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Effects of Induced Water Stress at the Flowering Stage of Bambara Groundnut (*Vigna subterranea* L. Verdc) on Its Yield

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Abstract: Bambara groundnut (*Vigna subterranea* L. Verdc), a neglected and underutilized legume is one of the main source of plant protein for poor families in tropical Africa, and is capable of contributing to increasing food production in Africa. This present study aimed to see how bambara groundnut respond to induced water stress during the flowering stage. The research was carried out at the Teaching and Research Farm of The Federal College of Agriculture, Akure (FECA), Ondo State, south west zone in Nigeria. The experiment was a split-plot experiment laid out in a Completely Randomized Design (CRD) with three replications during the late planting season of 2020. Data were collected on Plant height, Number of branches, Number of Leaves, Terminal Leaf Length, Terminal Leaf Width (cm), Biomass, Wet Pod Weight/Plant, Dry Pod Weight/Plant, Pod Length, Pod Width, Number of Pods/Plant, Seed Length, Seed Width, Number of Seeds/Plant, and Seed Weight/Plant. Result showed that among the growth parameters evaluated, Number of leaves and branches were significantly influenced by the various induced stress conditions and the control plot recorded the most significant difference. Among the accessions; accession B_8 recorded significantly higher number of leaves across the weeks, while accession B_1 recorded significantly higher number of branches in week 4 and 12 whereas, B_6 recorded against week 8. The interaction $C*B_8$ recorded significantly higher number of leaves and branches at week 4, whereas at week 8 and 12, the interaction $DRT*B_1$ recorded significantly higher number of leaves for both weeks, while $C*B_6$ with at week 8 and at week 12 recorded significantly higher number of branches. For the yield, the result obtained showed that the control significantly ($p \leq 0.05$) improved dry seed weight and other yield components (number of pods/plant, number of seeds/plant) of bambara groundnut. The bambara groundnut accessions exhibited differential yield potential. The highest wet and dry seed weight/plant was obtained in the B_4 followed by the B_7 and lowest is the B_{10}. The B_4 out-yielded the other accessions, indicating its high adaptability and suitability to the various induced stress conditions at the flowering stage of the bambara plant.

Keywords: Bambara Groundnut, Excess Watering, Flowering Stage, Drought

1. Introduction

Plant development and agricultural productivity are severely limited by abiotic stressors such as salinity, drought, high temperature, and flooding. Drought stress is defined as a shortage of available water, which might interfere with normal plant growth and development [1]. Drought can affect a variety of plant processes and result in changes in growth characteristics, such as a reduction in leaf area and dry matter output as reported in groundnuts (Arachis hypogaea) [2], cowpea (*Vigna unguiculata*) [3] and chickpea (*Cicer arietinum*) [4].

Drought has also been shown to impact pea (Pisum sativum) germination and early seedling vigour [5]. Drought stress can affect a crop at any stage of its growth, with the reproductive and grain filling stages being the most vulnerable [6]. When severe drought occurred during anthesis and the early reproductive phases of soybean (Glycine max), pod set was reduced by up to 40% [7]. When cowpea plants were treated to a stress regime in which water was provided at 20-day intervals, a drop in water use efficiency and seed output of at least 50% was seen at the reproductive stage [8]. The relevance of drought stress on various plant species has prompted researchers to look into underutilized crops that have been found to have better degrees of drought tolerance than major crop species. A grain legume called bambara groundnut (Vigna subterranea L. Verdc) is one of these species.

In tropical Africa, grain legumes are the principal source of plant protein for poor families [9]. Neglected and underutilized legumes, such as bambara groundnut (Vigna subterranea L. Verdc), have the potential to help poor rural Africans retain their livelihoods by increasing food availability, including protein absorption [10]. In addition to protein, bambara groundnut seed is strong in carbohydrates and lipids [11]. It has a 33% essential amino acid content and a 66% non-essential amino acid content [12]. Bambara groundnuts help to increase food production in Africa, but one of the major challenges with their production is that farmers often get low yields [13, 14]. This is owing to the fact that rainfall in the semi-arid areas where it is often grown varies greatly, not only in terms of overall volume but also in terms of distribution and intensity within and between seasons [15].

