009). Sun-dried seeds exhibit poor seedling emergence while seeds dried under shade have high seedling emergence. Ekpong (2009), Wasonga *et al.*, (2015), and Onyango *et al.*, (2016) reported similar findings in spider emergence in the grown field and greenhouse studies. Commercial variety (saga) emerged in 8 days in the field and 6 days in greenhouse compared to gene bank accessions which emerged in 10 days in the field and 9 days in the greenhouse. The early emergence recorded in the commercial variety (saga) may be attributed to selection and improvement by the seed companies (Onyango *et al.*, 2016). Accessions sown in the greenhouse generally emerged one day earlier than those grown in the field most probably due to high temperature in the greenhouse that increased seed metabolic activities that resulted in earlier emergence. Optimal temperatures increase physiological processes of the seed that accelerates seed germination and emergence (Shaban, 2013).

Seedling emergence percentage among the accessions varied with the location. This could be attributed to genotype-environment interaction. The differential response of cultivars to diverse environments is referred to as a crossover interaction when cultivar ranks change from one environment to another (Kang, 1998). This may explain the observed differences in the locations. Commercial variety (saga) had a high seedling emergence, 59% in the greenhouse and 55.8% in the field. The high seedling emergence of the commercial variety (saga) may be attributed to the proper processing and storage as well as using physiologically mature seeds. The seed companies prescribe quality attributes of the seed to be adopted by the contracted farmers including harvesting mature seeds. The variations and poor seedling emergence recorded among genebank and farmers' accessions may be partly attributed to poor processing before storage for some farmers' accessions and long storage in the genebank (more than 5 years) at low temperature (-20°C) which leads to long dormancy. Seeds that have attained physiological maturity will germinate once the dormancy is broken and necessary germination conditions availed (Ochuodho and Modi, 2007). Onyango *et al.*, (2016) reported similar findings for greenhouse grown accessions. In their study, seedling emergence varied from 16.7 % to 50.0 %. Methods of seed processing and storage determine emergence percentage of the seedlings. Farmers, sun-dry seeds before storage. Spider plant seeds that have been dried under the sun records low germination percentage and low vigor compared to

those dried under the shade (K'Opondo *et al.*, 2009). Days to emergence recorded strong negative correlation with plant height ( $r=-0.63$ ) and number of pods ( $r=-0.70$ ) in the greenhouse, implying that the longer it took for seeds to emerge the shorter the spider plant grew and the lower the number of pods the plant formed. Accessions that register long days to seedling emergence result in poor plant vigour as exhibited in shorter plants and low pod number, leading to low seed and leaf yield. Seeds that take longer in the soil before germinating are prone to higher chances of attack by soil borne pests and diseases that reduce their emergence (Nennich, 2000). Liu (2000) reported that a high seedling emergence percentage is a pre-requisite for successful commercial vegetable production. The heritability of any trait depends on the genotype as well as the environment it is grown (Sleper, 1983). Accessions GBK-031997, Kakamega and Kericho recorded higher seedling emergence than other accessions in the field at Kabete field station while in field grown at Nyabokarange village, accessions Awendo (68%), Baringo (62.7%) and Bungoma (60%) recorded higher seedling emergence than all other accessions. The variability in seedling emergence in the two locations could be attributed variations in weather condition recorded during the seedling emergence season. Kabete field station recorded an average rainfall of 110.4 mm while Kuria west sub county recorded average rainfalls of 144.7 mm in November, the sowing month (Table 3.2 and 3.3)

Spider plant accessions recorded an average of 10 primary branches per plant and a significant positive correlation between number of primary branches and number of leaves per plant ( $r=0.81$  and  $r=0.78$ ) in both greenhouse and field experiments. Munene *et al.*, (2018) also reported positive correlation between number of primary branches and number of leaves per plant. Number of primary branches significantly varied among the accessions both in the greenhouse and field experiments. In the field number of primary branches varied from 7.0 (accessions GBK-031997 and Mombasa) to 12.7 (accession GBK-031991) while in the greenhouse, they varied from 5.7 (accession Mombasa) to 12.7 (accession Baringo). Lawlor (1995) reports that leaf yield per unit area increases with increase in formation of primary branches.

Plant height varied from 16 cm (accession Mombasa) to 107.1 cm (accession GBK-045436) in the greenhouse and 17.0 cm (Mombasa) to 100.8 cm (GBK-031991) in the field suggesting genotypic variations. This corresponds to variations reported by Munene *et al.*, (2018) of 21 cm to 113 cm in spider plant. Plant height is a notable agronomic parameter that reveals the crop plant's vegetative growth behaviour (Anjum *et al.*, 2016 a; Wang *et al.*, 2016). Tallness trait is important for good vigor which enables the plant to grow to the height required for easier weeding and harvesting

during production (Chowdhury *et al.*, 2007). Tallness facilitates free air circulation in the plant thus preventing pest and diseases attack (Chowdhury *et al.*, 2007). There was strong significant positive correlation between plant height and number of leaves per plant ( $r=0.87$ ) in the greenhouse experiment. In vegetable crops, short plants and low plant population leads to rate of photosynthesis resulting to low leaf yield (Lawlor, 1995). The variations reported among the genotypes in the two location may be attributed to differences in weather and edaphic conditions. Analysis of soil collected in Kabete field station showed that it contained more organic carbon, nitrogen and phosphorus than that of Nyabokarange village. In Kabete accessions GBK-032253R (103.7 cm) and GBK-032302 (101.3 cm) recorded the highest plant height while in Nyabokarange, accessions GBK-031968 (109.7) and GBK-031991 (101.0 cm) recorded the highest plant height.

Number of leaves per plant varied from 23.2 (accession Mombasa) to 115.7 (accession GBK-032253R) in the field and 49.3 (accession Mombasa) to 121.7 (accession GBK-028563) in the greenhouse. Commercial variety (saga) recorded 86.0 leaves per plant in the field experiment and 99.0 per plant leaves in the greenhouse and these were lower than number of leaves per plant for some local landraces such as Bungoma, Kisii 2 and Kakamega. Leaves are the primary sites of photosynthesis in crop plants, therefore, one might assume that the greater the number of leaves in a field, the better the interception of sunlight and the higher the leaf yield (Silver tooth, 2014). Number of leaves per plant recorded significant positive correlation with number of pods and days to flowering ( $r=0.78$  and  $r=0.65$ ), respectively, for greenhouse grown accessions. An increase in the number of leaves is associated with an increase in pod formation. Similar findings have also been recorded in spider plant (Wasonga *et al.*, 2015). The number of leaves increased with increase in number of days to flowering that resulted in prolonged vegetative period. Accession GBK-032253R recorded the highest number of leaves per plant (125.7) while in Nyabokarange village accession Nyamira recorded the highest number of leaves per plant (120.3). When leaf count is high, it is likely that the amount of leaves per unit area will also be high and hence high photosynthetic rate resulting in high productivity per unit area, especially in leafy vegetables (Lawlor, 1995) such as spider plant.

Number of days to flowering varied significantly among the spider plant accessions from 29.7 (Nyamira) to 51.7 (GBK-028563), a variation of 22 days. This demonstrates that the accessions studied have relatively high genotypic variation in number of days to flowering. The differences in number of days to flowering are higher than those reported by Onyango *et al.*, (2016) by 12 days, possibly because of a wider range of genotypes evaluated in the current study at different locations. Farmers prefer late flowering to early flowering genotypes of vegetable species since the start of

flowering signals the end of the vegetative phase. In this case, the commercial variety (saga) and farmers' landraces may not be the most suitable for vegetable production as they flowered in 38 days compared to genebank accessions that flowered in 42 days. Reproductive phase in vegetable crops inhibits leaf production (Yamaguchi, 1983; Nonnecke, 1989). Late flowering thus enables a genotype to have a longer vegetative phase during the growth period (Omondi, 1990). In this case, accessions GBK-031991, GBK-032302, and GBK-031992 which took 45, 44.8 and 44.7 days to flowering could be candidates for cultivation by farmers and for the purposes of spider plant crop improvement for vegetable production.

Number of pods per plant varied from 19.7 (accession Mombasa) to 101.5 (accession Kakamega) in the field experiment and 31.7 (accession Mombasa) to 70.7 (accession Kuria) in the greenhouse experiment. Wider variations were observed in the field experiment than in the greenhouse, possibly due to high variability in soil and weather conditions in the locations. Sixty eight percent (68 %) of the evaluated accessions recorded a higher number of pods than the commercial variety (saga). Number of pods per plant and seed weight are the primary drivers of seed yield. Variation in number of pods per plant has also been previously reported in spider plant accessions (Wasonga, 2015 *et al.*; Onyango *et al.*, 2016). Number of pods strongly correlated with seed yield ( $r=0.77$  and  $r=0.62$ ) in greenhouse and field experiment respectively. This implies that the greater the number of pods the higher the seed yield of spider plant. These findings agree with those of Oyiga and Uguru (2011) in which a strong positive correlation between seed yield and number of pods per plant in Bambara was noted.

Number of seeds per pod varied from 14.0 (Mombasa) to 180.3 (GBK-031850) in the greenhouse and 23.7 (GBK-028563) to 156.1 (Migori) in the field. This suggests high genotypic variations in number of seeds per pod among spider plant genotypes. Seed counts per pod can vary widely among plant species and individual accessions within a species (Stephenson, 1984). Similar findings have also been reported in spider plant accessions evaluated in a greenhouse (Onyango *et al.*, 2016). In their studies, evaluated accessions recorded a variation of 12 to 170 seeds per pod. Field grown accessions recorded a higher average number of seeds per pod (108.3 seeds) than the greenhouse accessions (99.8 seeds). This may be attributed to low soil volume in the pots used in the greenhouse unlike the field experiment where the spider plants had a large volume of soil to explore nutrients and water. Number of seeds per pod and seed yield recorded a strong positive correlation. This denotes that a high number of seeds in a pod is likely to increase seed yield. A similar observation was also recorded by Esmail *et al.*, (1994). This suggests that the number of pods per



plant can aid in selection of accessions for seed production. In this case, accessions Awendo (151.4), GBK-031997 (151.8) and Migori (156.1) and accessions GBK-031850 (180.3), and GBK-032229 (178.7) recorded the highest number of seeds per pod in the field and greenhouse, respectively.

