Asian Journal of Agricultural and Horticultural Research

5(1): 1-13, 2020; Article no.AJAHR.52705
ISSN: 2581-4478

Root-shoot Growth and Water Status of Garden Egg in Moisture Stressed Conditions in Ghana

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/AJAHR/2020/v5i130038
Editor(s):
(1) Dr. Magdalena Valsikova, Professor, Department of Vegetables Production, Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture (SUA), Nitra, Slovakia.
Reviewers:
(1) Chemutai Roseline, Bukalasa Agricultural College, Uganda.
(2) H. Filiz Boyaci, Bati Akdeniz Agricultural Research Institute, Turkey.
Complete Peer review History: http://www.sdiarticle4.com/review-history/52705

Original Research Article

Received 01 October 2019
Accepted 04 December 2019
Published 04 January 2020

ABSTRACT

Garden egg (*Solanum* spp) growth and development is affected in varying drought and poor soil conditions in Ghana. A study was conducted to identify the response patterns of garden egg genotypes root growth and plants water status under varying moisture stressed conditions of the Coastal and Sudan Savannahs of Ghana. A two year experiment was conducted on sixteen genotypes of the crop in Randomized Complete Block Design with three replications at Manga Agricultural Research Station in the Upper East Region, and University of Ghana, Legon experimental farm in the Greater Accra Region. At the first fruit maturity stages of around 80-90 days after transplanting, genotypes roots and shoots dry matter and leaf relative water contents (LRWC) data were collected and analyzed using GenStat Statistical Software. The genotype x location interaction significantly affected the genotypes LRWC and root growth in the dry season and moisture-stressed conditions. The moisture stressed tolerant genotypes maintained relatively high LRWC and root-shoot dry matter across locations of Manga and Legon. There were varied and location specific genotypes in root growth and LRWC, with the conditions of Manga favouring higher root growth than Legon; and that of Legon favouring higher retention of LRWC than Manga. The genotypes under the moisture stressed conditions had their LRWC varying from 50.6% to 65% at Legon and from 47.4% to 56% at Manga. Their root-shoot ratios varying from 0.24-0.35 at Legon and from 0.39-0.52 at Manga. The contributions of roots to total plant dry matter also varied from 15.6% to 20.5% at Legon and 22.5% to 30.1% at Manga. The genotypes that sustained

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higher root growth and retained LRWC of 57% and above under the moisture stressed conditions across locations were A3, A6B, A7, A8, A9A, and A11. These are attractive genotypes for garden egg improvement under moisture stressed conditions of the Coastal and Sudan Savannah agro-ecologies of Ghana.

Keywords: Garden egg; root-shoot; dry matter; moisture-stressed; agro-ecologies.

1. INTRODUCTION

Garden egg (*Solanum spp*) is a vegetable crop cultivated and consumed in sub-Saharan Africa [1,2]. In Ghana, it is cultivated in agro-ecologies associated with poor and fragile soils, limited moisture, intermittent drought and variable climatic conditions. These conditions though unfavourable to the growth, development and yield of the garden egg crop, there are reports of the crop tolerance to many unfavourable environmental conditions, including moisture deficits and drought [3,4].

This could be due to the garden egg plants ability to undergo many physiological and agronomic processes that confer tolerance of the crop to moisture limiting environments. In physiological processes, drought tolerant plants sustain growth and produce seeds/fruits, whereas in agronomic processes, drought tolerant plants require sufficient growth to produce economic yield [5]. Drought effects on crop productivity could be exacerbated due to climate change [6], and warrant the need to identify genotypes that exhibit these physiological and agronomic tolerance to abiotic stresses [7].

Crop species however differ in adaptive mechanisms to cope with environmental stresses, by either avoiding, escaping from stress or through dehydration tolerance of the protoplast [8]. Plants dehydration tolerance is mainly determined by leaf relative water content (RWC) which reflects in plants water status, and the balance between water supply to the leaf tissues and transpiration rate [9]. Crop plants also avoid water deficits and attain high yields by developing vigorous root system in water-limited environments [10]. The vigorous root growth is necessary because, roots are the primary sensors of water deficit in soils and are also the main triggers of the physiological processes in plants. So vigorous root growth and stable leaf RWC are particularly important considerations when soil nutrients and water stress effects are significant [11,12]. There is therefore an inter-relationship between root growth and water relations of plants [13,14].

Naturally, it is the roots that provide anchorage, absorb and supply water, nutrients and hormones to shoots (leaves and stems) of plants for many physiological and biochemical processes associated with growth, development and consequently economic yields of crop plants [15,16]. The roots and shoots (stems and leaves) are functionally interdependent and maintain a dynamic balance in biomass, which reflects in relative abundance of above-ground resources (light and CO_2) compared with root-zone resources (water and nutrients) [17,15,16]. Roots for instance improve soil organic matter by contributing to soil pools of organic carbon, nitrogen, and microbial biomass [18,16].

