Effect of Water Stress on Growth and Yield of Selected Spider Plant Accessions

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ABSTRACT

Spider plant (*Cleome gynandra* L.) is one of the most popular underutilized African Indigenous Vegetables due to its known nutritional and health benefits. Currently, little information is available on its adaptability to drought stress. The objective of this study was to evaluate several spider plant accessions grown under drought stress and non-drought stress to identify genotypes for breeding programs. Two greenhouse experiments were conducted at Upper Kabete Field Station of the University of Nairobi, Kenya, in a randomized complete block design using 14 selected Kenyan spider plant accessions, five from the Muguga Genetic Resource Research Institute, eight sourced from farmers in Western, Nyanza, Rift Valley and Coastal parts of Kenya and one commercial seedlot. The plants were grown under drought stress levels of 40%, 60% and 80% field capacity (FC) in comparison to non-drought stress (100% FC) conditions between June 2018 and March 2019. Data was collected on plant growth, physiological and yield attributes. Drought stress reduced leaf number by 25.7%, 55.1%, 74.2% and leaf yield by 25.7%, 55.1%, and 74.2% for the treatments at 80%, 60% and 40% field capacity, respectively. Seed yield was reduced by 43.9%, 77.9% and 90.6% for the treatments at 80%, 60% and 40% FC, respectively. Chlorophyll content was reduced by 11.3%, 26.7%, 38.2%, and leaf relative water content by 9.3%, 26.3% and 36.6% for the treatments at 80%, 60% and 40% FC, respectively. Single leaf area was reduced by 11.8%, 22.4% and 31.0%, while leaf senescence (number of leaves) and dry matter partitioning increased by 2.1, 5.1 and 9.4, and 0.05 g, 0.10 g and 0.18 g for the treatments at 80%, 60% and 40% FC, respectively. Accessions GBK-032210, Baringo, Kuria, Homabay, Kakamega and GBK-040449 performed well with respect to growth and yield, even under increased levels of drought stress. Our results show that accessions GBK-032210, Baringo, Kuria, Homabay, Kakamega and GBK-040449 would be promising candidate genotypes to be used in the breeding for drought tolerant genotypes.

INTRODUCTION

Spider plant (*Cleome gynandra* L.) is widely used as a local vegetable across sub Saharan Africa (Chadha, 2003). The plant contains phytochemicals that are essential for human health and nutrition that protect the body against cardiovascular diseases, some forms of cancer and other degenerative diseases (Ayoola et al., 2008). Spider plant methanol extract has a good total antioxidant potential (Muchweti et al., 2007) that includes antioxidant enzymes and non-enzymatic antioxidants such as beta carotenes, flavonoids, carotenoids, tocophenols, gluthathione and beta-carotene that deter and scavenge free oxygen radicals giving the body protection against degenerative and infectious diseases (Liu, 2003). Several studies have reported a wide range of medicinal benefits of spider plants such as alleviating migraine, and reducing vomiting, pneumonia, aching 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 threadworm infections. Seeds and roots have anthelmintic properties (Schippers, 2002). Opole et al., *(*1995) reported that the juice or concoction of spider plant is known to treat marasmus and scurvy. Most serious health issues around the globe are deficiencies of vitamin A, zinc, iron and iodine. The evaluation of the nutrient content of spider plants showed high levels of calcium, magnesium, iron, zinc, vitamin A, C and E, proteins and high beta-carotene (Mnzava, 1997; Mahyao et al., 2008; Mbugua et al., 2011). The estimated spider plant yield using locally available resources varies from 1.0 to 3.0 tons/ha, compared to the potential yield of 20.5 to 30 tons/ha (Chweya, 1997). The relatively low yield, which is an impediment for commercial production, is partly attributed to drought stress and the use of low-yielding unimproved spider plant seeds, low soil fertility, poor farming techniques and limited research by the National Agricultural Research Institute (Vorster and Jansen Van Rensburg, 2005).

Production of spider plant is mainly rain-fed, therefore predisposing the crop to drought conditions due to low rainfall episodes that are further exacerbated by climate change. For effective production of spider plant, it is necessary to supplement rainfall with irrigation. Therefore, there is need to effectively manage water since it has the potential to lead to high production costs. Previous studies have shown that spider plant grows best when adequately supplied with water, especially in areas experiencing periods with low rainfall. Generally, spider plants can tolerate some amount of drought stress, but when periods of drought are prolonged flowering and leaf senescence accelerate (Chweya and Mnzava, 1997). Recently, Wasonga et al. (2014) phenotypically characterized and analyzed nutrient content of 32 Kenyan and South African spider plant genotypes. Masinde et al. (2003) studied effects of drought stress on two landrace spider plant varieties and a commercial variety. Few spider plant cultivars have been evaluated for adaptability to drought stress yet there are several cultivars that may have the potential to yield well under drought stress. Most studies have shown that production of crops can be sustained under drought conditions with adequate irrigation (Masinde et al., 2003). There is scant qualitative information on the plant's adaptability to drought stress, which is essential for the proper scheduling of irrigation and for informing breeding and conservation programs (K'Opondo et al., 2009). Therefore, the objective of this study was to evaluate the adaptive response of selected spider plant accessions to drought stress. We hypothesized that drought stress affects growth and yield of spider plants.

