

Original Research Article

ASSESSING GARDEN EGG GENOTYPES FOR SUGARS ACCUMULATION IN VARYING GROWTH CONDITIONS IN GHANA

ABSTRACT

An experiment was conducted on garden egg (*Solanum spp.*) under rain-fed and irrigated conditions at Manga, Bawku (Sudan Savannah) and University of Ghana, Legon (Coastal Savannah) experimental fields. Sixteen genotypes were grown over two years in Randomized Complete Block Design with three replications to identify sugars' accumulation response patterns of the genotypes in the two agro-ecological zones. During the reproductive (flowering and fruit set) stages of the genotypes, the leaf sugars accumulation data from each growth conditions 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 environment interaction effects on their accumulation. The genotypes were observed to develop internal drought survival mechanisms by decreasing total soluble sugars, starch and carbohydrates, thereby enabling plants to withstand periodic drought better. The adaptive response mechanism of the crop was also manifested in the genotypes lower sugars accumulation response patterns during drought-stress, but with Manga recording lower levels than Legon conditions. The genotypes A1, A2, A3, A4, A6B and A7 were the most stable in sugars accumulation under dry season and drought-stressed conditions with associated high temperatures across locations. These genotypes could be incorporated in drought tolerant improvement programs in Ghana.

Key Words: Garden eggs, Genotypes, Growth Conditions, Sugars Accumulation

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; 4; 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; 7; 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.

Sugars are very important bio-molecules involved in tolerance of water shortage, especially during reproductive stage [13]. Sugars' accumulation during reproductive stages from flowering to fruit formation are involved in various important physiological roles [14]. The soluble sugars, starch and carbohydrates in the form of storage products play significant role in structural stability of many different molecules [15], which confer tolerance to different environmental stresses.

Garden egg is one of the most drought tolerant solanaceous vegetables [16], 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 Savannas of Ghana.

MATERIALS AND METHODS

The Study Areas

The experiment was conducted at Savannah Agricultural Research Institute (SARI) experimental farm, Manga, Bawku, in the Sudan savanna agro-ecology and University of Ghana, Legon, Accra experimental farm located in the Coastal savanna 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.

Climatic Data Collection

Climatic data (Table 1) were 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 (Onset Computer Company, Pocasset, ME, USA), whereas those of Manga-Bawku were taken from on-farm weather station. The rainfall data from both experimental sites were collected using on-farm rain gauges.

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

Location	Manga-Bawku Experimental Farm							
Climatic Parameter	Rainfall (mm)		Temperature (°C)		Relative (%)	humidity	Sunshine (Hours)	
Year / Month	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Jan	0	0	24.4	26.8	39.8	38.9	8.1	8.2
Feb	0	0	27.3	30.4	29.8	30.3	8.5	8.3
Mar	0	0	31.6	32.7	38.7	36.7	9.4	9.1
Apr	1.2(1)*	0.5(1)	31.8	33.1	64.6	64.2	8.2	8.1
May	5.0(2)	3.5(1)	29.6	31.6	73.8	72.7	8.2	8.3
June	8.3(2)	5.7(2)	28.0	29.7	78.7	77.3	6.3	6.8
July	214.8(7)	194.8(5)	27.2	28.7	82.7	81.2	5.9	5.7
Aug	223.8(6)	207.9(6)	26.6	27.7	85.6	84.5	5.2	5.1
Sept	118.4(4)	102.4(4)	27.1	27.1	82.8	84.8	6.3	6.1
Oct	0	1.1(1)	28.4	27.9	77.8	76.8	7.3	7.5
Nov	0	0	29.7	29.1	60.6	61.4	8.4	8.5
Dec	0	0	28.1	28.1	41.7	42.8	8.1	8.4
Mean	47.6 (4)	43 (3)	28.3	29.4	63.1	62.6	7.5	7.4