A hundred seed weight was dependent on the genotypes and environment. This could be attributed to genotypic and environmental interactions. Heritability of any trait depends on the genotype as well as the environment it is grown (Nguyen and Sleper, 1983). Weight of 100 seeds strongly correlated with seed yield in both field and greenhouse ( $r=0.62$ ) experiments. One of the most essential criteria in determining seed quality is the 100-seed weight. It estimates the size of the embryo and food reserves of seeds for germination and emergence (Moshatati, 2012). Germination percent and seedling emergence increase with high 100-seed weight (Noor-Mohammadi *et al.*, 2000). In the field experiment, accessions GBK-031996 (146.7 mg), GBK-045456 (146.7 mg) and Kisii 2 (146.7 mg) and in the greenhouse experiment GBK-031994 (170 mg) recorded highest 100 seed among the spider plant accessions and the commercial variety (saga). The commercial variety was outperformed by 90% of the local spider plant landraces evaluated in the field. This implies that local landraces contain genes that could be exploited to improve seed weight in spider plant. It also suggests local landraces can be recommended for use by farmers.

Seeds yield per plant varied from 0.3 g (accession Mombasa) to 16.8 g (accessions GBK-045436 and GBK-045456). This suggest a high genotypic variation in seed yield among the genotypes. Seed yield is a complex trait having polygenic inheritance (Azhar and Neem, 2008). Wasonga *et al.* (2015) also reported significant variation in seed yield in spider plant accessions in field and greenhouse experiments. In this study, seed yield recorded strong positive correlation with parameters that drive seed yield in spider plant that include number of pods, number of seeds per pod, days to emergence and weight of 100 seeds. Salehi *et al.*, (2010) reported that results of stepwise multiple regression analysis based on seed yield as a dependent variable and other traits as independent variables, pods per plant explained 83.2% of the total variation suggesting that the number of pods per plant may be the main factor determining the seed yield. Eighty three percent (83 %) of the spider plant local landraces recorded a higher seed yield than the commercial variety. Accessions GBK-031991 (16.0 g), Eldoret (15.5 g), GBK-045456 (16.8 g), and Migori (14.4 g) recorded the highest seed yield per plant, they also recorded a high relative number of leaves per plant in the field experiments. Therefore, these genotypes are recommended to farmers for vegetable and seed production. Evaluation of the accessions for nutritional quality is also required to identify highly nutritious accessions with good agronomic traits.

### **3.10 Conclusion**

There exist significant genotypic differences in growth and seed yield traits among the evaluated spider plant accessions and the commercial variety. Genotypes that expressed superior agronomic traits for vegetable and seed yield such as accessions GBK-031991, Kakamega, GBK-045456, GBK-032302 and Migori are recommended for adoption by farmers and for breeding programmes. These accessions performed better than the commercial variety. Therefore, there is need to sensitize small-scale farmers to adopt them for vegetable and seed production. The significant variations in qualitative characters observed among the spider plant accessions from the two sites present great possibility for the development of suitable varieties for various agro-ecological zones.

## **CHAPTER 4: EFFECT OF WATER STRESS ON GROWTH AND YIELD OF SELECTED SPIDER PLANT (*Cleome gynandra* L.) ACCESSIONS**

### **Abstract**

Spider plant (*Cleome gynandra* L.) is one of the most popular African indigenous vegetables due to its known nutritional and health benefits. However, there is limited information on the potential of the existing spider plant genotypes for vegetable and seed production under water limited conditions. Knowledge of the adaptability to drought of the existing genotypes is crucial in the efforts to select superior ones for crop improvement. The objective of this study was to determine the effect of water stress on growth and yield of selected spider plant accessions. Greenhouse experiments were conducted at Kabete Field Station, University of Nairobi, between June 2018 and March 2019. The experiment was laid out in a randomized complete block design with three replications. Fourteen spider plant accessions were grown under varying moisture levels of 40%, 60%, 80% and 100% field capacity (FC). Data was collected on plant growth, physiological and yield attributes. Accession, moisture level and accession x moisture level significantly ( $P \leq 0.05$ ) affected spider plant growth and yield parameters. Leaf yield reduced by 25.7%, 55.1%, and 74.2% at 80%, 60% and 40% field capacity respectively. Seed yield reduced by 43.9%, 77.9% and 90.6% at 80%, 60% and 40% FC respectively. Chlorophyll content reduced by 11.3%, 26.7%, and 38.2% at 80%, 60% and 40% FC. Leaf relative water content reduced by 9.3%, 26.3% and 36.6% at 80%, 60% and 40%FC respectively. Single leaf area reduced by 11.8%, 22.4% and 31.0% at 80%, 60% and 40% FC, respectively. Leaf senescence increased by 2.1, 5.1 and 9.4 at 80%, 60% and 40%FC respectively. The findings show that there exists significant genotypic variation in adaptability to drought among the evaluated spider plant accessions. Accessions that expressed superior agronomic traits for yield such as GBK-032210, Kakamega and GBK-040449 denote existence of exploitable drought tolerance genes in spider plant accessions that could be preserved and explored in breeding programmes for drought adaptability.

**Key words:** African Indigenous Vegetable, Available water, Field Capacity, Leaf development

### **4.0: Introduction**

Spider plant (*Cleome gynandra* L.) is widely used as a local vegetable across sub-Saharan Africa (Chadha, 2003). A wide range of medicinal benefits have been attributed to spider plant. For example, sap of crushed spider plant, leaves and roots can ease childbirth and treat stomachache,

constipation and thread-worm infection (Schippers, 2002). Nutrient analysis shows that spider plant has high levels of proteins, vitamins such as A, C and E and macro and micro nutrients such as iron, magnesium, calcium, and zinc and beta-carotene (Mahyao *et al.*, 2008; Mbugua *et al.*, 2009). The crop can therefore be used to deal with malnutrition and lifestyle diseases in Africa (WHO, 2005).

Spider plant yield in Kenya, using locally available resources, varies from 1.0 to 5.3 t ha<sup>-1</sup> compared to a yield potential of 20.5 to 30 t ha<sup>-1</sup> (Abukutsa-Onyango, 2003; HCDA, 2017). The low yields per unit area are an impediment for commercial production of spider plant. Low spider plant yield is partly attributed to drought stress and use of low yielding, unimproved spider plant cultivars, low soil fertility, and poor farming techniques. Spider plant has previously not been given much research attention by national agricultural research institutes (Vorster and Jansen Van Rensburg, 2005) because of its status as a weed, volunteer or a wild crop and the general thought that it is a vegetable for the poor.

Production of spider plant is mainly rain-fed and this predisposes the crop to drought due to low and erratic rainfall exacerbated by climate change. In Kenya, drought stress has left 3.4 million people severely food insecure, an estimated 500,000 people without access to water and estimated 482,882 children require treatment for acute malnutrition, including 104,614 who are suffering from severe acute malnutrition (UNICEF, 2018). Severe dryness has disrupted planting operations and has severely impacted crop establishment and development across the counties (FAO, 2019). For effective production of spider plant, it is necessary to use supplementary irrigation. Therefore, there is need to effectively manage water as it is scarce leading to high cost of irrigation.

Previous studies have shown that spider plant grows best when adequately supplied with water, especially in areas experiencing short periods of adequate rainfall. Generally, spider plant can tolerate some minimal degree of water stress, but when the periods of drought are prolonged it quickens flowering and plant senescence (Chweya and Mnzava, 1997). Few studies have been conducted on the effect of water stress on spider plant. Masinde *et al.*, (2005) studied effects of water stress on two spider plant landraces and a commercial variety. However, there is a wider range of spider genotypes that have not been evaluated for drought stress adaptability. Most studies have shown that production of crops can be sustained under drought conditions through irrigation (Masinde *et al.*, 2005). There is scanty information on spider plant adaptability to water stress which is essential in scheduling irrigation and informing breeding and conservation programmes (K'Opondo *et al.*, 2009). Therefore, the objective of this study was to determine the effect of water stress on growth and yield of selected spider plant accessions.

## **4.2.0 Materials and Methods**

### **4.2.1 Study area description**

A greenhouse experiment was conducted at the University of Nairobi's Kabete field station. The experiment was carried out twice between June 2018 and February 2019. The agro-ecological zone of the area is upper midland zone three (UM3). The average temperature is 16<sup>0</sup> C to 23<sup>0</sup> C with an average annual rainfall of 1000 mm (Siderus, 1976). The site has deep, well drained dark reddish-brown clay humic nitisols with a pH range of 5.2 to 7.1 (Michieka, 1978).

### **4.2.2 Collection and selection of accessions**

Spider plant accessions were selected based on places where they are cultivated in Kenya and on desirable traits for vegetable and seed production. These traits include number of days to emergence, number of days from sowing to 50% flowering, number of leaves per plant, number of pods per plant and 100-seed weight. Fourteen accessions were selected from the agronomic traits evaluation in chapter three and evaluated in the current study. These were: GBK O40449, GBK O32340, GBK O27212, GBK O45494, GBK O32210, Commercial variety (saga), Mombasa, Kakamega, Baringo, Homabay, Migori, Bungoma, Eldoret and Kisii.

### **4.2.3 Treatments, experimental design and crop husbandry**

Treatments comprised 14 spider plant accessions and four moisture levels. The moisture levels were 100% field capacity (FC) which served as the control, 80% FC, 60% FC and 40% FC. Field Capacity (100%) of the soil was determined through gravimetric analysis. The treatments were set up in a greenhouse using a completely randomized design with a 14×4 factorial arrangement, replicated three times. Each pot was planted with four seeds and seedlings were later thinned to one per pot when plants were 15 cm above the ground. Each pot was 36.3 cm long x 18.3 cm wide. Pots were filled with 10 kg mixture of soil, sand and compost animal manure in the ratio 1: 2: 2 respectively. Ten grams of calcium ammonium nitrate (CAN) was applied in each pot just before planting. Before initiating water stress treatments, the 14 accessions were watered for 14 days to field capacity to enhance root establishment and development. Soil water potential was monitored using a tensiometer at 13 cm depth. The tensiometers were calibrated to measure availability of water in the pots. As soon as water potential reached – 0.008 MPa, plants were watered to 100%, 80%, 60% and 40% field capacity respectively.