There is therefore the need to understand plants root growth characteristics for improving productivity of crops in agro-ecosystems [19,16]. The development of robust root system is necessary for absorption and translocation of water and nutrients to shoots for photosynthetic products build-up and for good yields of crops [20,16]. Conventionally, plants with a higher proportion of roots can compete more effectively for soil nutrients and water uptake, while those with a higher proportion of shoots can intercept more light energy [21,15]. Although roots normally contribute only 10-20% of the total plant weight, a well-developed root system is essential for healthy plant growth and development [22,16]. Root growth can be measured in terms of root density, length, and weight, but root dry weight or biomass is often better related to crop yields than root length or density [12,15,16].

Comparatively, plants with high root ratio will most likely absorb more nutrients from the soil and help in increasing above ground (shoot) biomass than those with low root ratios [23]. As shoot growth is influenced by above-ground conditions, root biomass is influenced by below-ground conditions, where low availability of either water or nutrients leads to greater root-shoot ratio. Root-shoot ratio is therefore the amount of plant tissues that have supportive functions to the amount of those that have growth functions [16]. Change in root-shoot ratio during a plant's life cycle is part of an intrinsic ontogeny, but growth rates of roots and shoots continually adjust to resource availability with photo-assimilates, and hence biomass.

The use of crop species and cultivars tolerant to stress conditions, couple with the use of appropriate cultural practices, can improve plant root system function under favorable and unfavorable environmental conditions [16,8]. One of the methods for screening plants for abiotic stress tolerance is genotypes ability to maintain leaf water status and produce under water limiting conditions. Hence, variation in leaf RWC and root growth in response to varying growth conditions among garden egg genotypes is therefore needed for screening purposes in garden egg. The garden egg genotypes that sustain root growth and leaf RWC under stressed environmental conditions will be the attractive genotypes among many for crop improvement under drought conditions.

Genotypic differences in root growth among crop species and genotypes of the same species under similar and variable environmental conditions are now well demonstrated, and the possibility of developing genotypes of desirable root systems to soil properties offers prospects for the future [16].

Therefore, the incorporation of vigorous root growth and stable water status into desirable genotypes for moisture limiting environments can enhance yields in garden egg. However, information on garden egg root growth and LRWC dynamics in varying growth environments is scattered and not readily accessible. The objective of the study is to identify genotypes that sustain roots-shoots growth and LRWC under varying moisture conditions of Ghana.

2. MATERIALS AND METHODS

2.1 Planting Materials

Fourteen (14) garden egg (*Solanum aethiopicum*) genotypes were obtained from Crop Science Department, University of Ghana, Legon, and Plant Genetic Resources Research Institute (PGRRI) of the Council for Scientific and Industrial Research (CSIR), Bunso; and two popular local varieties of bitter garden egg (*Solanum incanum*) commonly cultivated in Bawku area, were obtained from garden egg farmers in Bawku. The genotypes were grown in two successive rainy and dry seasons' conditions of Coastal and Sudan savannah agro-ecologies for two years. The experimental procedure used for the genotypes was the same across seasons and locations.

2.2 Experimental Sites Characteristics

Field experiments were conducted at the Manga Agricultural Research Station near Bawku, in the Sudan savannah agro-ecology of the Upper East Region (11^{o} 11'N, 00^{o} 17' W, 249 m above sea level). and the University of Ghana, Legon experimental farm near Accra, in the Coastal savannah agro-ecology of the Greater Accra Region (5°38' N, 00°11' E, 300 meters above sea level) from 2012 to 2014. The experimental fields of Manga have gently sloping terrain of gradient 1-2% and those of Legon have gently sloping terrain of gradient 0.5-1%. The soil at Manga site is classified as Plinthic Lixisol whilst that of Legon is classified as Rhodic Lixisol [24]. The soils are deep to moderate deep and well drained.

2.3 Soil Sampling and Analysis

Six soil samples were taken at random from scrapped-off surface at the depth of 0-30 cm at different locations of Legon experimental farm and Manga experimental farm. The soil samples were dried and homogenised by passing them through 5mm sieve.

The soil samples were analyzed for their organic matter content following Nelson and Sommers [25], soil nitrogen following Macro - Kjeldahl [26] method, available phosphorus following Abdu [27], particle sizes following Beretta, *et al*. [28] and pH following ASTM [29]. Bulk density was determined using core sampler [30] to collect soil samples at six different locations at each of the experimental sites. All the samples were analyzed in duplicates. Table 2 contains the results from the physical and chemical analysis of the soil samples.

