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Assessing Garden Egg Genotypes for Sugars Accumulation in Varying Growth Conditions in Ghana

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Authors' contributions

This work was carried out in collaboration between all authors. Authors JKL and KO designed the study, collected the data and performed the statistical analysis. Authors JKL and FKK wrote the protocol and wrote the first draft of the manuscript. Authors JKL and KO managed the analyses of the study. Author JKL managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

An experiment was conducted on garden egg (*Solanum* spp.) genotypes to investigate sugars' accumulation response patterns of the genotypes in rain-fed and drought stress conditions at two locations in Ghana. Sixteen genotypes were grown over two years in randomized complete block design with three replications in experimental fields at Manga in the Sudan Savannah and University of Ghana, Legon in the Coastal Savannah agro-ecological zones. During the reproductive (flowering and fruit set) stages of the genotypes, the leaf sugars accumulation data from each growth condition and location were collected and analyzed. The sugars which confer tolerance of the crop to variable seasonal and drought conditions varied significantly due to the genotype and genotype x location interaction effects on their accumulation. The genotypes were found to develop internal drought survival mechanisms by decreasing total soluble sugars, starch and carbohydrates and increasing leaf relative water contents, thereby enabling plants to withstand periodic drought better. The adaptive response mechanism of the crop was also manifested in the

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genotypes lower sugars accumulation response patterns during drought-stress, but with Manga recording lower levels than Legon conditions. Among the genotypes studied, the A1, A2, A3, A4, A6B and A7 were the most stable in sugars accumulation under drought-stressed and dry season conditions with associated high temperatures across the locations. These genotypes could be incorporated in drought-stressed tolerant improvement programmes in Ghana.

Keywords: Garden eggs; genotypes; drought stress; sugars accumulation.

1. INTRODUCTION

Garden egg (*Solanum* spp.) is a widely cultivated and consumed vegetable crop across sub-Saharan Africa [1,2]. The crop is grown mainly under rain-fed and irrigated conditions of the arid and semi-arid zones including Ghana, where drought is a major yield-limiting factor. The emerging evidence of climate change is believed to even aggravate the drought situation further [3-5]. Drought therefore is a worldwide problem which largely affects plants growth, development and survival rate, leading to enormous crop yield losses.

In Ghana, garden egg is grown under highly unstable conditions of high temperatures, erratic rainfall and intermittent drought in the Sudan and Coastal Savannah ecologies. These unstable growth conditions greatly affect the crop's growth and yield in these agro-ecological zones. Drought stress in particular is very common in the fields of these ecologies, and numerous studies [6-8] elsewhere have shown that it has substantial negative impacts on plant growth and development. Drought effect on crop growth and yield however depend upon the timing and duration; and plants are most susceptible during reproductive phase, when brief periods of water shortage could greatly reduce yield [9,10,6].

In order to cope with and rapidly adapt to these drought-stress conditions, plants in the field evolve many tolerance mechanisms to sustain growth and productivity [11,12]. The mechanism of plants' drought-stress tolerance involves many physiological and biochemical metabolism, and interactions between several hormones. These hormones further help in developing different approaches to improve drought tolerance in plants and reduce yield losses. Many researches in recent times have therefore focused on the natural variations in biotic and abiotic stress tolerance in crop species. Studies indicate that drought-stress sensitive crop species show relatively high water loss and many drought stress tolerant physiological processes are related to changes in leaf water status [13].

Sugars are very important bio-molecules involved in tolerance of water shortage, especially during reproductive stage [14]. Sugars' accumulation during reproductive stages from flowering to fruit formation are involved in various important physiological roles [15]. The soluble sugars, starch and carbohydrates in the form of storage products play significant role in structural stability of many different molecules [16], which confer tolerance to different environmental stresses. So differentiating the natural variation in drought tolerance and physiological processes such as sugars accumulation in plants bring reliable basis and innovative insight for plant breeding.

Garden egg is one of the most drought tolerant solanaceous vegetables [17], but different genotypes under drought-stress may develop different strategies to tolerate or avoid drought stress conditions. Soluble sugars accumulation might have been one of the most vital response mechanisms of garden egg to resist changing environmental conditions in Ghana. Little published work exists on sugars accumulation pattern in garden egg plants. This study was therefore undertaken to assess soluble sugars accumulation in garden egg genotypes under varying growth conditions of the Coastal and Sudan Savannahs of Ghana.