#### 4.2.4 Data collection

Data was collected on physiological, growth and yield parameters. Three mature edible fully expanded leaves were randomly selected and tagged at vegetative phase. Length (L) of the leaf from the base to the tip and width at the widest part of the blade (W) of the central leaflet were recorded and single leaf area (SLA) (cm<sup>2</sup>) calculated following the formulae of Rivera *et al.*, (2007):  $SLA = 0.763L + 0.34W$ . Number of days to flowering was determined by counting the number of days from sowing to when 50% of the plants had flowered. Plant height (cm) was measured after 50% flowering from the base of the plant to the tip of the main stem using a meter rule. Leaf senescence was determined by counting the number of leaves that were wilting, yellowing, drying and falling off prematurely at vegetative phase. Stem girth (cm) was determined by measuring the circumference of the middle portions of the three plants at flowering stage.

Physiological data included chlorophyll content, relative water content of the leaf and dry matter partitioning between root and shoot. Chlorophyll content was determined using a SPAD meter (Soil Plant Analysis Development SPAD-502, Minolta Camera co.Ltd...Japan) (Ling *et al.*, 2011). Relative water content (RWC) of the leaf was determined by using the method proposed by Yamasaki and Dillenburg (1999). Leaf fresh weight (FM) was recorded then the leaves were put in petri-dishes containing deionized distilled water for 24 hours. After 24 hours turgid weight (TM) was determined after blotting. The leaves were then put in a pre-heated oven at 60° C for 48 hours and dried to a constant weight to obtain dry weight (DM). The values of FM, TM and DM were used to calculate leaf relative water content, using the equation:  $LRWC (\%) = [(FM - DM)/(TM - DM)] \times 100$  (Aguayoh *et al.*, 2013). Yield and related data were collected on number of leaves, leaf yield, number of seeds per pod, and seed yield. Yield data was calculated by harvesting and weighing leaves weekly during the vegetative phase. Yield of seeds was calculated by weighing dried seeds (at 13 % moisture content) from each plant.

#### 4.2.5 Data analysis

Collected data were subjected to analysis of variance using GenStat 15<sup>th</sup> edition at 5% level of significance. Mean separation for treatment effects that were significant was done by Fisher's protected least significant difference (LSD) test using GenStat version 15<sup>th</sup> edition (Payne *et al.*, 2011). Linear regression analysis of moisture level and plant height, number of leaves, stem girth, chlorophyll content, single leaf area, pod number, leaf yield and seed yield were done using GenStat version 15<sup>th</sup> edition.

### 4.3.0 Results

#### 4.3.1 Effect of water stress on spider plant height

Accession, moisture level and accession x moisture level significantly ( $P \leq 0.05$ ) affected spider plant height (Table: 4.1). Reduction of moisture level from 100% FC to 80% FC, 80%FC to 60% FC, and 60% FC to 40% FC did not have significant effect on accessions Mombasa and GBK-032210, GBK-031850, and Kisii respectively. Plant height of the rest of the accessions and the commercial variety significantly reduced with reduction of moisture level. Across the genotypes water stress reduced plant height by 9.87%, 26.15% and 38.5% at 80%FC, 60%FC and 40%FC, respectively, as compared to control (100% FC). At 40% FC, only accession GBK-032210 was taller than the commercial variety (saga). At 100% FC and 80% FC accessions GBK-032210 and Homabay were significantly the tallest while at 60% FC accession Baringo was significantly the tallest.

**Table 4.1: Effects of moisture level (%field capacity) on plant height (cm) of 14 spider plant accessions at 50% flowering**

Accessions	100%FC	80%FC	60%FC	40%FC	Means
Baringo	89.7	85.3	78.3	60.3	78.4
Bungoma	63.0	60.7	58.7	57.0	59.8
GBK-027212	84.7	69.7	56.7	44.3	63.8
GBK-031850	74.7	64.3	63.3	32.7	58.8
GBK-032210	98.7	88.3	68.3	66.0	80.3
GBK-032340	87.4	71.8	61.7	58.7	69.9
GBK-040449	92.1	75.0	63.7	55.7	71.6
Homabay	97.2	89.3	41.3	38.0	66.5
Kakamega	84.2	80.3	65.3	51.0	70.2
Kisii	89.0	84.7	61.0	59.7	73.6
Kuria	91.0	81.8	71.3	49.2	73.3
Mombasa	46.0	46.4	41.7	37.7	43.1
Nandi	72.7	69.0	58.0	41.7	60.3
Commercial (saga)	90.0	79.3	67.7	62.0	74.6
<b>Means</b>	82.9	74.7	61.2	51.0	67.5
P-Value (A)	<.001				
P-Value (ML)	<.001				
P-Value (A×ML)	<.001				
LSD <sub>≤0.05</sub> (A)	1.4**				
LSD <sub>≤0.05</sub> (ML)	0.8**				
LSD <sub>≤0.05</sub> (A×ML)	2.9**				
CV%	2.6				

LSD- Least significant difference, \*\*highly significant, A-accession, ML- moisture level, FC-field capacity

#### 4.3.2 Effect of water stress on spider plant stem girth (cm)

Accession, moisture level and accession x moisture level significantly ( $P \leq 0.05$ ) affected spider plant stem girth (Table 4.2). Reduction of moisture level from 100% to 80% FC significantly reduced

stem girth in accessions GBK-031850, GBK-032340 and Mombasa. Reduction of moisture level from 80% to 60% FC significantly reduced stem girth in accessions Baringo, GBK-032210, GBK-032340 and GBK-040449 whereas reduction of moisture level from 60% to 40% FC significantly reduced stem diameter in accessions GBK-040449, Kisii, Kuria and Mombasa. Accessions Bungoma, GBK-027212, Baringo, GBK-031850, GBK-032210 and GBK-040449 had significantly higher stem girth than commercial variety (saga), and accessions Nandi, Mombasa, Kisii, Kuria, Kakamega and GBK-032340 at 40% FC. Accession Mombasa had significantly lower stem girth than most accessions and commercial variety (saga). Accession Bungoma had the highest stem girth (3.5 cm) at 40%FC while accession Mombasa had the lowest stem girth (1.6 cm) at 40% FC. Generally, genebank genotypes had high stem girth across all moisture levels.

**Table 4.2: Effects of moisture level (%field capacity) on stem girth (cm) of 14 spider plant accessions at 50% flowering**

<b>Accessions</b>	<b>100%FC</b>	<b>80%FC</b>	<b>60%FC</b>	<b>40%FC</b>	<b>Means</b>
Baringo	3.8	3.6	3.4	3.0	3.5
Bungoma	4.5	4.4	3.9	3.5	4.1
GBK-027212	4.6	4.5	3.8	3.0	4.0
GBK-031850	4.2	3.9	3.6	2.9	3.7
GBK-032210	4.7	4.5	3.5	2.9	3.9
GBK-032340	3.4	3.1	2.9	2.0	2.9
GBK-040449	4.5	4.2	2.8	2.7	3.5
Homabay	3.4	3.2	2.6	2.1	2.8
Kakamega	3.5	3.4	2.7	2.4	3.0
Kisii	3.3	3.2	2.5	2.5	2.9
Kuria	3.8	3.6	2.7	2.5	3.2
Mombasa	3.0	2.4	1.8	1.6	2.2
Nandi	3.4	3.2	2.7	2.2	2.9
Commercial (saga)	3.8	3.5	3.1	2.5	3.2
<b>Means</b>	3.9	3.6	3.0	2.6	3.3
P-Value (A)	<.001				
P-Value (ML)	<.001				
P-Value (A×ML)	<.001				
LSD <sub>≤0.05</sub> (A)	0.1**				
LSD <sub>≤0.05</sub> (ML)	0.1**				
LSD <sub>≤0.05</sub> (A×ML)	0.3**				
CV%	5.4				

LSD- Least significant difference, \*\*highly significant, \* A-accession, ML- moisture level, FC-field capacity

#### **4.3.3 Effect of water stress on number of leaves per spider plant**

Accession, moisture level and accession x moisture level significantly influenced the number of spider plant leaves per plant (Table 4.3). Reduction in moisture level to 80% and below significantly



reduced the number of leaves per spider plant for all accessions except Kakamega and Mombasa. Reduction of moisture level from 100% FC to 80% FC did not significantly reduce the number of leaves per plant in accessions Kakamega and Mombasa. Reduction of moisture level from 100% FC to 40%, 80% to 60%, and 60% to 40% FC significantly reduced the number of spider plant leaves per plant in all accessions. Water stress reduced the number of spider plant leaves per plant by 25.7%, 55.1%, and 74.2% at 80%, 60% and 40% FC respectively. Water stress reduced the number of leaves from 13.1% to 63.8% with decline in moisture level from 100% to 40% FC. At 100 % FC, accession Homabay and Kuria recorded a higher leaf number per plant than the commercial variety (saga) while at 40 % FC accessions Kuria and Mombasa recorded a higher leaf number of leaves per plant than the commercial variety (saga). Average number of leaves per plant ranged from 70.82 (GBK-031850) to 112.75 (Kuria). Accession Kuria recorded the highest number of leaves at all moisture levels.