2.4 The Soils Moisture Content

Soil moisture content at the Legon and Manga Experimental farms was determined following standard procedures and methods. The sampled soils were weighed and measured at different pressure plates of 0.3 bars and 15 bars, and

Table 1. Physical and chemical characteristics of soils at 0-30 cm depths from Manga and Legon experimental fields

Location	Manga	Legon	
Soil Characteristics	**Mean**	**Mean**	**Method**
Physical			
Sand (%)	80.62	65.48	Beretta, et al. [28]
Silt (%)	2.42	7.76	
Clay (%)	18.45	27.85	
Bulk Density (g/cm^3)	1.45	1.65	Prikner, et al. [30]
Chemical			
pH1:1 H2O	6.44	5.53	ASTM [29]
Nitrogen (%)	0.13	0.15	Macro-Kjeldhal Method [26]
Organic Matter (%)	0.77	1.45	Nelson and Sommers [25]
Available P. (mg/L)	4.25	4.76	Abdu [27]

Table 2. The Monthly average climatic data at Manga and Legon experimental farms during the 2012 and 2014 experimental period

	Climatic Parameter							
Location/Year	**Rainfall(mm)**		**Temperature(°C)**		**Relative humidity (%)**		**Sunshine(Hours)**	
Year	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Manga								
Monthly Mean	47.6 (4)*	43 (3)	28.3	29.4	63.1	62.6	7.5	7.4
Legon								
Monthly Mean	62.0 (3)	37.6 (3)	27.3	27.6	76.5	74.9	5.8	6.2

( ) = Average days of rainfall per month*

oven-dried at 105ºC for 48 hours to constant weights before weighing [31,32]. During the rainy season, the respective soil moisture contents at Legon and Manga were 68.4% and 63.6%, in the dry season (irrigated condition) were 58.4% and 54.3% and under the moisture-stressed were 26.5% and 24.7%.

2.5 Climatic Data Collection

The garden egg genotypes were nursed and transplanted at two locations at each experimental sites of Manga and Legon, from 2012 to 2014 rainy and dry seasons. The temperature, relative humidity and sunshine data were collected at University of Ghana, Legon on Hobo Pro data loggers (Onset Computer Company, Pocassett, ME, USA) and at Manga from the weather station at the Manga Agricultural Research Station. The rainfall data from both experimental sites were collected using on-farm rain gauges. The climatic data were collected daily and averaged on monthly basis. Table 3 presents the summary description of the yearly mean climatic data collected during the study period at Legon and Manga.

Soils of both locations are generally sandy, low in organic matter and water-holding capacities (Table 2) and are prone to nutrient loss and accelerated soil drying and acidification. These characteristics of the soils at the experimental sites can influence plants roots and shoots development and hence crop performance.

2.6 Experimental Layout and Treatments

The experimental fields were ploughed, harrowed and laid out in a randomized complete block design (RCBD) with three replications in both rainy and dry season conditions at Manga and Legon. In the rainy season and dry season, each genotype was represented by a two-row plot in each replication. At both locations and seasons, the inter-row and intra-row spacing were 90 cm. The transplanting at both locations for the two-year period was done in May-June, coinciding with the onset of rainy season and November-December coinciding with the onset of dry season. The main treatments were genotype, location (Legon and Manga), rainy season, dry season, and moisture-stressed conditions. There were sixteen (16) genotypes, three (3) soil moisture conditions and two (2) locations, giving ninety-six (96) treatment combinations.

2.7 Field Practices

The compound fertilizer N: P: K (15-15-15) was applied to all plots at four weeks after transplanting at the rate of 250 kg\ha, and split dose of Ammonium Sulphate ($(NH4)_2SO_4$) was applied at the flower initiation. Weeds, pests and disease incidence were appropriately managed. The plants of the genotypes were sampled and uprooted at the first fruits physiological maturity stages of between 80-90 days after transplanting. Plants in selected plots were uprooted after depriving them of water for fourteen days.

2.8 Determination of Leaf Relative Water Content (LRWC)

Four uppermost freshly-green leaves were immediately picked after excision from four recorded plants per genotype per replication at first fruit maturity stages in the rainy season, dry season (irrigated) and fourteen-days of water deprivation (stressed). The excised leaves of each treatment per location were well cleaned for leaf relative water content (LRWC) determination following Wang *et al*. [33] and Yamasaki and Dillenburg [34].

2.9 Determination of Root-shoot Ratio and Dry Matter

At the first fruit maturity stages of about 80-90 days after transplanting, plant stands were dug 80 cm wide and 60 cm deep and the whole plant along with roots were lifted from the soil. The root portions were dipped in a bucket full of water to wash off soil particles. Before placing the roots in the bucket, a sieve was placed at the bottom of the bucket. The roots were separated from the soil by gradually moving the roots in the water. After washing, the peat masses on the roots were removed with forceps. The plants root portions were separated from shoots by cutting at the soil level. The broken root portion collected in the sieve was carefully washed and added to the respective roots. The roots and shoots were separately dried at 70ºC for 48 hours and weighed. The root-shoot ratio was determined as dry weight for root / dry weight for shoot of plant.

Roots contribution to total plant dry matter (%)

$$= \frac{\text{Root dry weight}}{\text{Dry weight of roots and shoots}} \times 100$$

2.10 Data Analysis

The determined genotypes root-shoot ratios, roots contributions to total dry matter and leaf relative water content (LRWC) data were subjected to analysis of variance using GenStat Statistical Software (12^{th} Edition). The determined parameters data sets for each location, seasons and moisture treatments for the two years were separately analyzed by general analysis of variance (ANOVA) for the estimation of variation among genotypes. Where ANOVA showed significant differences, means were separated by the least significant difference (LSD) at probability level of .05.