MATERIALS AND METHODS

Study area description. Greenhouse experiments were conducted at the field station Upper Kabete Campus University of Nairobi, Kenya. Kabete field station lies at a latitude of $0^0 14'45.00''$S and longitude of $36^0 44'19.51''$E and at an altitude of 1940 m above the sea level. The agro-ecological classification of the area is upper midland zone three (UM3) (Jaetzold and Schmidt, 1983). The experiment was carried out twice between June 2018 and February 2019. The agro-ecological classification of the area is upper midland zone three. The average outdoor temperature was 16^0 C to 23^0 C. Average annual rainfall precipitation is 1000 mm (Siderus, 1976). The site had deep, well-drained dark reddish-brown clay humic nitisols with pH ranging from 5.2 to 7.1 (Michieka, 1978).

Collection and selection of accessions. Fourteen accessions were evaluated in this study; five accessions were sourced from Muguga National Genetic Resource Research Institute, eight sourced from farmers in Western, Nyanza, Rift Valley and Coastal parts of Kenya where the vegetable is commonly grown. The accessions were given the names of the area from which they had been collected. One commercial variety (Saga) was obtained from the Simlaw seed company. Spider plant accessions were selected based on places where they are cultivated in Kenya and on desirable traits pertinent to vegetative and seed production. These traits included number of days to emergence, germination percentage, number of days from sowing to 50% flowering, number of leaves per plant, number of pods per plant, and the weight of 100 seeds. The accessions selected and evaluated in the study were GBK O40449, GBK O32340, GBK 027212, GBK O45494, GBK 032210 (from the Genetic resource Research Institute); farmers' accessions from Mombasa, Kakamega, Baringo, Homabay, Migori, Bungoma, Eldoret and Kisii; and a commercial variety (Saga).

Treatments, experimental design and crop husbandry. Treatments comprised the 14 spider plant accessions and four moisture levels. The moisture levels included 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 completely randomized in the greenhouse using a complete randomized design with a factorial arrangement of 14 spider plant accessions by 4 field capacity levels (14×4) with three replications. Each pot was planted with four seeds that were later thinned to one seedling per pot when plants reached a height of 15 cm above the ground. Each rounded pot was 36.3 cm tall x 18.3 cm wide. Pots were filled with a 10 kg air-dried mixture of sterilized soil, sand and composted animal manure in the ratio 1:2:2, respectively. One teaspoon of calcium ammonium nitrate equivalent to 10 grams was applied to each pot just before planting. Watering was done before and after planting of the seeds. Before initiating the drought 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 ("Quick Draw" Soil moisture probe CAT. NO.2900F-Soilmoisture Equipment Corp. Santa Barbara, California USA) positioned at 13 cm depth. The tensiometers were calibrated to measure availability of water in the pots. As soon as the water potential reached –8 kPa, plants were watered to 100%, 80%, 60% and 40% field capacity.

Data collection. Data was collected on physiological, growth and yield parameters. Three mature edible fully expanded leaves were randomly selected and tagged during the vegetative phase. Length (L) of the leaf from the base to tip and width at the widest part of the blade (W) of the central leaflet were recorded and single leaf area (SLA) (cm^2) calculated following the formulae of Rivera et al., (2007): $SLA=0.763L + 0.34W$. A leaf is a flattened structure of a higher plant typically green and bladelike that is attached to a stem directly or via a stalk while leaflets refers to a small leaf or leaf-like parts of a compound leaf. Spider plant has a palmately compounded leaf. Leaf senescence was determined by counting the number of leaves that showed signs of senescing during the vegetative phase and just before flowering.

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. Osaka, Japan) (Jarvis, 2008). Root to shoot ratio was determined by uprooting an entire plant, cutting it at the base of the stem to separate roots from shoot. Roots were cleaned under running water to remove the soil. Separated roots and shoots were dried in an oven at 100°C for 48 hours. Relative water Content (RWC) of the leaves was determined by using the method proposed by Yamasaki and Dillenburg (1999). Leaf fresh mass (FM) was recorded, and then the leaves were put in petri dishes containing deionized distilled water for twenty 24 hours. After 24 hours, the turgid mass (TM) was determined after blotting.

The leaves were then put in a pre-heated oven at 60ºC for 48 hours and dried to a constant weight to obtain their dry mass (DM). The values of FM, TM and DM were used to calculate LRWC, using the equation: LRWC (%) = [(FM – DM)/(TM – DM)] x 100% (Aguyoh et al., 2013).