**Table 4.3: Effects of moisture level (%field capacity) on number of leaves per plant of 14 spider plant accessions at vegetative phase**

<b>Accessions</b>	<b>100%FC</b>	<b>80%FC</b>	<b>60%FC</b>	<b>40%FC</b>	<b>Means</b>
Baringo	105.2	92.7	86.4	66.8	87.8
Bungoma	98.0	80.9	65.4	59.0	75.8
GBK-027212	95.8	90.1	74.3	59.9	80.0
GBK-031850	87.8	81.4	65.8	48.4	70.8
GBK-032210	118.2	96.0	75.9	60.3	87.6
GBK-032340	97.0	85.8	71.2	35.1	72.3
GBK-040449	93.7	83.5	63.4	51.8	73.1
Homabay	136.5	99.1	76.7	58.9	92.8
Kakamega	96.0	97.4	77.5	62.9	83.4
Kisii	102.6	89.1	80.1	63.6	83.9
Kuria	146.9	115.6	99.5	89.0	112.8
Mombasa	93.5	91.5	87.4	81.3	88.4
Nandi	93.0	85.1	66.9	46.9	73.0
Commercial (saga)	115.6	87.3	80.0	62.7	86.4
<b>Means</b>	<b>105.7</b>	<b>91.1</b>	<b>76.5</b>	<b>60.5</b>	<b>83.4</b>
P-Value (A)	<.001				
P-Value (ML)	<.001				
P-Value (A×ML)	<.001				
LSD <sub>≤0.05</sub> (A)	2.8**				
LSD <sub>≤0.05</sub> (ML)	1.5**				
LSD <sub>≤0.05</sub> (A×ML)	5.6**				
CV%	4.1				

LSD- Least significant difference, \*\*highly significant, A-accession, ML- moisture level FC-field capacity

#### 4.3.4 Effect of water stress on single leaf area of spider plant

Accession, moisture level and accession x moisture level significantly ( $P \leq 0.05$ ) affected spider plant single leaf area (Table 4.4). Single leaf area significantly decreased with decline in moisture level for most of the genotypes. Accession Kakamega had a higher single leaf area than all the other spider plant genotypes at 100%, 80% and 60% FC while accession Mombasa had a lower single leaf area than all other genotypes at all moisture levels. Commercial variety (saga) and accessions Kisii and Bungoma were less responsive to reduction in moisture level than most of the other spider plant genotypes. Water stress reduced single leaf area by 11.8%, 22.4% and 31.0% at 80%FC, 60%FC and 40%FC, respectively. Average single leaf area ranged from 5.2 cm<sup>2</sup> (Mombasa) to 8.7 cm<sup>2</sup> (Kakamega). Average decrease in single leaf area ranged from 1.1 cm<sup>2</sup> (Kisii) to 5.3 cm<sup>2</sup> (Kakamega) with reduction of moisture level from 100%FC to 40%FC.

**Table 4.4: Effects of moisture level (%field capacity) on single leaf area of 14 spider plant accessions at vegetative phase**

Accessions	100%FC	80%FC	60%FC	40%FC	Mean
Baringo	7.4	6.9	6.3	5.7	6.5
Bungoma	8.4	7.1	6.7	6.4	7.1
GBK-027212	9.5	7.7	6.9	6.1	7.5
GBK-031850	8.4	7.8	6.3	5.5	7.0
GBK-032210	8.6	7.6	6.6	6.1	7.2
GBK-032340	9.0	8.0	6.0	5.3	7.1
GBK-040449	9.4	8.0	7.3	6.8	7.9
Homabay	8.8	8.0	6.8	6.0	7.4
Kakamega	11.5	9.2	7.8	6.2	8.7
Kisii	7.0	7.1	6.8	5.9	6.7
Kuria	8.2	7.3	6.4	5.9	7.0
Mombasa	6.3	5.4	5.0	4.2	5.2
Nandi	7.0	6.6	5.7	4.8	6.0
Commercial (saga)	8.4	7.6	7.1	6.7	7.4
<b>Mean</b>	8.4	7.4	6.5	5.8	7.1
P-Value (A)	<.001				
P-Value (ML)	<.001				
P-Value (A×ML)	<.001				
LSD <sub>≤0.05</sub> (A)	0.2**				
LSD <sub>≤0.05</sub> (ML)	0.1**				
LSD <sub>≤0.05</sub> (A×ML)	0.5**				
CV%	4.0				

LSD- Least significant difference, \*\*highly significant, FC- field capacity. A-accession, ML- moisture level.

#### 4.3.5 Effect of water stress on number of days to flowering of spider plant

Accession, moisture level and accession x moisture level significantly ( $P \leq 0.05$ ) affected the number of days to flowering in spider plant (Table 4.5). Reduction of moisture level from 100% FC to 40% FC significantly reduced the number of days to flowering in all accessions except accessions Nandi and GBK-032210. Reduction of moisture level from 80% FC to 60% FC significantly reduced the number of days to flowering for accession Baringo but had no effect on all the other genotypes. Accessions Kisii recorded the lowest number of days to flowering at 100%, 80%, 60% and 40% FC while accession Nandi recorded the highest average number of days to flowering at 80%, 60% and 40% FC. Compared to control (100% FC), water stress reduced days to flowering by 4.7%, 6.8% and 9.7% at 80%, 60% and 40% FC respectively. Reduction of moisture from 100% to 40% FC increased the number of days to flowering by 1.3 days in Nandi and 1.7 days in GBK-032210.

**Table 4.5: Effects of moisture level (% field capacity) on days to flowering of 14 spider plant accessions**

Accessions	100%FC	80%FC	60%FC	40%FC	Means
Baringo	37.3	36.7	34.7	30.0	34.7
Bungoma	39.3	36.0	34.7	33.7	35.9
GBK-027212	39.0	38.7	37.7	36.3	36.8
GBK-031850	38.3	34.7	33.7	33.3	35.0
GBK-032210	40.0	38.7	38.3	41.7	39.7
GBK-032340	41.3	34.7	35.7	33.7	36.3
GBK-040449	36.3	35.3	33.7	33.0	34.6
Homabay	37.7	35.7	34.7	33.7	35.4
Kakamega	37.3	33.7	33.3	32.0	34.1
Kisii	33.0	31.0	30.7	29.7	31.1
Kuria	36.3	34.0	33.7	32.7	34.2
Mombasa	35.0	34.7	33.7	33.3	34.2
Nandi	38.0	41.7	41.3	39.3	40.1
Commercial (saga)	38.7	37.7	36.3	34.3	36.8
<b>Means</b>	37.7	35.9	35.1	34.1	35.7
P-Value (A)	<.001				
P-Value (ML)	<.001				
P-Value (A×ML)	<.001				
LSD <sub>≤0.05</sub> (A)	0.8**				
LSD <sub>≤0.05</sub> (ML)	0.4**				
LSD <sub>≤0.05</sub> (A×ML)	1.6**				
CV%	0.9				

LSD- Least significant difference, \*\*highly significant, FC- field capacity. A-accession, ML- moisture level.

#### 4.3.6 Effect of water stress on chlorophyll content of spider plant

Accession, moisture level and accession x moisture level significantly affected the chlorophyll content in spider plant (Table 4.6). At 100% and 80% FC, accessions Kuria and Homabay recorded the highest chlorophyll content while accession Baringo had the highest chlorophyll content at 60 and 40% FC. At moisture level 60% FC, water stress significantly reduced chlorophyll content in all accessions except for accessions Baringo and Mombasa while at 40% FC, water stress significantly reduced chlorophyll content of most genebank accessions. At 100%, 80% and 60% FC, accessions Homabay and Kuria recorded a significantly higher chlorophyll content than the commercial variety (saga) and other accessions evaluated in the study. At 60% FC, accession Baringo recorded the highest chlorophyll content. At 40% FC, accessions Baringo and Kakamega recorded a significantly higher chlorophyll content than the commercial variety (saga) other accessions.

**Table 4.6: Effects of moisture level (% field capacity) on SPAD value of 14 spider plant accessions at vegetative phase**

Accessions	100%FC	80%FC	60%FC	40%FC	Means
Baringo	77.7	70.7	72.3	65.3	71.5
Bungoma	71.0	67.7	46.6	36.0	55.3
GBK-027212	70.7	63.3	53.1	43.0	57.5
GBK-031850	56.3	51.2	40.0	37.7	46.3
GBK-032210	57.6	52.1	43.3	41.6	48.6
GBK-032340	68.0	55.9	45.8	43.1	53.2
GBK-040449	66.3	55.9	44.6	39.7	51.6
Homabay	86.0	80.3	62.7	46.4	68.8
Kakamega	67.0	57.4	50.2	49.7	56.1
Kisii	76.0	64.0	49.2	39.9	57.3
Kuria	86.7	77.3	67.0	42.4	68.3
Mombasa	54.0	46.3	43.0	36.8	45.0
Nandi	61.7	54.7	49.5	37.7	50.9
Commercial (saga)	83.0	74.3	52.7	47.5	64.4
<b>Means</b>	70.1	62.2	51.4	43.3	56.8
P-Value (A)	<.001				
P-Value (ML)	<.001				
P-Value (A×ML)	<.001				
LSD <sub>≤0.05</sub> (A)	2.1**				
LSD <sub>≤0.05</sub> (ML)	1.1**				
LSD <sub>≤0.05</sub> (A×ML)	4.1**				
CV%	4.5				

LSD- Least significant difference, \*\*highly significant, FC- field capacity. A-accession, ML-moisture level.

#### 4.3.7 Effect of water stress on leaf relative water content of spider plant accessions

Accession, moisture level and accession x moisture level significantly ( $P \leq 0.05$ ) affected leaf relative content in spider plant (Table 4.7). At moderate stress of 60% FC, accession Baringo recorded the highest leaf relative water content of 73.4. Reduction of moisture level from 100% FC to 80% FC did not have a significant effect on leaf relative water content for accessions GBK-032210, GBK-032340, Homabay, Kakamega, Kuria, Mombasa and Nandi. Reduction of moisture level from 80% to 60% significantly reduced leaf relative water for all accessions except for accessions Homabay and Mombasa. Reduction of moisture level from 60% to 40% FC had no effect on leaf relative water content of accessions GBK-027212, GBK-040449, Homabay, Kisii, Kuria, Mombasa and Nandi but significantly reduced leaf relative water content for the rest of the accessions. At 80% FC, accessions GBK-032210 and Kakamega had higher leaf relative water content than the commercial variety (saga).

**Table 4.7: Effects of moisture level (% field capacity) on leaf relative water content of 14 spider plant accessions at vegetative phase**

Accessions	100%FC	80%FC	60%FC	40%FC	Means
Baringo	89.2	78.1	73.4	57.5	74.6
Bungoma	87.4	72.9	61.7	47.4	67.3
GBK-027212	70.2	62.3	45.8	40.1	54.6
GBK-031850	73.8	62.9	55.8	46.9	59.8
GBK-032210	90.5	85.6	67.2	57.3	75.1
GBK-032340	65.1	62.5	51.7	40.6	55.0
GBK-040449	87.9	77.1	65.9	60.6	72.9
Homabay	64.5	63.0	61.6	59.7	62.2
Kakamega	91.0	87.0	64.6	47.4	72.5
Kisii	87.6	72.5	38.8	36.0	58.7
Kuria	81.3	75.3	50.9	49.6	64.3
Mombasa	66.4	64.6	61.4	58.5	62.7
Nandi	69.9	65.4	57.6	54.5	61.7
Commercial (saga)	86.4	78.9	63.9	48.2	69.4
<b>Means</b>	79.4	72.0	58.6	50.3	65.1
P-Value (A)	<.001				
P-Value (ML)	<.001				
P-Value (A×ML)	<.001				
LSD <sub>≤0.05</sub> (A)	3.3**				
LSD <sub>≤0.05</sub> (ML)	1.7**				
LSD <sub>≤0.05</sub> (A×ML)	6.5**				
CV%	0.8				

LSD- Least significant difference, \*\*highly significant, FC-field capacity. A-accession, ML- moisture level.