3. RESULTS

3.1 Leaf Relative Water Contents (LRWC) in Garden Egg

The growth and performance of crop plants in moisture stressed environments largely depend on their leaf water status. This calls for the study on the leaf water content of garden egg under varying moisture conditions of Manga and Legon. The location and genotype x location interaction significantly ($p = .05$) affected the genotypes LRWC during the rainy, dry season and drought-stressed conditions. Under these conditions, the LRWC of the genotypes within and across locations were also significantly different ($p = .05$).

The LRWC of the genotypes was highest under rainy season conditions, followed by dry season conditions, with the moisture-stressed conditions recording the lowest levels (Table 3). The rainy season at Manga had genotypes with LRWC ranging from 68.4% (A9F) to 77.5% (Bawku2); and at Legon from 68.3% (A4) to 79.2% (Bawku1). The rainy season conditions across locations had LRWC ranged from 70.4% (A2) to 78.1 % (Bawku1) (Table 3).

During the dry season conditions at Manga, the LRWC of genotypes ranged from 54.1% (A3) to 62.2% (A10); those under Legon dry season conditions were from 64.8% (A9F) to 69.1% (Bawku2); whereas LRWC of genotypes under dry season conditions across locations ranged from 60.2% (A3) to 65.2% (Bawku2). The first six highest genotypes in LRWC under the dry season conditions of Manga agro-ecology were A10 (62.2%), Legon1 (61.4%), Bawku2 (61.2%), A6F (59.6%), A8 (58.6%) and A7 (58.1%); while at Legon dry season conditions, the genotypes were Bawku2 (69.1%), A11 (68.2%), A8 (67.7%),

Table 3. Leaf relative water content (LRWC) of garden egg genotypes at first fruit maturity under varying moisture conditions at two locations

Condition	Rain season			Dry season			Moisture-stressed		
Location	Manga	Legon	Mean	Manga	Legon	Mean	Manga	Legon	Mean
Genotype	%	%	%	%	%	%	%	%	%
A1	68.9b	73.2a	71.2b	56.1b	65.6b	60.9b	42.2b	45.1c	43.6c
A2	69.1ab	71.2ab	70.4b	56.0b	66.7ab	61.4b	41.7b	44.9c	43.8bc
A3	74.7a	75.0a	74.8a	54.1b	65.8b	60.2b	46.6a	53.7a	49.9a
A4	73.9a	68.3b	71.2b	55.9b	67.1ab	61.8b	40.9b	45.8c	43.9bc
A6B	71.9ab	70.3b	70.6b	56.2b	66.5ab	61.4b	43.3b	47.6c	45.4b
A6F	75.8a	69.0b	72.5ab	59.6a	67.3ab	63.5a	44.7ab	51.9bc	48.3a
A7	71.7ab	77.0a	74.3a	58.1ab	65.4b	61.8b	47.4a	53.5ab	50.4a
A8	68.5b	75.1a	71.7ab	58.6ab	67.7ab	63.4a	47.8a	54.4ab	51.2a
A9A	74.6a	75.9a	75.3a	57.1b	65.4b	61.3b	46.8a	54.7ab	51.2a
A9F	68.4b	76.4a	72.4ab	57.8b	64.8b	61.3b	47.3a	51.4bc	49.3a
A10	71.1ab	76.6a	73.8a	62.2a	67.5a	64.9a	47.6a	44.8c	46.2b
A11	72.2a	75.6a	73.9a	57.3b	68.2a	62.8ab	45.6ab	55.3a	50.6a
A12	68.7b	76.6a	72.6b	55.8b	64.7b	60.3b	45.8b	51.2bc	48.6a
Legon1	70.4ab	75.1a	72.7b	61.4a	67.5a	64.5a	47.0a	46.4c	46.6b
Bawku1	77.3a	79.2a	78.1a	56.8b	67.3a	62.1ab	48.1a	57.5a	52.8a
Bawku2	77.5a	76.6a	77.0a	61.2a	69.1a	65.2a	49.6a	55.8a	52.7a
Mean	72.1	74.4	73.3	57.8	65.7	61.8	45.9	50.9	48.4
%CV	4.5	4.3	4.2	3.9	1.9	2.5	6.9	8.9	7.5

Means with same letters in a column are not significantly different at 5% level of probability.
Rainy season (Location; Genotype x Location**);*
*Dry season (Location **; Genotype x Location**); and, moisture-stressed (Location**; Genotype x Location**).*
**, ** = Significant at 5% and 1% level of probability respectively,*

Legon1 (67.5%), Bawku1 (67.3%), and A4 (67.1%). Across locations, the dry season conditions had the best six LRWC accumulating genotypes to be, Bawku2 (65.2%), A10 (64.9%), Legon1 (64.5), A6F (63.5%), A8 (63.4%) and A11 (62.8%) (Table 3).