2. MATERIALS AND METHODS

2.1 The Study Areas

Field experiments were conducted at the Savannah Agricultural Research Institute (SARI), Manga, Bawku, in the Sudan Savannah agro-ecology and at the University of Ghana, Legon, Accra, in the Coastal Savannah agro-ecology. These agro-ecological zones are among major garden egg growing areas in Ghana. The SARI at Manga, Bawku is located in the North-eastern corner of the Upper East Region of Ghana, on Latitude 11°11'and 10°40'N and Longitude 0°18' W and 0°6'E, with an altitude of 249 meters above sea level, with topography of gently sloping terrain of gradient 1-2%. The University of Ghana experimental farm is located in the north-east of the Greater Accra region of Ghana, on Latitude 5°38'45"N and Longitude 00°11'13"E with an altitude of approximately 300 meters above sea level and with an undulating terrain.

2.2 Climatic Data Collection

Climatic data (Table 1) was collected during the respective rainy and dry seasons of 2012-2013 and 2013-2014 at each experimental site of Legon and Manga. Until flowering, temperature, relative humidity and sunshine data were collected daily at the University of Ghana, Legon-Accra on Hobo Pro data loggers (Pocassett, ME, USA), whereas those of Manga-Bawku were taken from on-farm weather station. The rainfall data from both experimental sites was collected using on-farm rain gauges.

2.3 Soil Sampling and Analysis

Soil samples were randomly collected from the Legon and Manga experimental plots at 0-30 cm depth at six (6) different positions, after scrapping off the surface litters. The sampled soils from each experimental plot at each location in the rainy and dry seasons were air-dried and homogenised by sieving through 5 mm sieve.

The sieved soils were analyzed for their organic matter content following [18]. Nitrogen and available phosphorus contents were respectively determined using Macro-Kjeldhal [19] and P-Bray No. 1 methods. The soil pH, particle size, bulk density, gravimetric soil water content and soil available water were determined following [20] and [21]. The soil samples were analyzed in duplicates for their physical, mechanical and chemical compositions (Table 2).

There are variations in climatic and edaphic conditions of the Coastal and Sudan Savannah agro-ecologies of Ghana, suggesting that crop growth and general performance in these areas will be greatly influenced by those conditions. Soils of both areas are generally sandy, low in organic matter and soil available water (Table 2), which can exacerbate nutrient loss and accelerate soil drying and acidification. The seasonal rainfall, temperature, relative humidity and sun hours varied considerably on inter-annual timescale during the two year period (2012-2014) (Table 1).

Table 1. Location and seasonal differences in monthly average climatic data per year from Manga-Bawku and Legon-Accra experimental farms during the 2012-2014 experimental periods

Climatic Parameter	**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**
Location	**Manga-Bawku experimental farm**							
Mean	47.6(4)*	43 (3)	28.3	29.4	63.1	62.6	7.5	7.4
Location	**Legon-Accra experimental farm**							
Mean	62.0 (3)	37.6 (3)	27.3	27.6	76.5	74.9	5.8	6.2

( ) = Mean days of rainfall*

Table 2. Physical, mechanical and chemical characteristics of soils at 0-30 cm depths from Manga-Bawku and Legon-Accra

Location	**Manga-Bawku experimental farm**			**Legon-Accra experimental farm**		
Soil characteristics	**Rainy season**	**Dry season**	**Mean**	**Rainy Season**	**Dry Season**	**Mean**
Sand (%)	84.1	75.3	**79.7**	58.7	70.3	**64.5**
Silt (%)	1.5	2.9	**2.2**	6.3	9.0	**7.7**
Clay (%)	14.4	21.8	**18.1**	34.9	20.7	**27.8**
Bulk density (g/cm^3)	1.7	1.5	**1.6**	1.5	1.4	**1.5**
Available water (%)	3.3	5.4	**4.3**	5.8	4.7	**5.2**
pH 1:1 H_2O	6.6	6.2	6.4	5.8	5.3	5.5
Nitrogen (%)	0.12	0.13	**0.12**	0.13	0.15	**0.14**
Organic matter (%)	0.57	0.88	**0.73**	1.16	1.57	**1.37**
Available phosphorus (ppm)	3.70	4.13	**4.13**	4.28	5.15	**4.72**

Seasonal trends in temperatures and sun hours showed greater variations in Bawku, recording the highest in the hot, dry periods of middle February to early May, and the lowest between December and January. Both locations have periods of the year with little or no rains at all (November-March) with few months of continuous rains (June-September) (data not presented). This seasonal distribution of rainfall in few months in a year is increasing the frequency of drought [22] in these areas.