Accession Baringo had higher leaf relative water content than the commercial variety (saga) at 40 % FC and 60% FC while accessions Homabay and Mombasa had higher leaf relative water content than the commercial variety (saga) at 40 % FC.

#### 4.3.8 Effect of water stress on leaf senescence in spider plant accessions

Accession, moisture level and accession x moisture level significantly ( $P \leq 0.05$ ) affected the leaf senescence in spider plant (Table 4.8). Accession Mombasa was not significantly affected by reduction of moisture level from 100% FC to 40% FC. Reduction of moisture level to 80% FC did not significantly affect commercial variety and accessions Baringo, GBK-040449, Homabay, Kisii, and Nandi. Accessions Bungoma, GBK-032340, and Nandi were not significantly affected by reduction of moisture level from 80% to 60% FC. Reduction of moisture level from 60% to 40% significantly increased leaf senescence in all accessions except in accession Mombasa. At medium stress of 60% FC, accession Mombasa and Nandi recorded the lowest number of senesced leaves with decline in moisture level to 40%FC.

**Table 4.8: Effects of moisture level (% field capacity) on leaf senescence of 14 spider plant accessions**

Accessions	100%FC	80%FC	60%FC	40%FC	Means
Baringo	2.3	3.7	8.0	12.3	6.6
Bungoma	2.3	4.7	6.3	11.3	6.2
GBK-027212	4.0	7.7	13.0	16.7	10.3
GBK-031850	4.3	7.0	12.7	16.3	10.1
GBK-032210	3.3	5.7	8.3	14.7	8.0
GBK-032340	4.7	7.7	8.3	15.0	8.9
GBK-040449	2.0	3.0	7.0	12.0	6.0
Homabay	3.0	4.7	7.0	14.3	7.3
Kakamega	3.7	7.7	12.3	14.7	9.5
Kisii	4.7	5.7	8.3	10.3	7.3
Kuria	2.3	4.7	7.0	13.3	6.8
Mombasa	1.3	2.0	3.3	4.7	2.8
Nandi	2.7	3.7	4.7	7.0	4.5
Commercial	2.3	4.0	7.3	12.0	6.5
<b>Means</b>	3.1	5.2	8.2	12.5	7.2
P-Value (A)	<.001				
P-Value (ML)	<.001				
P-Value (A×ML)	<.001				
LSD <sub>≤0.05</sub> (A)	0.8**				
LSD <sub>≤0.05</sub> (ML)	0.5**				
LSD <sub>≤0.05</sub> (A×ML)	1.7**				
CV%	14.3				

LSD- Least significant difference, \*\*highly significant, FC- field capacity. A-accession, ML- moisture level.

#### 4.3.9: Effect of water stress on spider plant leaf yield

Accession, moisture level and accession x moisture level significantly ( $P \leq 0.05$ ) affected spider plant leaf yield (Table 4.9). Leaf yield per plant significantly reduced with increase in reduction of moisture levels except for accessions GBK-027212, GBK-031850, Kuria, Mombasa and Nandi. Reduction of moisture level from 100% to 80% FC did not significantly reduce leaf yield for accessions GBK-027212, GBK-031850, Mombasa and Nandi while reduction of moisture levels from 80% to 60% FC had no significant effect on accession Mombasa. Reduction of moisture level from 60% to 40% FC did not significantly reduce leaf yield for accessions Kuria, Mombasa and Nandi. Average leaf yield ranged from 7.6  $\text{tha}^{-1}$  (Mombasa) to 18.2  $\text{tha}^{-1}$  (GBK-032210). At 100 % FC accessions GBK-032210 and GBK-040449 recorded higher leaf yield than the commercial variety (saga) while at 40% FC accessions GBK-031850, GBK-032210 and Kakamega recorded a significantly lower leaf yield than the commercial variety (saga). At 80%FC, commercial variety (saga) had higher leaf yield than accessions GBK-031850, GBK-040449 and Kakamega.

**Table 4.9: Effects of moisture level (%field capacity) on leaf yield (tonnes) of 14 spider plant accessions at vegetative phase**

Accessions	100%FC	80%FC	60%FC	40%FC	Means
Baringo	19.0	15.4	10.0	5.3	12.4
Bungoma	18.4	12.4	8.9	5.4	11.3
GBK-027212	17.4	14.9	8.2	4.7	11.3
GBK-031850	12.0	22.6	12.9	8.2	13.9
GBK-032210	33.2	18.4	12.9	8.3	18.2
GBK-032340	22.1	18.4	6.9	2.9	12.6
GBK-040449	29.2	20.4	8.3	5.0	15.7
Homabay	25.2	15.7	9.7	6.0	14.1
Kakamega	28.6	20.5	12.7	8.6	17.6
Kisii	22.0	18.4	13.1	4.4	14.5
Kuria	23.1	14.1	8.6	6.3	13.0
Mombasa	10.7	8.3	6.6	4.7	7.6
Nandi	11.6	10.4	6.3	3.4	7.9
Commercial (saga)	26.1	16.0	11.3	5.4	14.7
<b>Means</b>	21.3	16.1	9.7	5.6	12.8
P-Value (A)	<.001				
P-Value (ML)	<.001				
P-Value (A×ML)	<.001				
LSD $_{\leq 0.05}$ (A)	1.3**				
LSD $_{\leq 0.05}$ (ML)	0.7**				
LSD $_{\leq 0.05}$ (A×ML)	2.7**				
CV%	12.8				

LSD- Least significant difference, \*\*highly significant, FC-field capacity. A-accession, ML- moisture level.

#### 4.3.10: Effects of water stress on number of spider plant seeds per pod

Accession, moisture level and accession x moisture level significantly ( $P \leq 0.05$ ) affected the number of spider plant seeds per pod (Table 4.10). Reduction of moisture level from 100% to 80% FC, significantly reduced the number of seeds per pod for accessions GBK-027212, Mombasa and Nandi. Accessions GBK-032340, Kakamega, Kisii, and Nandi were significantly affected by reduction of moisture level from 80% to 60% FC. Reduction of moisture level from 60% FC to 40% FC caused a significant reduction in number of seeds per pod in accessions GBK-032340, GBK-040449 and Mombasa. Water stress reduced the number of seeds by 16.7%, 30.4% and 44.6% at 80%, 60% and 40% FC, respectively, compared to the control (100%FC). Water stress reduced the number of seeds per pod by 10.1% (Nandi) to 50.9% (Mombasa) with decline in moisture level from 100%FC to 40%FC. Accession Baringo had higher number of seed per pod than the commercial variety at 100% and 80% FC. At 40%FC, accessions Baringo, Bungoma and Kakamega had higher number of seeds per pod than the commercial variety (saga).

**Table 4.10: Effects of moisture level (% field capacity) on number of seeds per pod of 14 spider plant accessions at harvesting stage**

Accessions	100%FC	80%FC	60%FC	40%FC	Means
Baringo	178.2	135.3	90.6	75.0	119.8
Bungoma	119.9	107.3	93.3	77.9	99.6
GBK-027212	94.6	89.1	72.8	61.6	79.5
GBK-031850	102.5	77.1	70.1	50.9	75.1
GBK-032210	91.1	88.6	74.8	63.3	79.4
GBK-032340	81.7	71.1	64.8	60.5	69.5
GBK-040449	95.6	74.3	67.4	61.1	74.6
Homabay	89.2	68.1	55.7	43.4	64.1
Kakamega	126.0	88.7	83.4	69.7	91.9
Kisii	115.7	93.9	89.4	66.4	91.4
Kuria	96.6	87.4	66.5	42.2	73.2
Mombasa	51.3	45.6	25.2	18.5	35.2
Nandi	88.6	81.8	79.6	68.2	79.6
Commercial (saga)	152.6	127.0	98.4	62.6	110.1
<b>Means</b>	106	88.2	73.7	58.7	81.6
P-Value (A)	<.001				
P-Value (ML)	<.001				
P-Value (A×ML)	<.001				
LSD <sub>≤0.05</sub> (A)	3.4**				
LSD <sub>≤0.05</sub> (ML)	1.8**				
LSD <sub>≤0.05</sub> (A×ML)	6.8**				
CV%	5.1				

LSD- Least significant difference, \*\*highly significant, FC- field capacity. A-accession, ML- moisture level.



Accession Mombasa (35.2) recorded the lowest number of seeds per pod while accessions Baringo (119.8) and Commercial variety-saga (110.12) recorded the highest number of seeds per pod. Average number of seeds per pod ranged from 105.0 (100%FC) to 58.7 (40%FC). On average, accessions Baringo, commercial variety (saga), Bungoma, Kakamega, and Kisii recorded the highest number of seeds per pod.

#### 4.3.11: Effect of water stress on seed yield

Accession, moisture level and accession x moisture level significantly ( $P \leq 0.05$ ) affected seed yield (Table 4.11). All accessions, except accession Mombasa, were significantly affected by reduction of moisture level from 100% to 80%FC. Reduction of moisture level from 60% to 40% FC did not significantly reduce in seed yield for accessions Baringo, Bungoma, GBK-027212, GBK-040449, Homabay, Mombasa and Nandi. At 60% FC, accessions Kakamega ( $0.7 \text{ t ha}^{-1}$ ) and Kuria ( $0.7 \text{ t ha}^{-1}$ ) recorded highest seed yield than all other genotypes except the commercial variety (saga) that recorded the higher seed yield at 100% FC ( $3.3 \text{ t ha}^{-1}$ ) and at 80 % FC ( $1.8 \text{ t ha}^{-1}$ ).