Plants of genotypes subjected to moisture-stressed conditions had LRWC with CV of 6.9% at Manga to 8.9% at Legon (Table 3). There was a general reduction trend in LRWC in genotypes from rainy season > dry season > moisture-stressed conditions. Under moisture stressed conditions, the genotypes LRWC ranged from 40.9% (A4) to 49.6% (Bawku2) at Manga and from 44.8% (A10) and 57.5% (Bawku1) at Legon. Those across locations recorded LRWC of between 43.6% (A1) and 52.8% (Bawku1). There were varying levels of LRWC in genotypes under moisture-stressed condition, but most of the genotypes recorded LRWC above 50% (Table 3). The first six genotypes highest in LRWC at Manga were, Bawku2 (49.6%), Bawku1 (48.1%), A8 (47.8%), A9A (54%), A10 (47.6%) and A7 (47.4%); while those of Legon were, Bawku1 (57.5%), Bawku2 (55.8%), A11 (55.3%), A9A (54.7%), A8 (54.4%) and A3 (53.7%). The highest six genotypes in LRWC under moisture-stressed conditions across locations were the Bawku1 (52.8%), Bawku2 (52.7%), A8 (51.3%), A9A (51.2%), A11 (50.6%) and A7 (50.4%).

In general, the LRWC in genotypes under Manga conditions was lower than that in genotypes under Legon conditions. Plants water status is crucial in moisture deficit conditions, and those genotypes that retained higher LRWC under moisture stressed conditions could be considered more tolerant to drought conditions. However, roots are the primary sensors of water deficit in the soil, and the interconnection between root development and leaf water relations have been the major triggers of many physiological perturbations in plants [13,14]. The root characteristics play important role in the adaptive mechanisms of plants and could help in screening for desirable genotypes under moisture stressed conditions. The root-shoot ratios or roots-total dry matter of plants under limited moisture conditions are the response mechanisms of plants to cope with moisture or drought stress conditions.

3.2 Root-shoot Growth in Garden Egg

The root relative to shoot dry matter of the genotypes showed significant differences (P = .05) under dry season conditions of growth in Manga and Legon (Fig. 1). The root relative to shoot dry matter between genotypes in the rainy season conditions of growth at each location were not significantly different (p = .05), but the root-shoot dry matter ratios were higher among genotypes at manga than at Legon. Root-shoot ratio of genotypes under rainy season conditions of Manga varied from 0.2 in A6F to 0.26 in A3; whilst at Legon they varied from 0.15 in A4 to 0.24 in A2 (Fig. 1).