The above agro-ecological characteristics of the Sudan and Coastal Savannah areas imply that plants growing in those areas may need supplemental nutrient supply and irrigation to give optimum crop performance. Crop genotypes however differ in their performance and adaptive strategies in varying growth conditions, due to inherent differences in their biophysical and biochemical processes [8].

2.4 Planting Materials

Fourteen garden egg (*Solanum aethiopicum*) genotypes were obtained from, the Department of Crop Science, University of Ghana, Legon and Plant Genetic Resources Research Institute (PGRRI) of the Council for Scientific and Industrial Research (CSIR), Bunso, Ghana; and two popular local genotypes of bitter garden egg (*Solanum incanum*) commonly cultivated in Bawku area, were obtained from garden egg farmers in Bawku. In simulating farmers' field conditions, the genotypes were grown in two successive rainy and dry seasons' (irrigated) conditions of Coastal and Sudan Savannah agro-ecological zones, in two consecutive years of 2012 and 2013, and 2013 and 2014. Experimental procedures for the trials on the 16 genotypes were the same across seasons and locations. In both locations, seeds were nursed and transplanted into prepared beds six weeks after emergence.

2.5 Treatments and Experimental Design

The genotype, rainy season, dry season (irrigated), water-stressed and location (Legon and Manga) were the main treatments. The respective soil moisture content values for Legon and Manga in the rainy season were 67.9% and 63.4%; dry season (irrigated) 56.7% and 52.5% and water-stressed, 26.4% and 23.6%.

The experimental fields were ploughed, harrowed and laid out in Randomized Complete Block Design (RCBD) with three replications in both rainy and dry seasons of 2012-2013 and 2013-2014. Plant-to-plant spacing within a row was 80 cm and planting in both years was done in May-June, and November-December, coinciding with the onset of rainy season and dry season. Weeds were hoed and 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.

2.6 Leaf Sampling, Drying and Milling

Leaves were sampled at 50% flowering stages of growth (6 weeks after transplanting) in both rainy and dry seasons at each experimental site. In order to avoid age effects on sugar accumulation, twelve (12) uppermost leaves were sampled from four record plants per genotype per replication at 50% flowering in both rainy and dry season experiments, During the dry season, the leaves were similarly sampled under well-watered and ten-days of water deprivation (stress) conditions at 50% flowering.

Four of the sampled twelve leaves for sugars determination were immediately picked after excision and well-cleaned for leaf relative water content (LRWC) following [23] and [24]. The remaining eight sampled leaves per treatment per location were oven-dried at 50 °C for 72 hours. The dried leaves from each location were bulked according to genotype and growth condition and ground into composite powders through a 1 mm mesh sized sieve. The composite leaf powders of the rainy season, dry season and drought-stressed conditions were packaged in air-tight black polythene containers and stored in a freezer for sugars determination.

2.7 Sugars Determination

The total soluble sugars were extracted according to the method of [25], whereas total soluble starch and carbohydrates were estimated following modified anthrone methods of [26] and [27].

Anthrone ($C_4H_{10}O$) reagent was prepared fresh daily by dissolving 0.25g of anthrone in a solution containing 190 ml of 72% sulphuric acid (H_2SO_4) for soluble sugars determination. 0.2g of anthrone in 100 ml of concentrated sulphuric acid (H_2SO_4) (reagent A); and 30 ml distilled water in 7.5 ml ethyl alcohol (reagent B) were prepared. The reagent A was slowly poured into reagent B and made up to 250 ml volumetric flask for soluble starch and carbohydrates determination. D-(+) - glucose standard was prepared and used to draw a working standard curve following [27].