**Table 4.11: Effects of moisture level (% field capacity) on seed yield (t/ha) of 14 spider plant accessions at harvesting stage**

Accessions	100%FC	80%FC	60%FC	40%FC	Means
Baringo	2.8	1.3	0.3	0.1	1.1
Bungoma	2.1	1.4	0.4	0.2	1.0
GBK-027212	1.0	0.6	0.2	0.1	0.5
GBK-031850	1.9	1.0	0.4	0.1	0.9
GBK-032210	2.0	1.2	0.6	0.3	1.0
GBK-032340	1.4	0.9	0.4	0.1	0.7
GBK-040449	1.7	0.9	0.4	0.2	0.8
Homabay	2.0	0.7	0.3	0.1	0.8
Kakamega	1.9	1.1	0.7	0.3	1.0
Kisii	2.2	1.2	0.5	0.2	1.0
Kuria	2.2	1.4	0.7	0.3	1.1
Mombasa	0.6	0.4	0.1	0.1	0.3
Nandi	1.2	0.8	0.3	0.2	0.6
Commercial (saga)	3.3	1.8	0.5	0.2	1.4
<b>Means</b>	1.9	1.1	0.4	0.2	0.9
P-Value (A)	<.001				
P-Value (ML)	<.001				
P-Value (A×ML)	<.001				
LSD <sub>≤0.05</sub> (A)	0.9**				
LSD <sub>≤0.05</sub> (ML)	0.1**				
LSD <sub>≤0.05</sub> (A×ML)	0.2**				
CV%	12.3				

LSD- Least significant difference, \*\*highly significant, FC- field capacity. A-accession, ML- moisture level

Commercial variety (saga) and accessions Baringo, Kuria, and Kisii had significantly higher seed yield than other accessions evaluated.

#### 4.4: Correlation among spider plant traits

There was a strong significant positive correlation between number of leaves with plant height ( $r=0.71$ ) and leaf relative water content ( $r=0.64$ ) and a significant negative correlation with number of senescing leaves ( $r=-0.69$ ). Number of senescing leaves also recorded a significant negative correlation with leaf relative water content ( $r=-0.68$ ). Single leaf area had a significant positive correlation with plant height ( $r=0.73$ ), and leaf relative water content ( $r=0.62$ ). Chlorophyll content (SPAD value) recorded a significant positive correlation with plant height ( $r=0.74$ ), single leaf area ( $r=0.58$ ), and leaf relative water content ( $r=0.61$ ) and a negative significant correlation with number of senescence leaves ( $r=-0.58$ ) (Table 4.12).

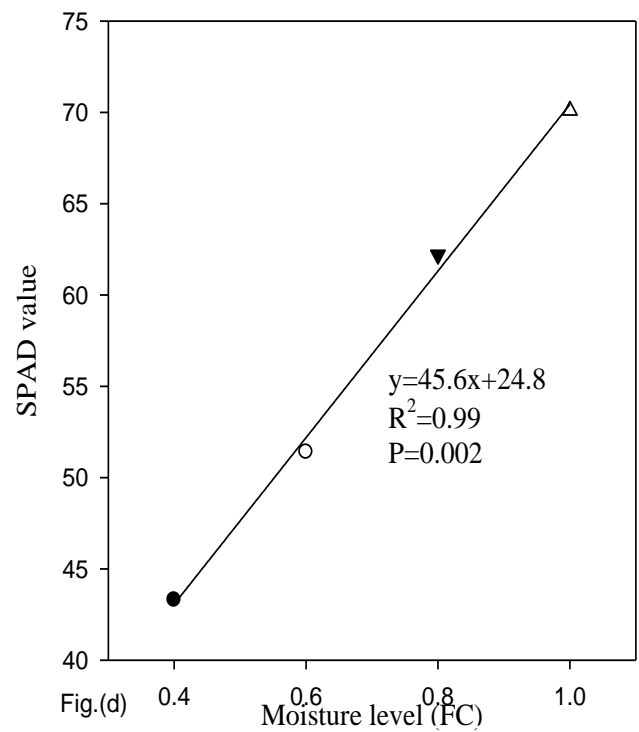
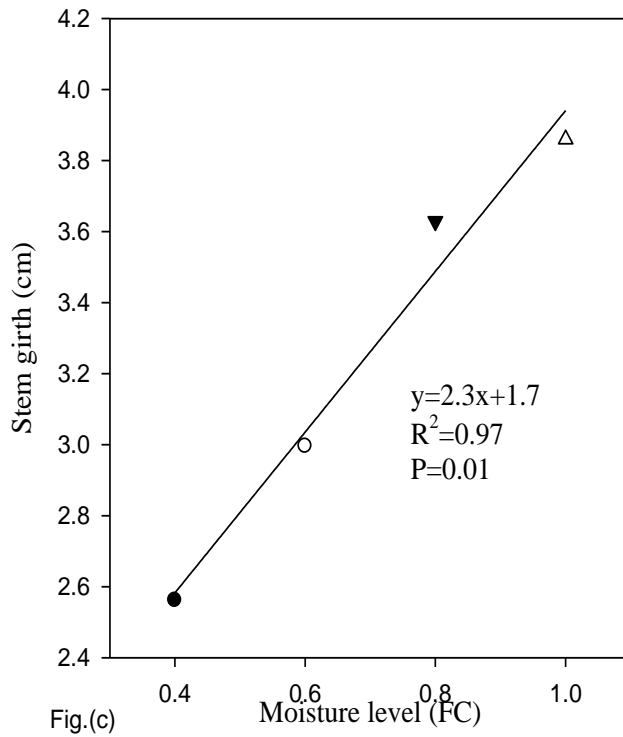
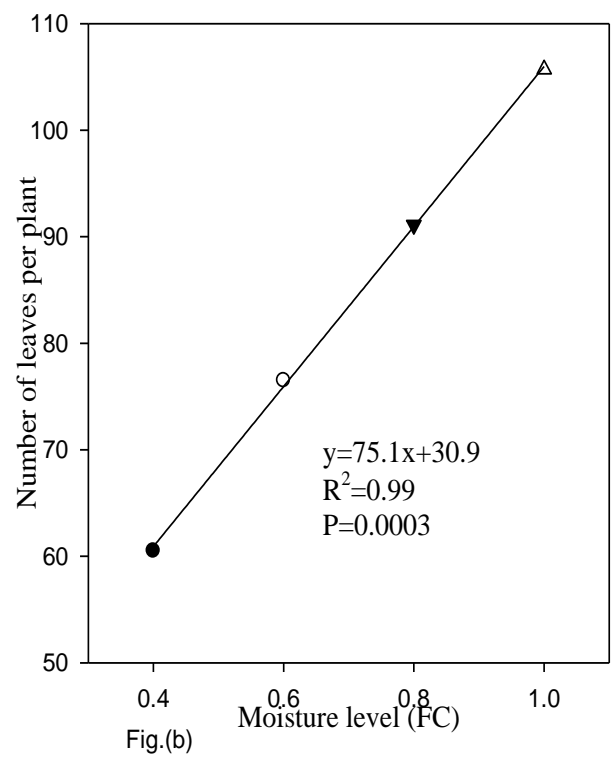
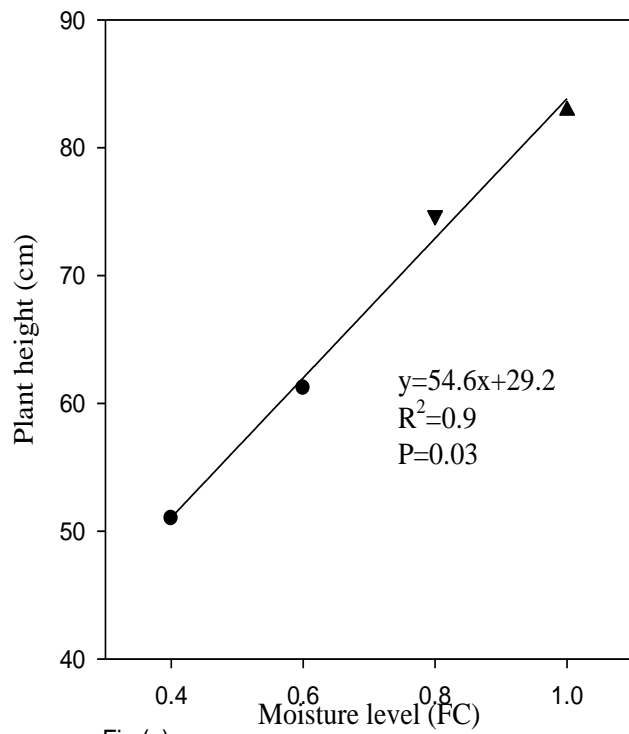
**Table 4.12: Correlation coefficient table for the quantitative traits recorded for 14 accessions of spider plant**

	DTF	PH	LRWC	NLP	NSL	SLA	SPAD
DTF	-						
PH	0.33	-					
LRWC	0.36	0.66	-				
NLP	0.25	0.71**	0.64*	-			
NSL	-0.37	-0.51	-0.68*	-0.69*	-		
SLA	0.32	0.73**	0.62*	0.57	-0.43	-	
SPAD	0.23	0.74**	0.61*	0.78**	-0.58	0.58*	-

DTF- Days to 50 % flowering PH –Plant height (cm), LRWC-Leaf relative water content, NLP-Number of leaves per plant, NSL- Number of senesced leaves per plant, SLA-Single leaf area (cm<sup>2</sup>), SPAD Value/Chlorophyll content, \*\* Correlation is significant at  $P \leq 0.01$  level, \*correlation is significant at  $P \leq 0.05$  level

#### 4.5 Relationship between available moisture level and plant height, number of leaves, stem girth, chlorophyll content, single leaf area, number of pods, leaf yield and seed yield

There was a significantly highly positive linear regression relationship between water stress levels and plant height, number of leaves per plant, stem girth, chlorophyll content, single leaf area, number of pods per plant, leaf yield and seed yield (Fig.1 (a-d) and Fig.2 (a-d) The relationship between water stress level and these parameters recorded an  $R^2$  of between 0.90-0.99. Number of leaves, chlorophyll content and single leaf area and leaf yield recorded a significantly higher relationship with increased water stress level,  $R^2$  of 0.99. Plant height, stem girth, number of pods and seed yield recorded an  $R^2$  of 0.90, 0.97, 0.98 and 0.93, respectively.