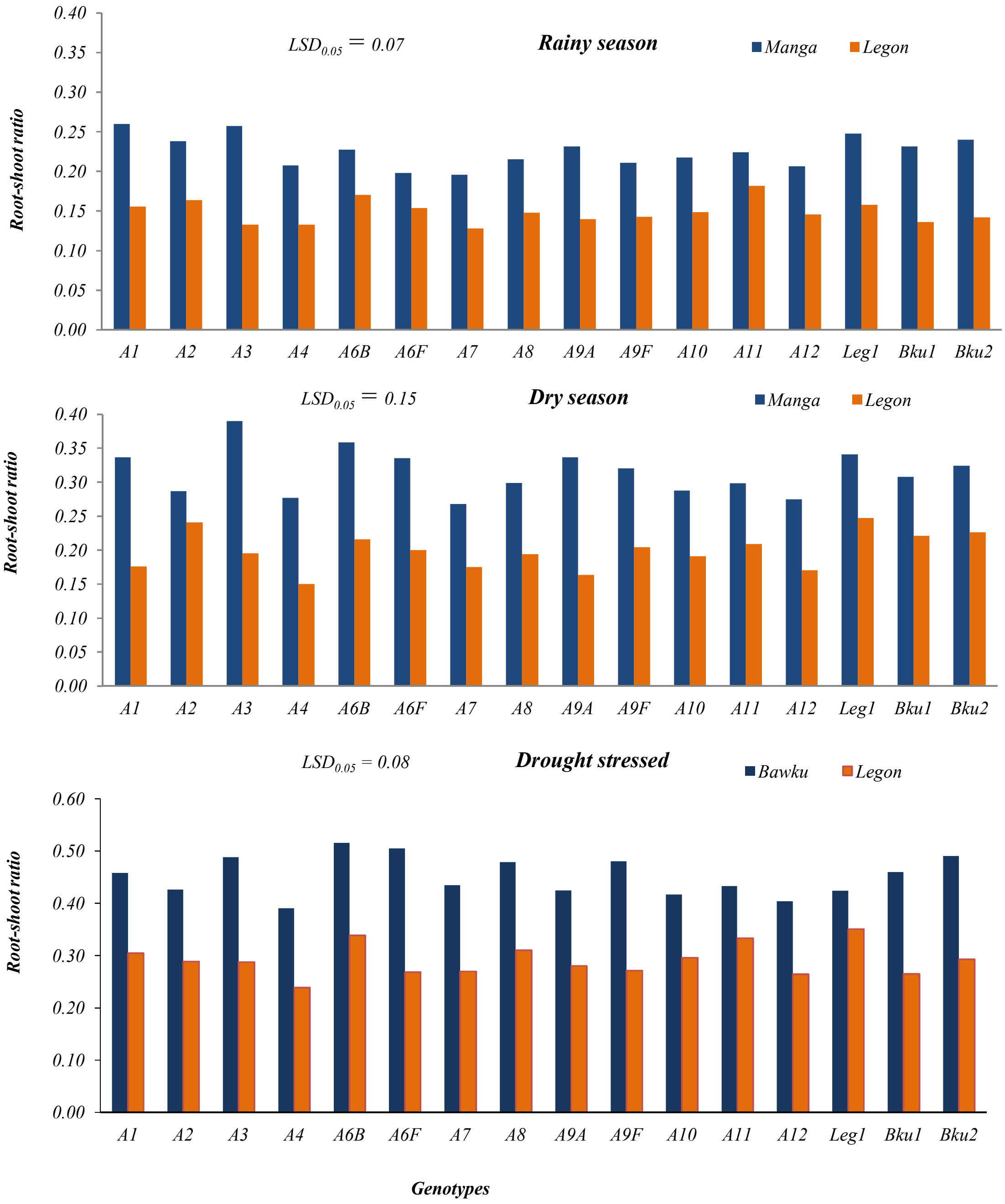

Fig. 1. Root-shoot growth ratios in garden egg genotypes under varying moisture conditions at two locations

Under the dry season conditions, the genotypes root-shoot ratios were higher than rainy season conditions, and ranged under Manga conditions from 0.27 in A7 to 0.39 in A3; under Legon conditions it varied from 0.15 in A4 to 0.25 in Legon1; whereas dry (irrigated) conditions across locations recorded root-shoot dry matter ratios in a range of 0.13 in A4 to 0.41 in Bawku2 (Fig. 1). Genotypes under moisture stressed conditions across both locations, had root-shoot biomass ratios of genotypes at Manga ranged from 0.39 in A4 to 0.52 in A6B; whereas those of Legon conditions ranged from 0.24 in A4 to 0.35 in Legon1.

The first six genotypes with the highest root-shoot ratios under dry season conditions at Manga were the A3, A6B, Legon1, A1, A9A and Bawku2; whereas those at Legon were the Legon1, A2, Bawku2, A6B, Bawku1 and A11. The highest six genotypes in root-shoot ratios under the drought stressed conditions at Manga were A6B, A6F, Bawku2, A3 and A8 and A9F; whereas those at Legon were the Legon1, A6B, A11, A8 and A10 and A1 (Fig. 1). Across both locations, the genotypes with the highest root growth relative to shoots under the drought stressed conditions were A6B, A8, Bawku2, A3, Legon1, and A11. Generally, the genotypes root to shoot growth ratios were higher under Manga conditions than under Legon conditions, indicating that more roots relative to shoots were produced by the genotypes under Manga conditions than under Legon conditions.

The contribution of roots dry matter to total dry matter of plants also showed significant differences (P = .05) between genotypes and locations (Fig. 2). In the rainy season, roots contribution to total dry matter at Legon, ranged from 10.5% in A4 to 15.1% in A11 and at Manga from 14.9% in A4 to 21.8% in Bawku2. In the dry season, genotypes roots contribution to total dry matter ranged from 13.2% in A4 to 18.2% in Bawku1 at Legon; and 19.3% in A4 to 24.3% in A6F. Under moisture stressed conditions, genotypes roots contributions to total dry matter ranged from 22.5% in A4 to 30.1% in A6B at Manga; and 15.6% in A4 to 21.% in Bawku1 (Fig. 2). This result is in line with reports elsewhere on other crops that roots can contribute up to 7-43% of the total plants aboveground and belowground biomass [35]. Similarly, the contribution of root weight to total plant weight of food crops has been reported varying from 3-21% [17].

In this study, promising garden genotypes under water limiting conditions were identified based on their roots dry matter relative to total plant dry matter under dry season and moisture-stressed conditions within and across locations of Manga and Legon.

The genotypes with the highest root dry matter under dry season conditions at Manga were A6F, A6B, A9F, Bawku2, A3 and Bawku1; and those of Legon were Bawku1, A2, Legon1, A8, A9F and A9. Similarly, genotypes with highest root dry matter under moisture stressed conditions at Manga were A6B, A6F, Bawku2, A3, Bawku1 and 9F; and those at Legon were A8, A2, Legon1, A11, A6B and A6F (Fig. 2).