Sample extracts of soluble sugars, starch and carbohydrates plus prepared blank solutions were heated for 8-10 minutes in boiling water bath and rapidly cooled in ice for 5-10 minutes and then incubated for 20 minutes at room temperature (25°C). The extracts and glucose standards were vortex and absorbance read over time at 630 nm against the blank on UV visible spectrophotometer.

The total soluble sugars, starch and carbohydrates concentrations were computed from the developed glucose standard curve as follows.

$$\%\ \text{sugars} = \frac{\text{Test sample reading x dilution factor x 100}}{\text{glucose readings x aliquot x sampe weight}}$$

2.8 Data Analysis

The recorded qualitative data was subjected to analysis of variance using GenStat Statistical Software (12^{th} Edition). Data sets for each location and season for the two years were separately analyzed by general analysis of variance (ANOVA), for the estimation of the extent of magnitude of variation among the measured traits. Where ANOVA showed significant differences, means were separated by the Least Significant Difference (LSD) at probability level of 0.05.

3. RESULTS AND DISCUSSION

Total soluble sugars, starch and carbohydrate contents in leaves of the sixteen garden egg genotypes at flowering were found to be variable in the different seasons at each growth location of Manga and Legon. The patterns of the seasonal variations in total soluble sugars, starch and carbohydrates concentrations were similar among genotypes, though significant differences were found in their average concentrations. Seasonally, the soluble sugars, starch and carbohydrates contents in the genotypes at both locations were maximized during the rainy season (Tables 3 and 4).

The high levels of carbohydrates in the rainy season (Table 5) could probably be due to high levels of soluble sugars within that period. This may also indicate that plants during the rainy

Table 3. Total soluble sugars accumulation in leaves of garden egg genotypes at rainy, dry season and drought-stressed conditions of two locations for two years

Condition	**Rainy season**			**Dry season**			**Drought-stressed**		
Location	**Manga**	**Legon**	**Mean**	**Manga**	**Legon**	**Mean**	**Manga**	**Legon**	**Mean**
Genotypes	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
A1	15.2b	11.6c	**13.4cd**	16.5a	15.8a	**16.1a**	9.9a	10.6b	**10.2a**
A2	16.8a	14.3a	**15.5a**	15.6ab	15.1a	**15.4a**	9.2b	11.9a	**10.5a**
A3	15.8b	14.7a	**15.2a**	14.8ab	12.1b	**13.4b**	10.0a	8.6c	**9.3b**
A4	16.0a	11.2c	**13.6c**	14.7ab	10.8d	**12.8bc**	10.1a	8.3cd	**9.2b**
A6B	15.3b	13.3b	**14.3b**	14.9ab	10.7de	**12.8bc**	9.5ab	10.8b	**10.1a**
A6F	15.0b	10.8d	**12.9d**	14.5b	11.0d	**12.7bc**	10.2a	7.0de	**8.6c**
A7	14.2c	11.8c	**13.0d**	13.9b	11.6cd	**12.7bc**	10.2a	11.7a	**11.0a**
A8	14.0c	10.5d	**12.3e**	13.9b	12.6b	**13.3b**	9.6ab	7.1de	**8.3cd**
A9A	15.0b	10.8d	**12.9d**	13.2b	10.9d	**12.0cd**	9.8ab	8.4c	**9.1bc**
A9F	14.6c	10.6d	**12.6d**	13.2b	10.3de	**11.8d**	10.1a	7.6d	**8.8bc**
A10	15.1b	10.0d	**12.5de**	12.8b	10.1e	**11.5d**	9.6ab	6.9e	**8.2d**
A11	14.4c	10.0d	**12.2e**	12.3c	10.4d	**11.3d**	10.1a	6.2e	**8.1d**
A12	14.0c	10.2d	**12.1e**	11.9c	12.7b	**12.3bc**	9.7ab	6.6e	**8.0d**
Legon1	14.4c	10.4d	**12.4e**	12.7c	11.8c	**12.2c**	9.5ab	6.7e	**8.1d**
Bawku1	14.6c	10.3d	**12.4e**	15.0ab	12.0b	**13.5b**	10.7a	6.6e	**8.6c**
Bawku2	14.4c	9.7d	**12.1e**	16.2a	10.0e	**13.1b**	9.8ab	6.9e	**8.3cd**
Mean	**14.9**	**11.3**	**13.1**	**14.1**	**11.7**	**12.9**	**9.9**	**8.2**	**9.1**
%CV	5.5	13.6	16.9	10.5	14.2	15.3	4.9	23.4	17.9