**Figure 1 (a-d) shows linear regression relationship between soil moisture level and plant height, number of leaves per plant, stem girth and SPAD value.**

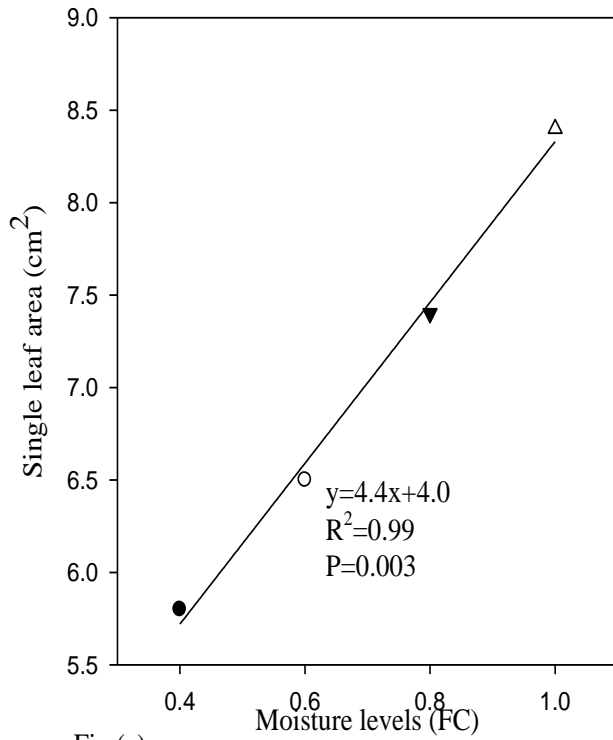


Fig.(a)

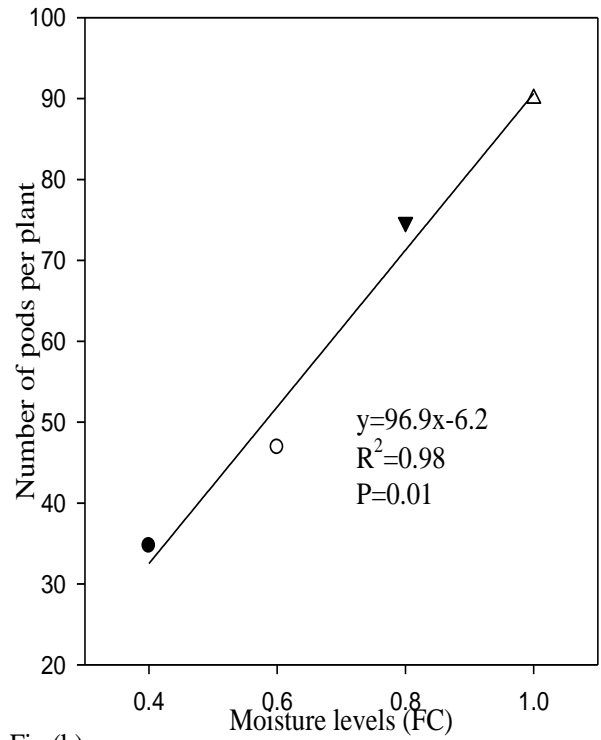


Fig.(b)

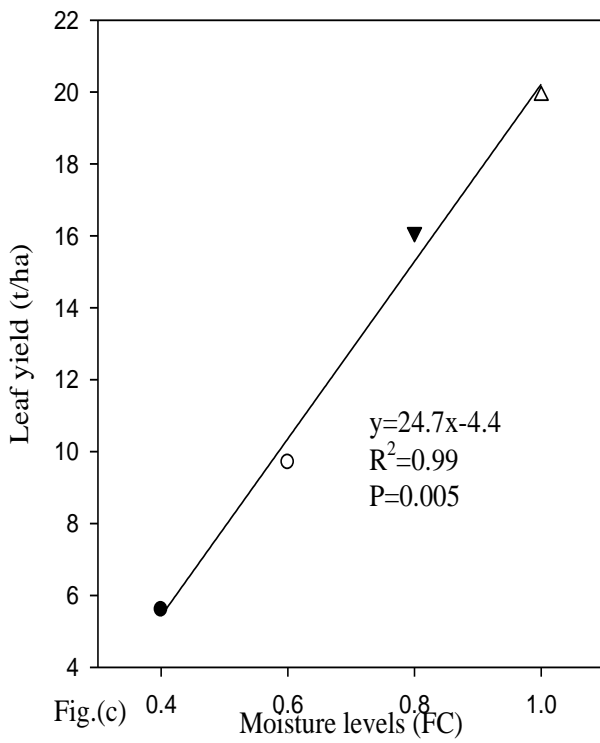


Fig.(c)

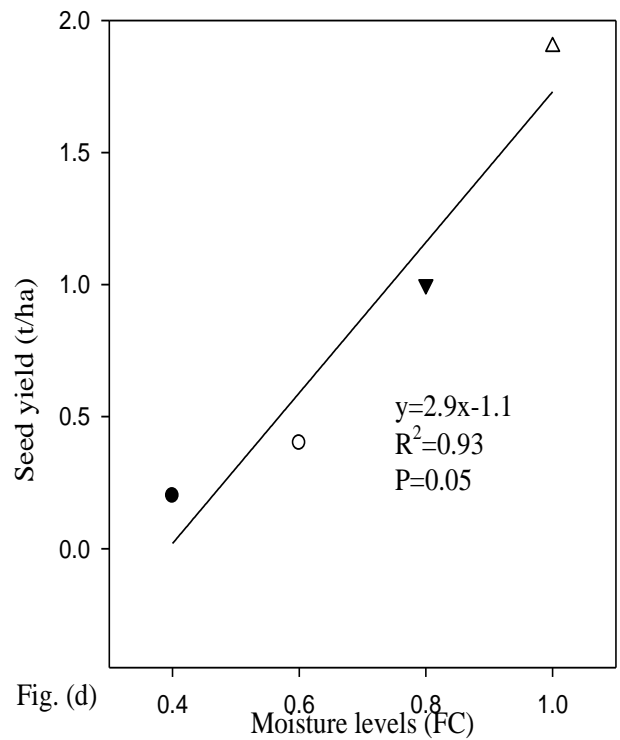


Fig.(d)

**Figure 2 (a-d) shows linear regression relationship between soil moisture level and single leaf area, number of pods per plant, leaf yield and seed yield.**

## 4.6 Discussion

Plant height decreased by 38.49% with reduction in moisture level from 100% to 40% FC. Linear regression analysis showed that increase in water stress level corresponded to a decrease in plant height. This may be attributed to negative effects of drought stress on cell expansion and elongation (Manivannan *et al.*, 2007; Jaleel *et al.*, 2009). Numerous studies have reported significant decrease in plant height due to drought stress. Aguyoh *et al.*, (2013) noted that plant height in tomato plant reduced by 22.3% with reduction in moisture level.

Effect of water stress level on stem girth varied significantly with spider plant accessions. The high variability denotes variations in adaptability to water stress among genotypes. Reduction in moisture level resulted in average reduction of stem girth by 33.3%. This may be attributed to shrinking of the stem diameter due to alterations in cell turgidity as a result of water stress. Moisture stress reduces cell growth rate and sizes of the stem hence resulting to thinner stems than when there is enough water supply (Amina *et al.*, 2014). Masinde *et al.*, (2005) reported that maximum spider plant stem diameter and leaf area were recorded in well-watered conditions, which gradually reduced with increasing water stress in spider plant. Stem girth is an important trait that determines lodging in plants. Reduction in stem girth results to increased lodging in plants and alters growth habit of the plant (Gunes *et al.*, 2006). The interaction between the spider plant accessions and moisture stress level was significant. Reduction of moisture level from 80% to 60% FC significantly reduced stem girth in accessions Baringo, GBK-032210, GBK-032340 and GBK-040449 whereas reduction of moisture level from 60% to 40% FC significantly reduced stem diameter in accessions GBK-040449, Kisii, Kuria and Mombasa compared to commercial variety (saga) and other accessions.

Number of days to flowering was significantly affected by water stress. This may be attributed to the fact that drought alters initiation and duration of the processes involved in conversion of vegetative meristems into floral parts. Prasad *et al.*, (2008) reported that moderate drought reduces the length of time from flowering to anthesis to avoid drought which was the case for most accessions in the current study. However, it might be increased under severe water stress as recorded in GBK-032210 whose time to flowering was increased by 1.7 days. Similar findings were recorded by Craufurd and Peacock (1993) in sorghum the flowering was delayed by 59 days under severe drought stress. Response to water stress level with respect to number of days to flowering varied with spider plant genotypes, from 31.1 (Kisii) to 40.1 (Nandi). These variations may be attributed to the fact that the accessions were sourced from different agro-ecological zones with varying moisture stress conditions.

Single leaf area significantly decreased with decline in moisture level for most of the genotypes. Severe drought stress (FC<40%) led to a significant reduction in spider plant single leaf area by 30.97%. Leaf growth and development have been reported to be sensitive to moisture stress. This may be attributed to rapid reduction of transpiration in leaves which is a drought avoidance mechanism usually associated with water conservation (Dosmann *et al.*, 1999). These results are in agreement with Lopez *et al.*, (1997) who noted that leaf area of pigeon pea decreased by 22.5% with reduction in moisture level. Impact of water stress on single leaf area was dependent on the accessions and moisture level. Commercial variety and accessions Kisii and Bungoma were less responsive to reduction in moisture level than most of the other spider plant genotypes. Accession Kakamega recorded a higher single leaf area in moisture level at 100%, 80% and 60% FC than all other accessions. Accession Kakamega can be a suitable candidate for developing spider plant variety for vegetable production in water limited areas.

Water stress reduced chlorophyll content by 38.2 % across all accessions. Reduction in chlorophyll content due to drought may be attributed to destruction of the pigment protein complexes which protect the photosynthetic apparatus or oxidative damage of chloroplast, lipids and proteins resulting in reduced synthesis of chlorophyll a, b and carotenoids (Huang *et al.*, 2013). These findings agreed with those of Amira (2015), and Heba and Samia (2014) who reported that reduction in chlorophyll content under water stress is a universally observed phenomenon. SPAD value varied significantly from accession Baringo (71.5) to Mombasa (45.0) while across the moisture levels SPAD value varied significantly from 43.3 at 40% FC to 70.1 at 100% FC. The interaction between spider plant genotypes and moisture stress level was significant. At moisture level 60% FC, water stress significantly reduced chlorophyll content in all accessions except for accessions Baringo and Mombasa while at 40% FC, water stress significantly reduced chlorophyll content of most genebank accessions such as GBK-027212 and GBK-040449. This may be attributed to collection of genotypes from different ecological zones that exhibit varying moisture levels resulting to variations in adaptability to water stress among the genotypes.