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4. DISCUSSION

4.1 Soil Moisture and Leaf Relative Water Content (LRWC) in Garden Egg

The location and seasonal differences significantly affected the LRWC in garden egg, with the rainy season recording higher levels than dry season (irrigated) and moisture stressed conditions (Table 3). There were significant genotype, genotype x environment interaction effects on LRWC, but average values were narrower in variations at seasonal and location levels. Although the LRWC were quite similar in genotypes, the Legon conditions registered higher values than Manga, advancing reasons that the relatively low temperatures and high relative humidity conditions of Legon could have greatly reduced the transpiration demand of the plants at Legon.

There were significant genotypic differences in LRWC, indicating that the genotypes differ in their adaptive abilities in varying soil moisture conditions. The moisture stressed conditions also had the genotypes recording lower levels of leaf relative water contents, and this could have been due to high temperatures and low relative humidity in the dry season, increasing the transpiration demand of the plants. The reduction in water content in leaves due to transpiration demand is conditioned by the stomatal aperture, signaling that water stress has developed in the leaves [36,37]. Additionally, the drastic reduction in LRWC under moisture stressed conditions could have been attributed to increased water demand for root growth to enhance plants tolerance to harmful effects of water shortage.

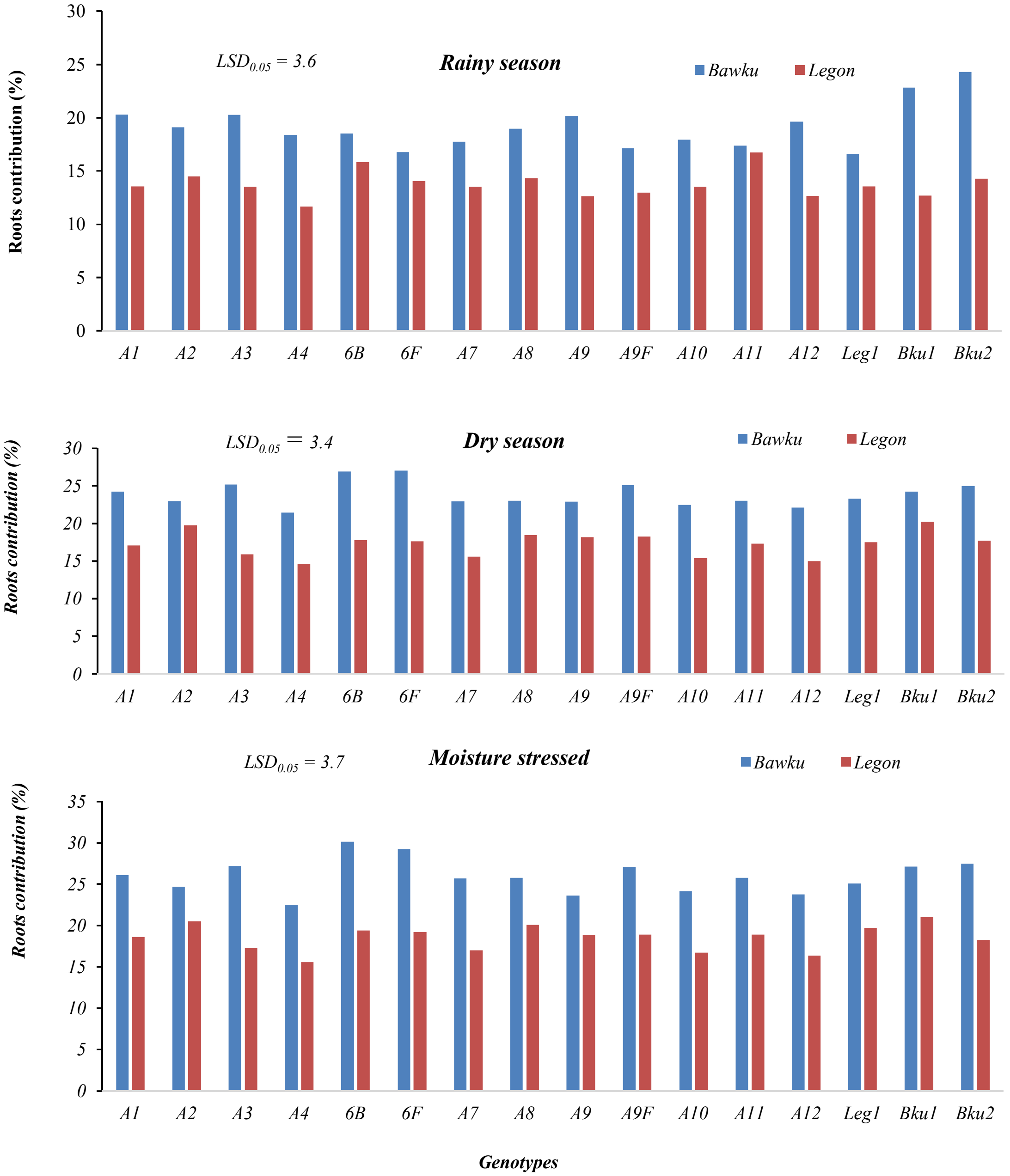

Fig. 2.The percentage contribution of roots to total plant dry matter of garden egg genotypes at first fruit maturity under varying moisture conditions at two locations

Although some plants of the genotypes were close to wilting under the moisture-stressed conditions, the LRWC was still more than 50% in almost all the sixteen genotypes. This is an indication that irrespective of genotypic variability, garden egg is generally hardy and tolerant to drought or moisture stressed conditions. This observed variability in the genotypes response to drought conditions could lead to the identification of traits that are important in selecting and breeding for drought tolerance [38] in garden egg. This also presupposes that environmental conditions could be one of the factors responsible for the fluctuation of moisture content of leaves in different seasons of growth [39] and subsequent yields of garden egg in Coastal and Sudan savannahs of Ghana.