Means with different letters in columns are significantly different at P<0.05.
*LSD 5% (Total soluble sugars): Location (Rainy season = 0.2**; Dry season = 0.3**; Drought-stressed = 0.2**); Genotype x location (Rainy season = 0.9** Dry season = 1.3**; Drought stressed= 0.8**). ** = Significant at 1% level of probability*

Table 4. Total soluble starch accumulation in leaves of garden egg genotypes at flowering under rainy, dry season and drought-stressed conditions of two locations for two years

Condition	**Rainy season**			**Dry season**			**Drought-stressed**		
Location	**Manga**	**Legon**	**Mean**	**Manga**	**Legon**	**Mean**	**Manga**	**Legon**	**Mean**
Genotypes	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
A1	17.6b	18.2b	**17.9bc**	14.7d	17.9b	**16.3e**	13.0cd	13.6b	**13.3b**
A2	17.9b	18.0b	**18.0c**	20.8a	18.7a	**19.8a**	13.4c	15.1a	**14.3a**
A3	17.3b	19.6a	**18.4ab**	20.2a	18.4a	**19.3b**	12.8d	15.1a	**14.0a**
A4	17.5b	19.2a	**18.3ab**	18.7b	17.8b	**18.3c**	13.0c	15.3a	**14.2a**
A6B	17.1bc	18.8a	**18.0bc**	16.2c	17.5b	**16.9d**	15.0a	12.2c	**13.6b**
A6F	17.4bc	17.8b	**17.6bc**	14.3d	16.7cd	**15.5ef**	13.0c	11.5d	**12.2c**
A7	17.3bc	17.8b	**17.6bc**	14.8d	15.9e	**15.4f**	12.7d	11.9cd	**12.3c**
A8	17.2bc	18.1b	**17.6bc**	16.0c	16.2e	**16.1e**	10.1e	10.1e	**10.1f**
A9A	17.5b	17.2bc	**17.4c**	14.2de	16.3e	**15.3f**	12.6d	10.2e	**11.4de**
A9F	16.8c	17.1bc	**16.9c**	13.6e	16.5d	**15.1fg**	12.3d	10.1e	**11.2e**
A10	19.1a	18.6b	**18.9a**	14.9d	17.0c	**15.9e**	13.8b	9.9ef	**11.8d**
A11	19.4a	17.6bc	**18.5ab**	13.6e	16.0de	**14.8g**	13.5c	9.9ef	**11.7de**
A12	19.5a	17.8b	**18.7a**	13.3e	17.5b	**15.4f**	14.1b	9.7ef	**12.0cd**
Legon1	19.4a	17.6bc	**18.5ab**	12.2f	16.9c	**14.6g**	13.2c	9.4f	**11.3e**
Bawku1	19.2a	17.2bc	**18.2b**	11.8f	16.9c	**14.4g**	12.8d	8.9f	**10.9e**
Bawku2	19.1a	16.7c	**17.9bc**	14.2de	18.8a	**16.5de**	13.1c	9.8e	**11.4de**
Mean	**18.1**	**18.0**	**18.0**	**15.2**	**17.2**	**16.2**	**13.0**	**11.4**	**12.2**
%CV	5.6	4.7	5.2	17.0	5.4	13.4	7.7	19.2	15.2

Means with different letters in columns are significantly different at P<0.05.
*LSD 5% (Total soluble starch): Location (Rainy season = 0.2ns; Dry season = 0.1**; Drought-stressed = 0.1**); Genotype x location (Rainy season = 0.8**; Dry season = 0.6**; Drought-stressed = 0.5**). ns = Not significant; ** = Significant at 1% level of probability*

Table 5. Total soluble carbohydrates levels in leaves of garden egg genotypes at flowering under rainy, dry season and drought-stressed conditions of two locations for two years