The crop yields between 650 and 850 kg ha-1 as a single crop, however output potential of over 3000 kg ha-1 has been observed [16]. Bambara groundnut can out produce most other legumes in difficult growing circumstances. The crop can withstand droughts, adapt to hard settings, and produce some yield when other legumes are struggling.

Crop plants have a variety of responses to water scarcity [17]. Most of these responses are adaptive mechanisms that help crops cope with water shortages or droughts, ensuring their survival and reproduction. The three essential components of plant morphological behavior in response to drought are the regulation of root growth, the modulation of leaf size, and changes in leaf orientation [18, 19]. The reactions of bambara groundnut to two extremes of induced water stress – excessive watering (water-logged condition) and drought – applied at various growth and development stages, particularly during the flowering stage of the plant, are unknown. Knowledge of the bambara groundnut's reaction pattern to these extremes, will aid in the stabilization of yields and yield-related traits in the face of changing climatic conditions. As a result, the focus of this research was to determine how bambara groundnut responded to induced water stress during flowering.

2. Materials and Methods

2.1. Experimental Site and Research Design

The research was carried out at the Teaching and Research Farm of The Federal College of Agriculture, Akure (FECA), Ondo State, south west zone in Nigeria, The annual rainfall ranges between 2000 – 3000 mm per annum with relative humidity of about 85% while temperature ranges from 27°C - 30°C sandy loamy soil. The coordinate of the area was between N7.2703617 and the E5.2240575. The topography of the area is about 1000 m above the sea level. The experiment was a split-plot experiment laid out in a Completely Randomized Design (CRD) with three replications during the late planting season of 2020.

2.2. Land Preparation and Growth Media Preparation

Clearing of the vegetation and tilling of the land were done manually using a machete and spade. Ninety (90) units of polythene bags of ten liters capacity were filled with top weighing 5kg per bag and divided into three of 30 each for the induced water stress conditions. Prior to pot filling, surface (0-30 cm depth) soil samples were randomly collected from a designated location, bulked and taken to the Department of Crop, Soil, and Pest Management, Federal University of Technology, Akure (FUTA) for the laboratory for analysis of the physico-chemical properties. The process was repeated post the trial, but the soil were taken from twenty (20) plots at random and bulked. The bulk samples were air-dried in the laboratory and ground to pass through 2-mm sieve and used for the analysis according to the standard laboratory procedures described by [20].

2.3. Plot Size, Experimental Treatments and Design

Unit plot size was 30 cm x 30 cm (0.09 m^2) and separated either way by 30 cm paths within the block while adjacent blocks were 50 cm apart. The treatments were factorial combinations of ten bambara groundnut landraces designated as (B_1, B_2, B_3, B_4, B_5, B_6, B_7, B_8, B_9, B_{10}) and three levels of Induced Water Stress (IWS) (Control, Excess Watering, Drought) fitted in a randomized complete design with three replicates.

2.4. Planting of Bambara Groundnut and Treatment Application

Two seeds of Bambara groundnut were sown per hole and the seedlings thinned to one at two weeks after planting when they were fully established. The control plots were watered normally throughout the duration of the experiment. At flowering stage of the plant, the unit representing excess watering, the plants were watered continuously for 21 days, starting 46 Days after Sowing (DAS), while the unit representing drought, the plants were stressed without watering for 21 days, starting 46 Days after Sowing (DAS).

2.5. Crop Management

Weeding was done manually when necessary to reduce competition for growth factors and enhance crop growth. During weeding soil was gathered around the base of the plants to cover the developing pods. There was no threat either from pests or diseases.