Location	Legon-Accra Experimental Farm							
Climatic Parameter	Rainfall (mm)		Temperature (°C)		Relative (%)	humidity	Sunshine (Hours)	
Year / Month	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14

Jan	25.0(2)*	50.8(2)	26.2	26.8	74.5	72.8	6.2	6.4
Feb	0	0	28.0	28.6	75.7	74.2	5.6	5.8
Mar	23.9(1)	13.2(1)	30.5	30.9	79.0	78.6	6.2	6.8
Apr	86.1(3)	43.7(2)	30.0	30.3	78.4	77.5	6.5	6.9
May	120.6(3)	134.4(5)	28.2	27.5	76.9	75.5	7.4	7.8
June	184.9(5)	102.1(4)	26.9	27.8	79.0	78.6	4.8	5.3
July	20.3(2)	17(1)	25.9	26.3	77.7	73.3	5.3	5.8
Aug	0	0	25.7	25.9	76.6	75.9	5.1	5.7
Sept	50.6(2)	77.4(4)	26.0	26.4	78.0	76.5	5.6	6.2
Oct	154.4(4)	12.7(1)	26.2	26.7	75.7	74.4	4.4	5.3
Nov	0	0	27.3	27.5	73.0	70.5	6.2	6.7
Dec	77.9(3)	0	25.9	26.3	73.1	71.1	5.7	5.9
Mean	62.0 (3)	37.6 (3)	27.3	27.6	76.5	74.9	5.8	6.2

()* = Mean days of rainfall

Soil Sampling and Analysis

Soil samples were collected from six (6) different randomly selected locations of the experimental plots of the Legon experimental farm and SARI-Manga experimental farm, at 0-30 cm depth after scrapping off the surface litters. The sampled soils of each experimental plot in the rainy and dry seasons were combined and air-dried. The soil samples were then homogenised by passing them through 5 mm sieve.

The soils were analyzed for their organic matter content following [17]. Nitrogen and available phosphorus contents were respectively determined using Macro - kjeldhal [18] and P-Bray No. 1 methods. Particle sizes, exchangeable bases and pH were also determined from the sieved soil samples. Core samplers were used to collect soil samples at six (6) different locations in each of the experimental sites for bulk density determination. All the samples were analyzed in duplicates. The results of the physical and chemical analysis of sampled soils are shown in Table 2

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

Soil Characteristics	Manga-Bawku Experimental Farm			Legon-Accra Experimental Farm		
Particle Sizes	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
Field Capacity at 0.3bar	5.7	11.4	8.6	12.5	8.5	10.5
Wilting Point at 15 bars	2.4	6.0	4.5	6.7	3.9	5.3
Available Water	3.3	5.4	4.3	5.8	4.7	5.2
pH1:1 H ₂ O	6.6	6.2	6.4	5.8	5.3	5.5
EC (μS/cm)	152	153	153	175	139	157
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 P. (ppm)	3.70	4.13	4.13	4.28	5.15	4.72

EC = Electrical Conductivity

There are variations in climatic and edaphic conditions of the Coastal and Sudan 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 water-holding capacities (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). 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-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), and this seasonal distribution of rainfall in few months in a year is increasing the frequency of drought [19] 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].

Planting materials

Fourteen (14) 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 Savannah 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.

Treatments, Experimental Design and Field Layout

The genotype, rainy season, dry season (irrigated), water-stressed and location (Legon and Manga) were the main treatments. Thus, there were sixteen (16) genotypes, three (3) soil moisture conditions and two (2) locations, giving ninety-six (96) treatment combinations. The respective soil moisture content values for Legon and Manga for 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 and harrowed, after which the fields were 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 250kg/ha.

Leaves 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, and were oven-dried at 50 °C for 72 hours. During the dry season, leaves were sampled under well-watered and ten-days of water deprivation (stress) conditions at 50% flowering. The dried leaves from each location were bulked according to genotype and growth condition and ground into composite powders through a sieve with mesh size 1 mm. The composite leaf powders of the rainy season, dry season and stressed conditions were packaged in air-tight black polythene containers and stored in a freezer for sugars determination. Four upper most two leaves from each of four record plants per genotype per replication were excised and well-cleaned for leaf relative water content (LRWC) following [20] and [21].