Yield data included number of leaves, weight of leaves and weight of seeds. The number of leaves per plant were counted and recorded for the plant in each pot. This was done at the vegetative stage. Yield of leaves per plant was calculated by harvesting and weighing leaves weekly during the vegetative phase. Yield of seeds per plant was calculated by weighing dried seeds from each plant and determining their means. Collected data were subjected to analysis of variance using GenStat 15th 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 15th edition (Payne et al., 2011). Variability within each quantitative trait was calculated using statistical measures of mean, standard deviation and coefficient of variation.

RESULTS AND DISCUSSION

Number of leaves per plant. Drought stress reduced the number of leaves by 25.7%, 55.1%, and 74.2% at field capacities of 80%, 60% and 40%, respectively (Table 1). These results are in agreement with those reported by Kirnak et al. (2001) who stated that drought stress reduced the vegetative growth of eggplant. The average number of leaves per plant ranged from 70.8 (accession GBK-031850) to 112.8 (accession Kuria). The imposed drought stress reduced the number of leaves by 13.1% to 63.8% for FC levels declining from 100% to 40%. The reduction in available water significantly reduced the number of leaves for all accessions, except for accession Kakamega and accession Mombasa. The interaction between spider plant genotypes and available water was significant. A reduction of available water from 100% FC to 80% FC had no significant effect on accessions Kakamega and Mombasa. The number of leaves of accession Mombasa was not significantly affected with reduction in field capacity from 80% to 60%. Accession Kuria recorded the highest number of leaves at all moisture levels. The reduction of available water from 100% FC to 40% FC significantly reduced the number of leaves for accession GBK-032340 (63.8%), while accession Mombasa (13.1%) was least affected. Drought stress reduced the number of leaves by 25.7%, 55.1%, and 74.2% for the 80%, 60% and 40% FC treatments, respectively. The reduced leaf formation observed in their study was attributed to the reduction in soil water potential. Factors responsible for the expansion of leaves including leaf turgor, accumulation of photosynthates and growing temperature were affected by drought stress in *Arachis hypogeae* (L.) (Reddy et al., 2003). However, Abdelmula and Sabiel (2007) argued that drought stress does not completely explain changes in vegetative traits such as the number of leaves per plant, a phenomenon that was confirmed in accessions GBK-031850 and Kakamega that recorded lower leaf yields at 100% FC compared to 80% FC. The reduction in leaf yield corresponds with drought intensification. Shuppler et al., (1998) suggested that leaf drop due to drought stress reduces the plant water use at the expense of yield. Accessions GBK-032340 (63.8%) and Homabay (56.8%) recorded highest yield reduction with increased drought stress. A reduction in leaf formation and total leaf area results in a decrease in transpiration surface area and is considered one of the most basic developmental changes a plant experiences under drought stress (Alves and Setter, 2004). The result of drought stress is that the leaf meristems produce fewer and smaller cells (Tardieu et al., 2000).

Single leaf area. The average decrease in single leaf area ranged from 1.1 cm^2 (Kisii) to 5.3 cm^2 (Kakamega) for the drop in field capacity from 100% to 40% (Table 1). Severe drought stress (FC≤40%) led to a 31.0% reduction in spider plant single leaf area, which is mainly attributed to leaf senescence and shedding. These results were in agreement with Lopez et al., (1997) who noted that the leaf area of pigeon pea decreased by 22.5% under drought stress. The reduction of available water significantly reduced the single leaf area for all accessions. The single leaf area for accession Bungoma was not significantly affected by the reduction of available water from 80% to 60% FC and 60% to 40% FC. Similarly, the reduction of available water from 100% to 80% FC, and 80% to 60% FC did not significantly affect the single leaf area for accession Kisii. The reduction of available water from 100% to 80%, 80% to 60%, 60% to 40% FC did not have a significant effect on accessions Nandi, Mombasa and the commercial variety (Saga). Drought stress reduced the single leaf area by 11.8%, 22.4% and 31.0% for the 80% FC, 60% FC, and 40% FC treatments, respectively. Similar results have been reported by Borell et al., (2000) and Rosenthal et al., (1987). Accession Kakamega recorded the highest single leaf area for the 100%, 80% and 60% FC treatments. At maximum drought stress of 40% FC, accession GBK-040449 recorded the highest single leaf area. Leaf growth and development has been reported to be more sensitive to drought stress than the growth and development of roots because vigor and photosynthetic potential of plants are traits enhanced by increased leaf area. Under drought stress, plant reduce their transpiration in order to conserve water (Dosmann et al., 1999). The reduction in leaf area under increasing drought conditions was matched by an increase in leaf shedding. As older leaves shed off, new smaller and thicker leaves remain (Husain et al., 1990). Such high sensitivity of leaf expansion to drought stress has also been reported for various other crops grown under greenhouse conditions such as chickpea (Soltani et al., 1999). Drought stress reduces the net photosynthetic rate due to the reduction in leaf growth and area. Reduction in leaf area serves as a drought avoidance mechanism that reduces water loss (Farooq et al., 2009).