Leaf relative water content significantly decreased with increasing drought. Across the moisture levels, leaf relative water content varied from 50.3 at 40% FC to 79.4 at 100% FC. This finding is in agreement with that of Lagat *et al.* (2016) who established that relative water content of eggplant decreased with reduction in moisture level. In their study, they observed that leaf relative water content ranged from 88.4% in well-watered plants to 43.8% in water stressed eggplants. Amira (2015) also found similar results in soybean leaves. Leaf relative water content varied with

spider plant accessions and moisture levels. Among the accessions, leaf relative water content varied from accession GBK-027212 (54.6) to accession GBK-032210 (75.1). This denotes different adaptability to water stress among spider plant accession. The interaction between the spider plant accessions and moisture stress level was significant. At moderate water stress (60% FC), accession Baringo had higher leaf relative water content than the commercial variety (saga) while at severe water stress (40% FC), accessions Baringo, Homabay and Mombasa had higher leaf relative water content than the commercial variety (saga). The higher relative water content reported for most farmers' accessions compared to commercial variety (saga) may be attributed to the presence of drought resistant genes possibly due to the fact that farmers' accessions have not yet undergone selection pressure that may lead to loss of traits for drought adaptability. Masinde *et al.* (2005) reported similar findings in spider plant genotypes and a commercial variety (saga). Reduction of leaf relative water content with drought intensification is aimed at increasing the sap concentration of the leaf that result in increased osmotic pressure. This in turn results to osmotic adjustment of the leaf, which is a mechanism that adapts the plant to drought stress (Kirnak *et al.*, 2001).

Reduction of moisture level significantly increased leaf senescence in all spider plant genotypes. At 40% FC, a significant increase in number of senescent leaves was reported in all the accessions except for accessions Mombasa and Kakamega. Leaf senescence is considered a drought adaptive mechanism for the plants. Leaf senescence due to drought enhances timely remobilization of resources from vegetative growth to reproductive growth, subsequently prompting the hastened completion of the vegetation cycle (Munné-Bosch and Alegre, 2004). The response of spider plant to moisture stress was dependent on the accessions. Water stress significantly increased leaf senescence for commercial variety (saga) at 60% and 40% FC but it did not significantly affect it at 80% FC. This could mean that commercial variety (saga) can withstand slight water stress but cannot withstand high drought stress.

Water stress significantly reduced leaf yield by 25.7%, 55.1% and 74.2% at 80%, 60% and 40%, respectively, compared to 100% FC. The reduced leaf yield may be attributed to the negative effect of water stress on number of leaves and leaf area leading to reduction in photosynthetic rate and carbon assimilates in plants and consequently less biomass produced (Vurayai *et al.*, 2011). Leaf number, size and weight are the first parameters to be affected when the plant faces any abiotic stress (Anjum *et al.*, 2016 b). Similar results have been reported in groundnut (*Arachis hypogea* L.) (Reddy *et al.*, 2003) and peanuts (Rucker *et al.*, 1995). The interaction between the spider plant accessions and moisture stress level was significant. Reduction of moisture levels from 80% to 60% FC had

significant effect on all accessions except accession Mombasa. Reduction of moisture level from 60% to 40% FC did not significantly reduce leaf yield for accessions Kuria, Mombasa and Nandi but significantly affected other accessions. This variations demonstrates huge variability among spider plant accessions in adaptability to water stress.

Water stress significantly reduced seed yield from 1.9 t/ha at 100% FC to 0.2 t/ha at 40% FC. Previous studies have demonstrated that soil water deficit reduced yield in eggplant (Lagat *et al.*, 2016), cowpea and nightshade (Chemutai, 2018). The interaction between the spider plant accessions and moisture stress level was significant. All accessions, except accession Mombasa, were significantly affected by reduction of moisture level from 100% to 80% FC while reduction of moisture level from 60% to 40% FC significantly reduced seed yield for accessions such as GBK-031850, GBK-032210, GBK-032340, Homabay and Kakamega, Kuria, and Commercial variety (saga) while accessions Baringo, Bungoma, GBK-027212, GBK-040449, Homabay, Mombasa and Nandi were not significantly affected. Similar findings have been reported in cowpea (Chemutai, 2018). Drought shortens seed formation and filling period resulting to reduced seed size, number of seeds in a pod and seed yield with drought intensification among cultivars (Pervez *et al.*, 2009). If water stress occurred during seed filling period then it might bring about decrease in number of seeds and seed yield (Pervez *et al.*, 2009).

#### **4.7 Conclusion**

Water stress significantly reduced plant height, stem girth, number of leaves per plant, single leaf area, chlorophyll content, leaf relative water content, leaf yield and seed yield. It, however, increased leaf senescence. Results indicate that there exist significant genotypic differences in adaptation to drought among the evaluated spider plant genotypes. The interaction between the spider plant accessions and moisture stress level was significant. Genotypes GBK-031850 and Bungoma at 80 % FC, Kisii and GBK-032210 at 60% FC, and Kakamega at 40% FC expressed superior adaptability to drought. These accessions could be recommended for breeding programmes aimed at developing high yielding drought adapted spider plant varieties. Molecular studies are required to identify drought resistant genes in the drought adaptable accessions for introgression into existing spider plant commercial varieties and also in development of highly drought adapted spider plant accessions.



## **CHAPTER 5: GENERAL DISCUSSION, RECOMMENDATIONS AND CONCLUSIONS**

### **5.1 General Discussion**

Spider plant genotypes varied significantly in growth and yield parameters in greenhouse and field experiments. Variations observed among the spider plant genotypes could be partly attributed to different evolutionary pathways of development as the accessions were sourced from different regions. In the field experiment location  $\times$  spider plant interaction had significant effect on growth and yield parameters. Interactions between genotypes and the environment are important in some instances and could be used to explain the observed variations.

Spider plant accessions varied significantly in number of days to seedling emergence in both greenhouse and field experiments. This could be attributed to developmental stage at which the seeds were harvested and the way the seeds were processed. Spider plant seeds that are harvested when the pods have ripened and yellow have shown to exhibit high seedling emergence. Early harvesting results to seed dormancy and poor-quality seeds whose emergence tends to be low.

Spider plant accessions sourced from farmers emerged earlier and had higher seedling emergence than those collected from the genebank. The delayed seedling emergence of accessions sourced from the genebank may be attributed to long storage under very low temperatures that could result to dormancy and loss of viability. Generally, spider plant accessions recorded lower seed germination than the commercial variety (saga). The poor seedling emergence is partly attributed to poor processing before storage for farmers accessions and long storage (more than 5 years) at low temperatures ( $-20^{\circ}\text{C}$ ) for genebank accessions.

Spider plant accessions grown in the field were the earliest to flower. Early flowering in the field grown accessions could be attributed environmental stresses which plants tend to escape by hastening flowering period accompanied with seed formation. Late flowering accessions including accessions Nandi, GBK-032210, GBK-027212, and GBK-032340 recorded the longest vegetative phase which is a desirable trait for spider plant since it's grown primarily for vegetable production as reproductive phase inhibits leaf formation.

Genebank and farmers' accessions including accessions GBK-031991, Kakamega, GBK-045456, GBK-032302 and Migori recorded significantly better performance in number of primary branches per plant, number of leaves per plant, number of days to flowering, number of pods per

plant, number of seeds per pod, 100-seed weight and seed yield per plant in both greenhouse and field experiments than commercial variety. This points to the existence of desirable agronomic traits that can be harnessed in breeding programmes for developing high performing spider plant varieties. The accessions could be recommended for farmers' cultivation.

The study showed that water stress reduced most spider plant agronomic traits. Reduction in moisture level led to reduced plant height that may be attributed to negative effect of drought stress on cell expansion and elongation. Reduction of leaf number due to water stress may be associated with high leaf senescence and reduced branching.

Severe drought stress led to a significant reduction in spider plant single leaf area that could be attributed to significant reduction in plant cell turgor pressure. Reduction in soil moisture may have adequately affected synthesis of chlorophyll pigment complex that led to reduced chlorophyll content. As the field capacity fell to 40%FC, the plants may have lost turgor with relative water content reaching lowest values when all the plant available water had been used up. Intensification of drought stress led to reduced leaf yield, possibly due to reduction in leaf components such as leaf number, leaf fresh weight and leaf area. Leaf size and weight are the first parameter affected when the plant faces any abiotic stress.

Reduced seed yield was associated with dramatic decrease in all grain components such as number of pods per plant, number of seeds per pod and seed weight with decrease in moisture levels. Intensification of drought results in shortened seed formation and filling period which is associated with reduced seed size, number and yield. Evaluation of spider plant indigenous genotypes demonstrated that indigenous genotypes; farmers' accessions and genebank accessions performed better than the commercial variety in both growth and yield.

## **5.2 Conclusion**

Spider plant accessions varied significantly in agronomic traits such as accessions GBK-031991, Kakamega, GBK-045456, GBK-032302 and Migori recorded superior agronomic traits for growth and yield in the field and greenhouse experiments in both locations hence may be used in the development of improved spider plants. The interaction between spider plant accessions and the environment was significant. The significant variation in quantitative traits observed among the accessions from the two sites presents great possibility for the development of suitable varieties for various agro-ecological zones by making use of the available potential of the genotypes.

The responses to drought in most of the physiological, growth and yield parameters varied in their response to moisture stress with the accessions and water stress. Further, genotypes GBK-031850 and Bungoma at 80 % FC, Kisii and GBK-032210 at 60% FC, and Kakamega at 40% FC, expressed superior adaptability to water stress compared to other accessions. This points to the existence of exploitable drought tolerance genes in spider plant landraces that can be utilized in breeding programs for drought adaptability.

### **5.3 Recommendations**

1. Genotypes that expressed superior adaptability to drought such as accessions GBK-032210, GBK-040449, Kakamega, and Kuria could be recommended for adoption by small scale farmers for direct production.
2. Further research is required to evaluate adaptation of spider plant genotypes to drought stress under field conditions.
3. Molecular studies are required to identify drought resistant genes in the drought adaptable accessions for introgression into existing spider plant commercial varieties.
4. Evaluation of the accessions for nutritional quality is also required to identify highly nutritious accessions.

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