Total soluble sugars determination

The total soluble sugars were extracted according to the method of [22]. 0.5 g of the powdered leaf samples were homogenized in 5 ml distilled water by shaking on a reciprocal shaker for 10 minutes. 7 ml of 80% ethanol was added and centrifuged at 3000 g for 5 minutes and supernatant filtered into 50 ml volumetric flask. The remaining residue was repeatedly washed with 80%

ethanol and the extracts were filtered into 50ml volumetric flask and made up to the mark with distilled water. The filtrate was used for the determination of total soluble sugars.

Total soluble starch and carbohydrates determination

Total soluble starch and carbohydrates were estimated following modified anthrone methods of [23] and [24]. The remaining residues after soluble sugars extraction were added five (5) ml of distilled water and 6.5 ml of 72% perchloric acid (HClO₃). The extraction of starch was carried out by incubating samples at 0 °C for 20 minutes, and centrifuging at 3000 g for 5 minutes. The extract was retained by filtering the supernatant thrice into 100 ml volumetric flask and topping up to 100 ml with distilled water as starch extract.

Preparations of Anthrone and Glucose standard solutions

Anthrone (C₄H₁₀O) reagent was prepared fresh daily by dissolving 0.25g of anthrone in a solution containing 190 ml of 72% sulphuric acid (H₂SO₄) for soluble sugars determination. 0.2g of anthrone in 100 ml of concentrated sulphuric acid (H₂SO₄) (reagent A) prepared on ice; and 30 ml distilled water in 7.5 ml ethyl alcohol (reagent B) were prepared for soluble starch and carbohydrates determination. The reagent A was slowly poured into reagent B and made up to 250 ml volumetric flask. D-(+) - glucose standard was prepared and used to draw a working standard curve following Brooks, *et al.*, [24].

Spectrophotometer readings

Four milliliters of the prepared anthrone reagent was taken and mixed with 1 ml of extract sample aliquots in 15 ml screw-capped test tubes to prevent evaporation. 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 total soluble sugars, starch and carbohydrates 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.

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

Data Analysis

The recorded qualitative data were subjected to analysis of variance using GenStat Statistical Software (12th 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, and where ANOVA showed significant differences, means were separated by the Least Significant Difference (LSD) at probability level of 0.05.

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 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.

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	15.2	11.6	13.4	16.5	15.8	16.1	9.9	10.6	10.2
A2	16.8	14.3	15.5	15.6	15.1	15.4	9.2	11.9	10.5
A3	15.8	14.7	15.2	14.8	12.1	13.4	10.0	8.6	9.3
A4	16.0	11.2	13.6	14.7	10.8	12.8	10.1	8.3	9.2

A6B	15.3	13.3	14.3	14.9	10.7	12.8	9.5	10.8	10.1
A6F	15.0	10.8	12.9	14.5	11.0	12.7	10.2	7.0	8.6
A7	14.2	11.8	13.0	13.9	11.6	12.7	10.2	11.7	11.0
A8	14.0	10.5	12.3	13.9	12.6	13.3	9.6	7.1	8.3
A9A	15.0	10.8	12.9	13.2	10.9	12.0	9.8	8.4	9.1
A9F	14.6	10.6	12.6	13.2	10.3	11.8	10.1	7.6	8.8
A10	15.1	10.0	12.5	12.8	10.1	11.5	9.6	6.9	8.2
A11	14.4	10.0	12.2	12.3	10.4	11.3	10.1	6.2	8.1
A12	14.0	10.2	12.1	11.9	12.7	12.3	9.7	6.6	8.0
Lagon1	14.4	10.4	12.4	12.7	11.8	12.2	9.5	6.7	8.1
Bawku1	14.6	10.3	12.4	15.0	12.0	13.5	10.7	6.6	8.6
Bawku2	14.4	9.7	12.1	16.2	10.0	13.1	9.8	6.9	8.3
Mean	14.9	11.3	13.1	14.1	11.7	12.9	9.9	8.2	9.1
LSD (5%)	0.9**	0.9**	0.6**	1.9**	0.5**	0.9**	0.9ns	0.8**	0.6**
%CV	5.5	13.6	16.9	10.5	14.2	15.3	4.9	23.4	17.9