Chlorophyll content. The chlorophyll content reduced by 11.3%, 26.7% and 38.2% under the 80%, 60% and 40% FC treatments, respectively, compared to 100% FC (Table 2). A reduction in chlorophyll content under drought stress conditions is a widely observed phenomenon (Heba and Samia, 2014), and is ascribed to reduced synthesis of the major chlorophyll pigment complexes encoded by the cab gene family (Nikolaeva et al., 2010). The interaction between spider plant genotypes and available water was significant. For FC levels declining from 100%, to 80%, and 60%, the accessions Kuria, Homabay, and Baringo recorded the highest chlorophyll content. At the lowest FC level of 40%, accession Baringo had the highest SPAD value of 65.3. For FC levels declining from 100% to 40%, accession Baringo showed the smallest decline in SPAD values. The average decrease in SPAD value as the FC declined from 100% to 40% ranged from 16.0% (accession Baringo) to 51.1% (accession Kuria). The degree of impact of drought stress on the chlorophyll content was dependent on the spider plant accession. SPAD readings varied from 45.0 for accession Mombasa to 71.5 for accession Baringo. These numbers are in agreement with those reported by Aguyoh et al. (2013) who reported SPAD readings of 41.9 for drought stressed and 61.5 in non-stressed tomato plants.

Leaf Relative Water Content. A reduction in the available water resulted in a marked decrease in the relative water content of the leaves (Table 2). Drought stress reduced the leaf relative water content by 9.3%, 26.3% and 36.6% under the 80%, 60% and 40% FC treatments compared to the control (100% FC). These results are similar to those reported by Kirnak et al., (2001) who noted that the relative water content of tomato decreased with increased drought stress. Amira (2014) also reported similar findings for soybean leaves. The interaction between spider plant genotypes and available water was significant. A reduction in the available water from 100% FC to 80% FC did not have a significant effect on accessions GBK-032210, GBK-032340, Homabay, Kakamega, Kuria, Mombasa and Nandi. Accessions Homabay and Mombasa were not significantly affected when the available water dropped from 80% to 60% FC. A drop in available water from 60% to 40% FC did not have significant effect on the relative water content in the leaves of accessions GBK-027212, GBK-040449, Homabay, Kisii, Kuria, Mombasa and Nandi. Leaf relative water content of accessions Homabay and Mombasa was not significantly affected when the available water dropped from 60% FC to 40% FC. During the initial stages of drought stress, the leaf relative water content was generally high (above 79.4%). As the field capacity fell below 60% FC and dropped toward 40% FC, the plants lost turgor and the relative water content reached the lowest values (50.3%) when all the plant available water had been used up. Similar results have been reported for peanut (Erickson et al., 1991), vegetable amaranth (Liu, 2000), and soybean (Luquez and Guiamet, 2002). The decrease in available water reduced the leaf relative water content from 7.5% (Homabay) to 59.0% (Kisii) when the field capacity dropped from 100% FC to 40% FC. Similar findings were reported for eggplant where the leaf relative water content ranged from 63.5% in accession RV100242 to 70.3% in accession RV100328 (Lagat et al., 2016), showing that the spider accessions adapted more strongly to drought stress.

Leaf Senescence. Leaf senescence was not significantly affected for accessions from Mombasa when the available water dropped from 100% FC to 40% FC (Table 3). Accession, available water and accession versus available water interaction significantly affected leaf senescence in spider plants. A reduction in the available water content to 80% FC did not significantly affect accessions Baringo, GBK-040449, Homabay, Kisii, Nandi and the commercial variety. Leaf senescence in accessions Bungoma, GBK-032340, and Nandi was not significantly affected by reductions in available water from 80% FC to 60% FC. A reduction in available water from 60% FC to 40% FC significantly increased leaf senescence in all accessions except in accession Mombasa. At maximum drought stress at 40% FC, accessions GBK-027212 and GBK-031850 recorded the highest number of leaves that senesced per plant. Starting at the medium drought stress of 60% FC, accessions Mombasa and Nandi recorded the lowest number of senesced leaves when the available water dropped to 40% FC, while accessions GBK-027212 and GBK-031850 recorded the highest increase in number of senesced leaves when the available water dropped to 40% FC. Average number of senesced leaves ranged from 3.1 (100% FC) to 12.5 (40% FC). Drought stress increased the number of senesced leaves from 2.1, to 5.1 and 9.4 under the 80%, 60% and 40% FC treatments, respectively. This increased leaf abscission rate is considered a drought adaptive mechanism for plants (De Souza et al., 1997; Munné-Bosch and Alegre, 2004). As the leaf ages, a significant number of stomata closes, decreasing transpiration and making the limited amounts of water available to the younger leaves. This way, spider plants remobilize resources from sources (senescing leaves) to sinks (younger leaves). Leaf senescence due to drought also enhances the timely remobilization of resources from vegetative growth to reproductive growth, prompting the hastened completion of the vegetative growth cycle (Munné-Bosch and Alegre, 2004).