Condition	**Rainy season**			**Dry season**			**Drought-stressed**		
Location	**Manga**	**Legon**	**Mean**	**Manga**	**Legon**	**Mean**	**Manga**	**Legon**	**Mean**
Genotypes	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
A1	48.5bc	50.1b	**49.3bc**	40.4d	49.3b	**44.0d**	35.9d	37.6b	**36.8b**
A2	49.5b	49.6bc	**49.6bc**	57.5a	51.6a	**54.5a**	36.9c	41.7a	**39.3a**
A3	47.7bc	54.1a	**50.9a**	55.8a	50.9a	**53.4a**	35.4d	41.6a	**38.5a**
A4	48.2bc	53.1a	**50.6a**	51.6b	49.1b	**50.4b**	36.0c	42.2a	**39.1a**
A6B	47.3c	51.9a	**49.6bc**	44.7c	48.4b	**46.5c**	41.3a	33.8c	**37.5b**
A6F	48.1bc	49.1bc	**48.6bc**	39.5d	46.2c	**42.8e**	35.8d	31.7d	**33.8c**
A7	47.9bc	49.1bc	**48.5c**	40.9d	44.0d	**42.5e**	35.0d	32.9c	**34.0c**
A8	47.4c	49.9b	**48.7bc**	44.1c	44.6d	**44.3d**	29.9f	28.0f	**28.0g**
A9A	48.3bc	47.6bc	**47.9cd**	39.3de	45.0cd	**42.2e**	34.8de	28.2ef	**31.5e**
A9F	46.3c	47.2c	**46.8d**	37.6e	45.7c	**41.6ef**	33.9e	27.7f	**30.8ef**
A10	52.7a	51.5a	**52.1a**	41.2d	46.9c	**44.0d**	38.0b	27.4fg	**32.7d**
A11	53.6a	48.5bc	**51.1a**	37.6e	44.2d	**40.9ef**	37.2c	27.3fg	**32.3d**
A12	53.9a	49.2bc	**51.6a**	36.6e	48.2b	**42.4e**	38.9b	27.1fg	**33.0c**
Legon1	53.6a	48.6bc	**51.1a**	33.8f	46.6c	**40.2f**	36.4cd	26.0g	**31.2e**
Bawku1	53.1a	47.3c	**50.2a**	32.6f	46.7c	**39.7f**	35.4d	24.7h	**30.0f**
Bawku2	52.8a	46.2c	**49.5bc**	39.0d	51.9a	**45.4c**	36.0cd	29.9e	**31.5c**
Mean	**49.9**	**49.6**	**49.7**	**42.0**	**47.4**	**44.7**	**35.9**	**31.5**	**33.7**
%CV	5.6	4.7	5.2	17.0	5.4	13.4	7.7	19.2	15.2

Means with different letters in columns are significantly different at P<0.05.
*LSD 5% (Total Soluble carbohydrates): Location (Rainy season = 0.6ns; Dry season= 0.4**; Drought-stressed = 0.4**); Genotype x location (Rainy season = 2.2**; Dry season=1.6**; drought-stressed = 1.4**). ** = Significant at 1% level of probability*

season maintained constant carbohydrate and starch reserves and so sugars produced during the period did not exceed the energetic and constructive demands for growth and reproduction. Regardless of growth condition, there were marked location differences in total soluble sugars, starch and carbohydrates concentrations among genotypes and this could have been due to differences in climatic conditions, in which Legon conditions favoured their accumulation more than Manga. The variation in genotypes soluble starch and carbohydrates contents was higher during dry season conditions at Manga (CV = 17%) and drought stress conditions at Legon (CV = 19.2%) (Tables 4 and 5) indicating that drought conditions have marked influence on sugars accumulation in garden egg.

The other reason could be that the high temperatures of Manga inhibited the enzymatic hydrolyses of starch to sugars. This seasonal pattern of sugar accumulation is similar to the findings of [7] and [28]. The total soluble carbohydrate concentration has been reported to increase in leaves of plant species growing under seasonally dry climate [29-31]. There were significant genotype and environment interaction (GEI) effects on total soluble sugars, starch and carbohydrate levels in leaves of the genotypes at flowering across seasons and conditions of growth, which indicate that the genotypes responded linearly to the environmental changes in respect of sugar concentrations.