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**). ns = Not significant; ** = 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	Lagon	Mean	Manga	Lagon	Mean	Manga	Lagon	Mean
Genotypes	%	%	%	%	%	%	%	%	%
A1	17.6	18.2	17.9	14.7	17.9	16.3	13.0	13.6	13.3
A2	17.9	18.0	18.0	20.8	18.7	19.8	13.4	15.1	14.3
A3	17.3	19.6	18.4	20.2	18.4	19.3	12.8	15.1	14.0
A4	17.5	19.2	18.3	18.7	17.8	18.3	13.0	15.3	14.2
A6B	17.1	18.8	18.0	16.2	17.5	16.9	15.0	12.2	13.6
A6F	17.4	17.8	17.6	14.3	16.7	15.5	13.0	11.5	12.2
A7	17.3	17.8	17.6	14.8	15.9	15.4	12.7	11.9	12.3
A8	17.2	18.1	17.6	16.0	16.2	16.1	10.1	10.1	10.1
A9A	17.5	17.2	17.4	14.2	16.3	15.3	12.6	10.2	11.4
A9F	16.8	17.1	16.9	13.6	16.5	15.1	12.3	10.1	11.2
A10	19.1	18.6	18.9	14.9	17.0	15.9	13.8	9.9	11.8
A11	19.4	17.6	18.5	13.6	16.0	14.8	13.5	9.9	11.7
A12	19.5	17.8	18.7	13.3	17.5	15.4	14.1	9.7	12.0
Lagon1	19.4	17.6	18.5	12.2	16.9	14.6	13.2	9.4	11.3
Bawku1	19.2	17.2	18.2	11.8	16.9	14.4	12.8	8.9	10.9
Bawku2	19.1	16.7	17.9	14.2	18.8	16.5	13.1	9.8	11.4

Mean	18.1	18.0	18.0	15.2	17.2	16.2	13.0	11.4	12.2
LSD (5%)	0.7**	1.0**	0.6**	0.7**	0.5**	0.4**	0.5**	0.6**	0.4**
%CV	5.6	4.7	5.2	17.0	5.4	13.4	7.7	19.2	15.2

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	48.5	50.1	49.3	40.4	49.3	44.0	35.9	37.6	36.8
A2	49.5	49.6	49.6	57.5	51.6	54.5	36.9	41.7	39.3
A3	47.7	54.1	50.9	55.8	50.9	53.4	35.4	41.6	38.5
A4	48.2	53.1	50.6	51.6	49.1	50.4	36.0	42.2	39.1
A6B	47.3	51.9	49.6	44.7	48.4	46.5	41.3	33.8	37.5
A6F	48.1	49.1	48.6	39.5	46.2	42.8	35.8	31.7	33.8
A7	47.9	49.1	48.5	40.9	44.0	42.5	35.0	32.9	34.0
A8	47.4	49.9	48.7	44.1	44.6	44.3	29.9	28.0	28.0
A9A	48.3	47.6	47.9	39.3	45.0	42.2	34.8	28.2	31.5
A9F	46.3	47.2	46.8	37.6	45.7	41.6	33.9	27.7	30.8
A10	52.7	51.5	52.1	41.2	46.9	44.0	38.0	27.4	32.7
A11	53.6	48.5	51.1	37.6	44.2	40.9	37.2	27.3	32.3
A12	53.9	49.2	51.6	36.6	48.2	42.4	38.9	27.1	33.0
Legon1	53.6	48.6	51.1	33.8	46.6	40.2	36.4	26.0	31.2
Bawku1	53.1	47.3	50.2	32.6	46.7	39.7	35.4	24.7	30.0
Bawku2	52.8	46.2	49.5	39.0	51.9	45.4	36.0	29.9	31.5
Mean	49.9	49.6	49.7	42.0	47.4	44.7	35.9	31.5	33.7
LSD (5%)	1.9**	2.6**	1.6**	1.8**	1.4**	1.1**	1.3**	1.7**	1.0**
%CV	5.6	4.7	5.2	17.0	5.4	13.4	7.7	19.2	15.2