Root-to-Shoot ratio. The response to drought stress with respect to their dry matter partitioning by the spider plant genotypes evaluated in this study was significantly different ($P \leq 0.05$) (Table 3). This differential sensitivity to drought stress has also been reported for crops such as beans (Boutraa and Sanders, 2001). The root-to-shoot ratio increased by 0.1 g, 0.1 g and 0.2 g under the 80% FC, 60% FC and 40% FC treatments compared to the control (100% FC). The interaction between spider plant genotypes and available water was significant. A reduction in the available water from 80% FC to 60% FC did not have a significant effect on the root to shoot dry matter partitioning in accessions Baringo, Bungoma, GBK-027212 and Kisii. A reduction in the available water from 100% FC to 80% FC and from 60% FC to 40% FC significantly increased dry matter partitioning in all accessions, except accessions GBK-032210 and Nandi. At 40% FC, accession Kakamega recorded the highest dry matter partitioning, while at the moderate drought stress of 60% FC, accession Homabay, Kuria, Kakamega and the commercial variety (Saga) recorded the highest dry matter partitioning. Each decrease in available water led to a significant increase in root to shoot dry matter partitioning. The increase in the root to shoot ratio under drought stress is attributed to a difference in sensitivity of the root and shoot biomass production to drought. Under drought stress, plant productivity relies on crucial processes such as time-based biomass distribution and dry matter partitioning. At maximum drought stress (40% FC), the average root to shoot ratio increased by 42.3% compared to non-stressed conditions. These findings are in agreement with Jones (1992) and Masinde (2003) who also reported that water stress affects dry matter partitioning in spider plant. Spider plants partitioned more of their assimilates to the roots than to the shoots under severe drought stress, a phenomenon also reported by Li et al., (1994). Spider plants demonstrated drought adaptation through assimilate partitioning that favored starch accumulation and the growth of the root system. Torres et al., (2006) suggested that an extended root structure is useful for the extraction of water from significant soil depths. In addition, studies further suggest that the uptake of water during the growing season is highly related to the distribution and structure (i.e., quality) of roots rather than the quantity of available water (Subbarao et al., 1995). Therefore, the selection of spider plant genotypes with deep and extensive root systems is an important criterion to obtain higher productivity.

Leaf Yield. A reduction in the available water significantly reduced the leaf yield, levels except for accessions GBK-027212, GBK-031850, Kakamega, Kuria, Mombasa and Nandi (Table 4). The interaction between spider plant genotypes and available water was significant. 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. Accession Mombasa was not significantly affected by a 20% decrease in FC at all drought stress levels. A reduction in available water from 100% FC to 80% FC did not result in a significant decline in leaf yield per plant for accessions GBK-027212, GBK-031850, Kakamega and Nandi. A reduction in available water from 60% FC to 40% FC did not have a significant effect on leaf yield for accession Kuria. Accession GBK-032210 recorded the highest leaf yield per plant at 100% FC. At moderate drought stress (60% FC), accession Kisii recorded the highest leaf yield per plant. Average leaf yields ranged from 7.6 tons/ha (Mombasa) to 18.2 tons/ha (GBK-032210). The average decrease in leaf yield as the FC declined from 100% FC to 40% FC ranged from 56.5% (accession Mombasa) to 86.9% (accession GBK-032340). The reduction in available water to 40% FC significantly reduced leaf yield per plant. A decrease in available water by 20% FC significantly affected leaf yield per plant. Leaf size and weight is the first parameter to be affected when plants face any abiotic stress (Anjum et al., 2016). For efficient photosynthesis, leaf formation, elongation, and expansion are very important traits. Leave yield per plant is correlated to number of leaves per plant, size of the leaf, weight of leaves and rate of leaf formation, and all these parameters impact the rate of photosynthesis (He et al., 2009). Processes such as cell division, elongation and vertical growth of apical leaf parts and leaf curling are sensitive to drought. During severe stress all these processes are inhibited, resulting in limited leaf formation and photosynthesis. (Reddy et al., 2003; 2004; Rucker et al., 1995). Reductions in fresh biomass production in response to drought stress have been reported for several crops, for example, green gram (Webber et al., 2006) and parsley (Petropoulos et al., 2008). A typical negative impact of drought stress on crop plants is decreased decrease in fresh and dry biomass production (Farooq et al., 2009). Accessions GBK-032210 had the highest leaf yield under both well-watered and drought stress conditions with a 27% increase over the commercial variety under well-watered conditions and more than 50% increase in leaf yield under 40% field capacity drought treatment.