It is therefore suggestive that genotypes that are able to produce desirable yields under dry season conditions should have greater abilities to maintain high leaf relative water contents (LRWC). Though there were genotypes with high levels of LRWC at seasonal or location levels, the highest six genotypes in LRWC under moisture-stressed conditions across locations were Bawku1, Bawku2, A9A, A8, A11 and A7. These genotypes maintained high leaf water contents under moisture stress across locations, and the maintenance of high water content in leaves is a mechanism for drought tolerance under soil drying conditions [40]. The genotypes may also tolerate better, the periodic drought stressed conditions commonly encountered in Sudan and Coastal savannahs of Ghana.

4.2 Soil Moisture and Root-shoot growth in Garden Egg

The locational and seasonal differences in soil moisture and stressed conditions significantly influenced roots-shoots growth in garden egg plants (Figs. 1 & 2). The root-shoot dry matter followed soil moisture pattern under rainy, dry season and moisture stressed conditions, with the highest root-shoot growth occurring in moisture stressed conditions (Figs. 1 & 2). This suggests that soil moisture status and hence roots explorative and absorptive ability are the main determinants of plants water status and general performance of crop plants.

So root growth, water uptake and plant water status are the main triggers of many physiological processes in plants [13,14]. The development of robust root system is therefore necessary for absorption and translocation of water and nutrients to shoots for photosynthetic products build-up and good crop yields [20,16]. Plants with higher proportion of roots can compete more effectively for soil nutrients and water uptake, while those with a higher proportion of shoots can intercept more light energy [21,15].

The increased root growth under moisture deficit conditions could be attributed to channeling of soluble sugars to roots as the main storage organs and thereby enhancing root growth. It could also be that when nutrients and water are supplied to leaves from roots at the fruit formation and maturity stages, the photosynthesis process remains high, and this secures the supply of carbohydrates to roots [17] for storage and growth.

There were higher genotypes root-shoot ratios and root contribution to total plant dry matter at Manga than at Legon conditions which is an indication that Manga conditions are more favourable for garden egg root growth than Legon conditions (Figs. 1 & 2). The Manga soils were sandier than that of Legon, suggesting that root growth in garden egg is enhanced in sandy soils. The higher root growth could have also been attributed to genotypes explorative ability for nutrients and moisture in sandy, low moisture retention and poor soil conditions at Manga.

Clearly, the availability of soil nutrients and water for plant roots uptake are independent processes but are closely related [13,14]. Under moisture stressed conditions, roots first sense water deficit and increase its exploration, but the development of aerial parts of plants declines, due to reduction in uptake of nutrients and water by the plant [13, 14].

The allocation of assimilates for higher dry matter to root parts during moisture stressed conditions (Figs. 1 & 2) is an indication of greater ability of the garden egg crop to survive during drought. Apart from environmental conditions influencing root growth, its growth varies among genotypes of the same crop species [41,42,43,44]. Therefore, identifying and selecting superior genotypes for extensive root development is important consideration in developing drought tolerant genotypes [13,16].

The genotypes A3, A6B, Legon1, A9A, Bawku1 and A6F developed more roots under moisture stressed conditions of Manga and Legon, and could be considered as drought tolerant genotypes. Therefore, genotypes ability to develop vigorous roots in moisture stressed conditions should form part of the requirements in garden egg improvement programmes for drought-prone savannah areas of Ghana.

5. CONCLUSION

There were genotypic differences in garden egg LRWC, root-shoot ratio and root contribution to total plant dry matter at the location, seasonal and soil moisture levels. The genotypes were adaptive to response under moisture stressed conditions, by allocating assimilates to root growth and concurrently reducing LRWC due to increased water demand for root growth. Genotypes that reduced LRWC and increased root growth were considered tolerant to moisture stressed environments. The inherent ability of garden egg to develop vigorous roots and retain high water status in moisture stressed conditions enhances its tolerance to harmful physiological effects associated with plant development in moisture limiting environments.

There were location specific adapted genotypes, but with wide variations among genotypes in retaining LRWC, root-shoot ratio and roots contributions to total plant dry matter. Six of the sixteen genotypes that sustained higher root growth and retained LRWC of 57% and above under moisture stressed conditions across locations were A3, A6B, A7, A8, A9A, and A11. These genotypes are promising for garden egg improvement in moisture limiting conditions of the Coastal and Sudan Savannah agro-ecologies of Ghana.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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