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.

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 [25]. The total soluble carbohydrate concentration has been reported to increase in leaves of plant species growing under seasonally dry climate [26; 27; 28]. 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 [29; 30; 31] 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), accumulated more soluble sugars during drought-stress to maintain photosynthetic activity, and therefore had low starch pools and storage capacity (Table 4). The drought-stressed conditions of both locations were also associated with low leaf relative water contents of the genotypes (Table 6); suggesting that, the accumulation of soluble sugars is probably a mechanism to withhold water during periods of water stress [32].

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	78.4	82.7	80.5	63.4	75.2	69.3	47.7	51.0	49.3
A2	78.7	80.4	79.5	63.3	75.3	69.3	48.2	50.7	49.5
A3	84.2	84.8	84.5	61.1	73.7	67.4	52.6	60.7	56.4
A4	83.5	77.2	80.4	63.2	75.9	69.5	47.4	51.7	49.6
A6B	80.1	79.4	79.8	63.5	75.0	69.2	48.9	53.8	51.3
A6F	85.8	78.0	81.9	67.3	77.2	72.3	50.5	58.7	54.6
A7	81.0	87.0	84.0	65.7	73.4	69.5	53.6	60.5	57.0
A8	77.1	84.9	81.0	66.2	75.4	70.8	54.0	61.5	57.8
A9A	84.3	85.8	85.1	64.5	73.9	69.2	54.0	61.8	57.9
A9F	77.3	86.3	81.8	65.3	73.2	69.3	53.4	58.1	55.7
A10	80.3	86.5	83.4	70.3	75.2	72.7	53.8	50.6	52.2
A11	81.5	85.4	83.5	64.8	76.8	70.8	51.5	62.5	57.0

A12	77.4	86.5	82.0	63.1	75.0	69.1	51.8	57.9	54.9
Legon1	79.5	84.9	82.2	69.0	74.1	71.6	53.1	52.4	52.7
Bawku1	87.4	89.3	88.3	64.3	76.1	70.2	54.4	65.0	59.7
Bawku2	87.6	86.5	87.0	68.9	78.0	73.5	56.0	63.1	59.6
Mean	81.5	84.1	82.8	65.3	75.2	70.2	51.9	57.5	54.7
LSD (5%)	2.2**	2.9**	1.2**	3.8**	2.6*	2.4**	5.0**	7.5**	4.8**
%CV	4.9	4.9	5.1	6.0	3.4	8.5	9.3	14.3	13.3

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.

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 [33]. In dry conditions, the photosynthetic processes in garden egg remained active and so some amount of accumulation of starch reserves was made possible (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, 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 [34; 35]. Soluble carbohydrates serve as important regulators of the physiological adjustment of plants to drought and dry season conditions. However, plants 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 [36; 37]. 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 (Tables 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 were 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 production areas of Coastal and Sudan savannahs of Ghana. The stress conditions of the areas often result from limited amounts and erratic distribution of rainfall or shortage of water in dry season conditions. The concentrations of the total soluble sugars were 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 [25]. 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.

Conclusion

The sugars' accumulation abilities varied significantly among garden egg genotypes and this 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. 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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