Seed Yield. Seed yield reduced by 43.9%, 77.9% and 90.6% under the 80%, 60% and 40% FC treatments, respectively, compared to the control (100% FC) (Table 4). These findings are in agreement with those by Birhanu and Tilahun

(2010) who reported significant decreases in fruit weight, number of fruits per plant and fruit yield under drought stress. The interaction between spider plant genotypes and available water was significant. Progressive reductions in available water by 20% FC significantly affected seed yield in all the accessions except accessions GBK-027212, Mombasa and Nandi. For the later, seed yield was not significantly affected with reductions in available water from 60% FC to 40% FC. At the lowest level of available water at 40% FC, accessions GBK-032210, Kakamega and Kuria recorded the highest seed yield of 0.3 tons/ha. At the moderate drought stress of 60% FC, accessions Kuria and Kakamega recorded the highest seed yield of 0.7 tons/ha. The average seed yield ranged from 0.3 tons/ha (Mombasa) to 1.4 tons/ha (Commercial). The average decrease in seed yield as the available water declined from 100% FC to 40% FC ranged from 83.7% (accession Nandi) to 98.5% (accession Baringo). Drought significantly shortens seed formation and filling period resulting in reduced final seed size and low yield, especially when drought conditions intensify during the seed filling period. (Pervez et al., 2009). If drought stress occurred during the seed filling period, the number of seeds might be decreases. The spider plant accessions evaluated responded significantly ($P \leq 0.05$) different to drought stress with respect to seed yield. The seed filling period is considered a variable characteristic across plant species exposed to drought stress (Fougereux et al., 1997).

Water stress significantly reduced number of leaves per plant, single leaf area, chlorophyll content, leaf relative water content, leaf yield and seed yield. It, however, increased leaf senescence and root to shoot ratio (Table 5). Results indicate that there exist significant genotypic differences in adaptation to drought among the evaluated spider plant accessions. The interaction between the spider plant accessions and available was significant. Accessions GBK-032210, Baringo, Kuria, Homabay, Kakamega and GBK-040449 performed well with respect to growth and yield, even under increased levels of drought stress. Our results show that accessions GBK-032210, Baringo, Kuria, Homabay, Kakamega and GBK-040449 would be promising candidate genotypes to be used in the breeding for drought tolerant genotypes.

Table 1. Effects of available water (% field capacity) on the number of leaves per plant and single leaf area (cm$^{2)}$ of 14 spider plant accessions.

	Number of leaves per plant					Single leaf area				
ACCESSION	**100%**	**80%**	**60%**	**40%**	**MEANS**	**100%**	**80%**	**60%**	**40%**	**MEANS**
Baringo	105.2	92.7	86.4	66.8	**87.8**	7.4	6.9	6.3	5.7	**6.5**
Bungoma	98.0	80.9	65.4	59.0	**75.8**	8.4	7.1	6.7	6.4	**7.1**
GBK-027212	95.8	90.1	74.3	59.9	**80.0**	9.5	7.7	6.9	6.1	**7.5**
GBK-031850	87.8	81.4	65.8	48.4	**70.8**	8.4	7.8	6.3	5.5	**7.0**
GBK-032210	118.2	96.0	75.9	60.3	**87.6**	8.6	7.6	6.6	6.1	**7.2**
GBK-032340	97.0	85.8	71.2	35.1	**72.3**	9.0	8.0	6.0	5.3	**7.1**
GBK-040449	93.7	83.5	63.4	51.8	**73.1**	9.4	8.0	7.3	6.8	**7.9**
Homabay	136.5	99.1	76.7	58.9	**92.8**	8.8	8.0	6.8	6.0	**7.4**
Kakamega	96.0	97.4	77.5	62.9	**83.4**	11.5	9.2	7.8	6.2	**8.7**
Kisii	102.6	89.1	80.1	63.6	**83.9**	7.0	7.1	6.8	5.9	**6.7**
Kuria	146.9	115.6	99.5	89.0	**112.8**	8.2	7.3	6.4	5.9	**7.0**
Mombasa	93.5	91.5	87.4	81.3	**88.4**	6.3	5.4	5.0	4.2	**5.2**
Nandi	93.0	85.1	66.9	46.9	**73.0**	7.0	6.6	5.7	4.8	**6.0**
Commercial	115.6	87.3	80.0	62.7	**86.4**	8.4	7.6	7.1	6.7	**7.4**
MEANS	**105.7**	**91.1**	**76.5**	**60.5**	**83.4**	**8.4**	**7.4**	**6.5**	**5.8**	**7.1**
P-Value(A)	<.001					<.001				
P-Value(ML)	<.001					<.001				
P-Value (A×ML)	<.001					<.001				
LSD$_{\leq 0.05}$ (A)	2.8**					0.2**				
LSD$_{\leq 0.05}$ (ML)	1.5**					0.1**				
LSD$_{\leq 0.05}$ (A×ML)	5.6**					0.5**				
CV%	4.1					4.0				
MEAN	83.4					7.1				

LSD- Least significant difference, CV- Coefficient of variation, **Highly significant, * Significant, ns- Not significant, *100% field capacity, 80% field capacity, 60% FC and 40% field capacity. A-accession, ML- available water.

Table 2. Effects of available water (% field capacity) on the SPAD values (nmol/mg) and leaf relative water content of 14 spider plant accessions.