2.6. Data Collection and Analysis

Data were collected on Plant height (cm), Number of branches, Number of Leaves, Terminal Leaf Length (cm), Terminal Leaf Width (cm), Biomass (g), Wet Pod Weight/Plant (g), Dry Pod Weight/Plant (g), Pod Length (mm), Pod Width (mm), Number of Pods/Plant, Seed Length (mm), Seed Width (mm), Number of Seeds/Plant, Seed Weight/Plant.

Data collected were subjected to analysis of variance (ANOVA) using MINITAB, version 17 Statistical Software and the significant means were separated using Tukey's Honest Significant Difference at 5% probability level.

3. Results

3.1. Result on Growth Parameters

Plant height, Terminal leaf length, Terminal leaf width, Number of leaves and Number of branches of bambara groundnut varied across the weeks (Table 1), of which, significant (P≤0.05) difference was only observed on the Number of leaves and branches at week 8 and 12 respectively, where the drought produced significantly (P≤0.05) higher number of leaves (265.63) than the control and excess watering while the number of branches for the control (130.83) was significantly (P≤0.05) higher than the excess watering and drought respectively.

Table 1. Effects of Induced Water Stress on the growth parameters of Bambara Groundnut @4th, 8th, and 12th Week.

4TH WEEK							
IWS	PH	TLL	TLW	NL	NB	PH	TLL
Control	16.63a	4.60a	1.67a	59.87a	19.57a	19.94a	7.33a
Excess Watering	16.66a	4.79a	1.90a	59.03a	19.47a	19.34a	7.10a
Drought	17.38a	4.73a	1.77a	64.00a	21.57a	19.37a	7.23a

8TH WEEK					
IWS	TLW	NL	NB	PH	TLL
Control	2.64a	173.50b	115.53a	19.91a	7.58a
Excess Watering	2.86a	167.70b	59.50c	20.68a	7.37a
Drought	2.64a	265.63a	104.10b	19.74a	7.25a

12TH WEEK			
IWS	TLW	NL	NB
Control	3.56a	173.50b	130.83a
Excess Watering	3.39a	177.70b	78.63c
Drought	3.46a	265.63a	120.63b

Values are means of three replicates. Means with different alphabets in a column differed significantly at 5% level of probability according to Tukey HSD. IWS = Induced Water Stress, PH = Plant Height, TLL = Terminal Leaf Length, TLW = Terminal Leaf Width, NL = Number of Leaves, NB = Number of Branches.

Plant height, Terminal leaf length, Terminal leaf width, Number of leaves and Number of branches of bambara groundnut varied across the weeks (Table 2), of which, significant (P≤0.05) difference was only observed on the Number of leaves and branches at week 4, 8 and 12, Plant height was also significantly (P≤0.05) different at week 8 and 12. Plant height B_9 of week 8 (20.82 cm) and B_{10} of week 12 (21.82 cm) respectively were significantly higher than the other accessions. Bambara Accession 8 (B_8) 76.89, 238.89 and 242.22 were significantly (P≤0.05) higher in number of leaves at 4th, 8th, and 12th week respectively, while B_1 (25.00) and (122.22) at week 4 and 12 respectively, while B_6 (106.33) at week 8 were significantly (P≤0.05) higher in number of branches.

Table 2. Effects of Bambara Accessions on the growth parameters of Bambara Groundnut @4th, 8th, and 12th Week.

4TH WEEK							
B A	PH	TLL	TLW	NL	NB	PH	TLL
B_1	14.64a	3.97b	1.69a	71.22ab	25.00a	16.50bc	6.94a
B_2	15.31a	4.09ab	1.94a	62.44a-d	21.56ab	16.22c	6.49a
B_3	17.77a	4.88ab	1.86a	53.67de	18.11b	20.18a-c	7.20a
B_4	17.26a	4.87ab	1.56a	44.44e	16.11b	20.63ab	7.74a
B_5	18.62a	4.73ab	2.40a	53.67de	17.56b	20.53ab	6.59a
B_6	18.86a	5.79a	1.81a	54.67c-e	19.44ab	20.29a-c	7.59a
B_7	18.00a	4.12ab	1.58a	66.00a-d	21.78ab	20.88a	7.04a
B_8	15.60a	4.88ab	1.59a	76.89a	21.78ab	18.80a-c	7.41a
B_9	16.09a	4.76ab	1.88a	58.11b-e	19.44ab	20.82a	7.41a
B_{10}	16.74a	5.00ab	1.51a	68.56a-c	21.22ab	20.64ab	7.80a