In both locations, the starch reserves of all the sixteen genotypes were significantly reduced during drought-stress, suggesting that the genotypes were adopting different ecological strategies under increased respiratory demands of the plants, which might have been enhanced by high temperatures within the period (Table 1). It could also have meant that, the starch reserves were being consumed during drought stress in order to produce soluble sugars for the continuation of the plants metabolic processes (Tables 3). Accumulation of sugars in response to drought is well documented in many crop species [32-34] as a protective mechanism against drought.

Soluble sugars may function as a typical osmo-protectant, stabilizing cellular membranes and maintaining turgor pressure. The total soluble sugar concentrations in plants under stressed conditions play vital role in the adaptive strategies of plants to either avoid or tolerate those conditions. The drought-stressed avoiding genotypes (A2, A4, A3, A6B, A1 and A7) accumulated enough starch during reproductive growth as a carbon source for respiration, resulting in low pools of total soluble sugars (Table 3 and 5); whereas the stress-tolerant genotypes (A8, A9F, Bawku1, A6F, A11 and Legon1) had low starch pools and storage capacity (Table 4) possibly due to their abilities to maintain photosynthetic activity under water-stress.

The drought-stressed conditions of both locations were also associated with low leaf relative water contents (LRWC) of the genotypes (Table 6); suggesting that, the accumulation of soluble sugars is probably a mechanism to withhold water during periods of water stress [35].

It could be observed from Tables 6 that garden egg genotypes, A2, A3, A4, A6B, A1 and A7 under water-stress had the lowest LRWC but accumulated higher soluble sugar levels (Table 3); whereas genotypes A8, A9A, Bawku1, Bawku2, and A11 with higher LRWC accumulated lower soluble sugar levels (Table 3). It be stated that, accumulation of sugars in garden egg leaves is related to changes to changes in the leaf water status, which is in line with the findings in other plant species [13].

The reduction in moisture content of leaves in the dry season could also be due to utilization of the moisture to build carbohydrate reserves and other leaf constituents [36]. It could also be that the photosynthetic processes in garden egg remained active in the dry season conditions, making it possible for some accumulation of starch reserves (Table 4). Since leaves are the main assimilative organs of plants, differences in LRWC might have led to different periods of carbon gain, and therefore affected the seasonal course of carbohydrates concentrations.

This suggests that under dry season conditions of both locations of Manga and Legon, carbon reserves were able to accumulate since stress factors were not severe enough to constraint carbon-acquisition. Carbohydrates stored as reserves enable plants to uncouple growth from carbon-assimilation throughout growth period, allowing survival under seasonal stressful conditions, and facilitating recovery after environmental disturbance [37; 38]. Soluble carbohydrates serve as important regulators of the physiological adjustment of plants to drought and dry season conditions. However, plants

Table 6. Leaf relative water content (LRWC) of garden egg genotypes at flowering under rainy, dry season and drought-stressed conditions of two locations for two years

Condition	**Rain season**			**Dry season**			**Water-stressed**		
Location	**Manga**	**Legon**	**Mean**	**Manga**	**Legon**	**Mean**	**Manga**	**Legon**	**Mean**
Genotypes	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
A1	78.4d	82.7c	**80.5f**	63.4b	75.2b	**69.3b**	47.7b	51.0b	**49.3b**
A2	78.7d	80.4c	**79.5f**	63.3b	75.3b	**69.3b**	48.2b	50.7b	**49.5b**
A3	84.2b	84.8bc	**84.5c**	61.1c	73.7b	**67.4c**	52.6a	60.7a	**56.4ab**
A4	83.5b	77.2d	**80.4f**	63.2b	75.9a	**69.5b**	47.4b	51.7b	**49.6b**
A6B	80.1c	79.4d	**79.8f**	63.5b	75.0b	**69.2b**	48.9b	53.8b	**51.3b**
A6F	85.8a	78.0d	**81.9e**	67.3a	77.2a	**72.3a**	50.5b	58.7a	**54.6ab**
A7	81.0c	87.0ab	**84.0c**	65.7b	73.4b	**69.5b**	53.6a	60.5a	**57.0ab**
A8	77.1d	84.9b	**81.0e**	66.2b	75.4a	**70.8b**	54.0a	61.5a	**57.8a**
A9A	84.3b	85.8b	**85.1c**	64.5b	73.9b	**69.2b**	54.0a	61.8a	**57.9a**
A9F	77.3d	86.3b	**81.8e**	65.3b	73.2b	**69.3b**	53.4a	58.1a	**55.7ab**
A10	80.3c	86.5ab	**83.4d**	70.3a	75.2b	**72.7a**	53.8a	50.6b	**52.2b**
A11	81.5c	85.4b	**83.5d**	64.8b	76.8a	**70.8b**	51.5a	62.5a	**57.0ab**
A12	77.4d	86.5ab	**82.0e**	63.1b	75.0b	**69.1c**	51.8a	57.9a	**54.9ab**
Legon1	79.5c	84.9b	**82.2e**	69.0a	74.1b	**71.6a**	53.1a	52.4b	**52.7b**
Bawku1	87.4a	89.3a	**88.3a**	64.3b	76.1a	**70.2b**	54.4a	65.0a	**59.7a**
Bawku2	87.6a	86.5ab	**87.0b**	68.9a	78.0a	**73.5a**	56.0a	63.1a	**59.6a**
Mean	**81.5**	**84.1**	**82.8**	**65.3**	**75.2**	**70.2**	**51.9**	**57.5**	**54.7**
%CV	4.9	4.9	5.1	6.0	3.4	8.5	9.3	14.3	13.3