	SPAD Value					Leaf relative water content				
ACCESSION	**100%**	**80%**	**60%**	**40%**	**MEANS**	**100%**	**80%**	**60%**	**40%**	**MEANS**
Baringo	77.7	70.7	72.3	65.3	**71.5**	89.2	78.1	73.4	57.5	**74.6**
Bungoma	71.0	67.7	46.6	36.0	**55.3**	87.4	72.9	61.7	47.4	**67.3**
GBK-027212	70.7	63.3	53.1	43.0	**57.5**	70.2	62.3	45.8	40.1	**54.6**
GBK-031850	56.3	51.2	40.0	37.7	**46.3**	73.8	62.9	55.8	46.9	**59.8**
GBK-032210	57.6	52.1	43.3	41.6	**48.6**	90.5	85.6	67.2	57.3	**75.1**
GBK-032340	68.0	55.9	45.8	43.1	**53.2**	65.1	62.5	51.7	40.6	**55.0**
GBK-040449	66.3	55.9	44.6	39.7	**51.6**	87.9	77.1	65.9	60.6	**72.9**
Homabay	86.0	80.3	62.7	46.4	**68.8**	64.5	63.0	61.6	59.7	**62.2**
Kakamega	67.0	57.4	50.2	49.7	**56.1**	91.0	87.0	64.6	47.4	**72.5**
Kisii	76.0	64.0	49.2	39.9	**57.3**	87.6	72.5	38.8	36.0	**58.7**
Kuria	86.7	77.3	67.0	42.4	**68.3**	81.3	75.3	50.9	49.6	**64.3**
Mombasa	54.0	46.3	43.0	36.8	**45.0**	66.4	64.6	61.4	58.5	**62.7**
Nandi	61.7	54.7	49.5	37.7	**50.9**	69.9	65.4	57.6	54.5	**61.7**
Commercial	83.0	74.3	52.7	47.5	**64.4**	86.4	78.9	63.9	48.2	**69.4**
MEANS	**70.1**	**62.2**	**51.4**	**43.3**	**56.8**	**79.4**	**72.0**	**58.6**	**50.3**	**65.1**
P-Value(A)	<.001					<.001				
P-Value(ML)	<.001					<.001				
P-Value(A×ML)	<.001					<.001				
LSD$_{\leq 0.05}$ (A)	2.1**					3.3**				
LSD$_{\leq 0.05}$ (ML)	1.1**					1.7**				
LSD$_{\leq 0.05}$ (A×ML)	4.1**					6.5**				
CV%	4.5					0.8				
MEAN	56.8					65.1				

LSD- Least significant difference, CV- Coefficient of variation, **Highly significant, * Significant, ns- Not significant, *100% field capacity, 80% field capacity, 60% FC and 40% field capacity. A-accession, ML- available water.

Table 3. Effects of available water (% field capacity) on the leaf senescence and root-to-shoot ratio of 14 spider plant accessions.

	Leaf senescence					Root-to-shoot ratio				
ACCESSION	**100%**	**80%**	**60%**	**40%**	**MEANS**	**100%**	**80%**	**60%**	**40%**	**MEANS**
Baringo	2.3	3.7	8.0	12.3	**6.6**	0.14	0.18	0.20	0.30	**0.21**
Bungoma	2.3	4.7	6.3	11.3	**6.2**	0.04	0.22	0.23	0.27	**0.19**
GBK-027212	4.0	7.7	13.0	16.7	**10.3**	0.13	0.16	0.18	0.28	**0.19**
GBK-031850	4.3	7.0	12.7	16.3	**10.1**	0.13	0.16	0.19	0.26	**0.19**
GBK-032210	3.3	5.7	8.3	14.7	**8.0**	0.16	0.17	0.21	0.27	**0.20**
GBK-032340	4.7	7.7	8.3	15.0	**8.9**	0.14	0.18	0.25	0.30	**0.22**
GBK-040449	2.0	3.0	7.0	12.0	**6.0**	0.12	0.16	0.23	0.29	**0.20**
Homabay	3.0	4.7	7.0	14.3	**7.3**	0.10	0.17	0.29	0.34	**0.23**
Kakamega	3.7	7.7	12.3	14.7	**9.5**	0.15	0.18	0.22	0.48	**0.26**
Kisii	4.7	5.7	8.3	10.3	**7.3**	0.09	0.16	0.17	0.28	**0.18**
Kuria	2.3	4.7	7.0	13.3	**6.8**	0.19	0.22	0.26	0.37	**0.26**
Mombasa	1.3	2.0	3.3	4.7	**2.8**	0.12	0.16	0.26	0.29	**0.21**
Nandi	2.7	3.7	4.7	7.0	**4.5**	0.07	0.13	0.18	0.20	**0.15**
Commercial	2.3	4.0	7.3	12.0	**6.5**	0.17	0.20	0.26	0.36	**0.25**
MEANS	**3.1**	**5.2**	**8.2**	**12.5**	**7.2**	**0.13**	**0.18**	**0.23**	**0.31**	**0.21**
P-Value(A)	<.001					<.001				
P-Value(ML)	<.001					<.001				
P-Value(A×ML)	<.001					<.001				
LSD$_{\leq 0.05}$ (A)	0.8**					0.02**				
LSD$_{\leq 0.05}$ (ML)	0.5**					0.01**				
LSD$_{\leq 0.05}$ (A×ML)	1.7**					0.03**				
CV%	14.3					9.2				
MEAN	7.2					0.21				

LSD- Least significant difference, CV- Coefficient of variation, **Highly significant, * Significant, ns- Not significant, *100% field capacity, 80% field capacity, 60% FC and 40% field capacity. A-accession, ML- available water.