Means with different letters in columns are significantly different at P<0.05.
*LSD(5%) (LRWC at flowering): Rainy season (Location= 0.4**; Genotype x Location = 1.7**); Dry season (Location = 0.9**; Genotype x Location = 3.4**); and, Drought-stressed (Location = 1.69**; Genotype x Location = 6.8**). *, ** = Significant at 5% and 1% levels of probability*

grown under similar environmental conditions may show different dynamics of carbohydrates storage and use in relation to differences in their life forms or ecological strategies [39; 40].

In both seasons and locations, the patterns of variation of carbohydrates concentrations were similar among genotypes, but significant differences were found in their average concentrations (Table 5). The different concentrations of total soluble sugars, starch and carbohydrates found in the genotypes in different seasons of growth emphasized the importance of analyzing separately soluble sugars, starch and total carbohydrates when studying seasonal patterns of leaf sugars in garden egg.

There were positive association between concentrations of carbohydrates and soluble sugars, as well as between carbohydrates and starch accumulation in the leaves of the sixteen garden egg genotypes under varying growth conditions (Tables 3, 4 and 5). This suggests that the carbohydrate concentration dynamics was more dependent on the levels of soluble sugars, whereas the pattern of carbohydrates accumulation was better explained by starch concentrations.

In this study, the imposed drought-stress during the flowering stage was simulative of drought-stress encountered in many garden egg producing areas of the Coastal and Sudan Savannahs of Ghana. These stressed conditions stem from the limited amounts and erratic distribution of rainfall or due to shortage of water in the dry season.

The concentration of the total soluble sugars was highly related to the genotypes, season and conditions of growth and to some extent the location of growth (Tables 3 and 5), suggesting that these factors should be considered in selecting genotypes of desirable traits as their performance could be affected under varying growth conditions or environments [27]. Though there were location and seasonal specific genotypes in terms of their total soluble sugars, starch and carbohydrates accumulation abilities, the genotypes, A1, A2, A3 A6B, A4 and A7 were the highest in soluble sugars, starch and carbohydrates accumulation during drought-stress conditions at both locations and could be considered as tolerant across drought-stress conditions of Coastal and Sudan Savannah of Ghana.

4. CONCLUSIONS

The sugars' accumulation abilities varied significantly among garden egg genotypes and were related to their changing leaf relative water contents. These natural variations in the genotypes could be considered in the adaptive strategies of the crop in drought-stressed environments. The genotypes A2, A3, A7, A6B and Bawku1 were stable in sugars accumulation, and tolerated high temperatures and drought-stressed conditions better. The genotypes that were stable in sugars accumulation may thrive well in limited nutrients soils, since they were grown at locations inherently poor in soil nutrients. In general, genotypes A2, A3, A4, A6B and A7 could be selected for crop improvement purposes in drought-prone areas across seasons and locations of the Coastal and Sudan Savannah of Ghana.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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