Table 4. Effects of available water (% field capacity) on the mass of leaves and seeds (tons/ha) of 14 spider plant accessions.

	Mass of leaves (t/ha)					Mass of seeds (t/ha)				
ACCESSION	**100%**	**80%**	**60%**	**40%**	**MEANS**	**100%**	**80%**	**60%**	**40%**	**MEANS**
Baringo	19.0	15.4	10.0	5.3	**12.4**	2.8	1.3	0.3	0.1	**1.1**
Bungoma	18.4	12.4	8.9	5.4	**11.3**	2.1	1.4	0.4	0.2	**1.0**
GBK-027212	17.4	14.9	8.2	4.7	**11.3**	1.0	0.6	0.2	0.1	**0.5**
GBK-031850	12.0	22.6	12.9	8.2	**13.9**	1.9	1.0	0.4	0.1	**0.9**
GBK-032210	33.2	18.4	12.9	8.3	**18.2**	2.0	1.2	0.6	0.3	**1.0**
GBK-032340	22.1	18.4	6.9	2.9	**12.6**	1.4	0.9	0.4	0.1	**0.7**
GBK-040449	29.2	20.4	8.3	5.0	**15.7**	1.7	0.9	0.4	0.2	**0.8**
Homabay	25.2	15.7	9.7	6.0	**14.1**	2.0	0.7	0.3	0.1	**0.8**
Kakamega	8.6	20.5	12.7	8.6	**12.6**	1.9	1.1	0.7	0.3	**1.0**
Kisii	22.0	18.4	13.1	4.4	**14.5**	2.2	1.2	0.5	0.2	**1.0**
Kuria	23.1	14.1	8.6	6.3	**13.0**	2.2	1.4	0.7	0.3	**1.1**
Mombasa	10.7	8.3	6.6	4.7	**7.6**	0.6	0.4	0.1	0.1	**0.3**
NANDI	11.6	10.4	6.3	3.4	**7.9**	1.2	0.8	0.3	0.2	**0.6**
Commercial	26.1	16.0	11.3	5.4	**14.7**	3.3	1.8	0.5	0.2	**1.4**
MEANS	**19.9**	**16.1**	**9.7**	**5.6**	**12.8**	**1.9**	**1.1**	**0.4**	**0.2**	**0.9**
P-Value(A)	<.001					<.001				
P-Value(ML)	<.001					<.001				
P-Value(A×ML)	<.001					<.001				
LSD$_{\leq 0.05}$ (A)	1.3**					0.9**				
LSD$_{\leq 0.05}$ (ML)	0.7**					0.1**				
LSD$_{\leq 0.05}$ (A×ML)	2.7**					0.2**				
CV%	12.8					12.3				
MEAN	12.8					0.9				

LSD- Least significant difference, CV- Coefficient of variation, **Highly significant, * Significant, ns- Not significant, *100% field capacity, 80% field capacity, 60% FC and 40% field capacity. A-accession, ML- available water.

Table 5. Average performance characteristics at different treatment levels (percentage of field capacity) for the 14 spider plant accessions evaluated.

Treatment	Leaves Per Plant	SPAD Value	LRWC	SLA (cm^2)	Senescing Leaves/ Plant	Leaf Yield (Tons/Ha)	Seed Yield (Tons/Ha)	DMP
100% FC	105.7	70.1	79.4	8.4	3.1	19.9	1.9	0.1
80% FC	91.1	62.2	72.0	7.4	5.1	16.1	1.0	0.2
60% FC	76.5	51.4	58.6	6.5	8.1	9.7	0.4	0.2
40% FC	60.5	43.3	50.3	5.8	12.5	5.6	0.2	0.3
MEAN	83.4	56.8	65.1	7.0	7.2	12.8	0.9	0.2
P-VALUE	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
LSD	1.5	1.1	1.7	0.1	0.5	0.7	0.1	0.01
CV%	**4.1**	**4.5**	**0.8**	**4**	**14.3**	**12.8**	**12.3**	**9.2**

Table showing means of measured values, P-Value at 5%, Least Significance Difference (LSD), and Coefficient of Variation (CV), SPAD value-Chlorophyll content, LRWC-Leaf Relative Water Content, SLA-Single Leaf Area (cm^2), FC-Field Capacity, DMP-Dry matter partitioning.

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