8TH WEEK				
B A	TLW	NL	NB	PH
B_1	2.40a	228.33ab	101.89ab	18.19ab
B_2	2.58a	205.89b-d	86.78c	16.26b
B_3	3.00a	202.22b-d	100.89ab	21.73a
B_4	2.87a	159.22e	74.00d	18.62ab
B_5	2.93a	188.89cd	90.67bc	21.68a
B_6	2.84a	186.44cd	106.33a	20.64ab
B_7	2.78a	216.44ab	91.00bc	20.42ab
B_8	2.77a	238.89a	92.11bc	20.91ab
B_9	2.49a	212.44a-c	97.89a-c	20.81ab
B_{10}	2.51a	184.00de	88.89c	21.82a

12TH WEEK				
B A	TLL	TLW	NL	NB
B_1	7.67a	3.29a	231.67ab	122.22a
B_2	7.72a	3.33a	209.22b-d	102.22cd
B_3	7.37a	3.57a	205.56b-d	115.00ab
B_4	7.13a	3.70a	162.56e	93.56d
B_5	7.43a	3.31a	192.22cd	104.44b-d
B_6	7.23a	3.33a	189.78cd	117.78a
B_7	7.09a	3.41a	219.78ab	112.11a-c
B_8	7.16a	3.57a	242.22a	112.56a-c
B_9	7.17a	3.44a	215.78a-c	115.22ab
B_{10}	8.07a	3.73a	187.33de	105.22bc

Values are means of three replicates. Means with different alphabets in a column differed significantly at 5% level of probability according to Tukey HSD. B. A = Bambara Accessions, B_1 =TvSu-1047, B_2 =TvSu-102, B_3 =TvSu-505, B_4 =TvSu-486, B_5 =TvSu-1532, B_6 =TvSu-1531, B_7 =TvSu-1547, B_8 =TvSu-273, B_9 =TvSu-691, B_{10} =TvSu-315, PH = Plant Height, TLL = Terminal Leaf Length, TLW = Terminal Leaf Width, NL = Number of Leaves, NB = Number of Branches.

In the interaction between the various water stress conditions and bambara accessions (Table 3), significant (P≤0.05) difference was also observed on the Number of leaves and branches only among the other parameters evaluated at week 4, 8 and 12. At week 4, the interaction

C*B_8 recorded significantly (P≤0.05) higher number of leaves (88.33) and branches (25.67), whereas at week 8 and 12, the interaction DRT*B_1 recorded significantly (P≤0.05) higher number of leaves (298.33) for both weeks, while C*B_6 with (132.67) at week 8 and (142.67) at week 12 gave significantly (P≤0.05) higher number of branches.

Table 3. *Interactive Effects of Induced Water Stress and Bambara Accessions on the growth parameters of Bambara Groundnut @4th, 8th, and 12th Week.*

4TH WEEK

IWS*BA	PH	TLL	TLW	NL	NB	PH	TLL
C*B_1	13.33ab	4.13a	1.83a	75.00a-d	25.33a	17.67a	7.17a
C*B_2	17.97ab	3.60a	1.67a	62.67a-e	21.67ab	18.30a	6.60a
C*B_3	19.30ab	5.07a	1.60a	61.33a-e	20.33ab	22.20a	7.10a
C*B_4	19.00ab	5.90a	1.90a	47.00c-e	16.33ab	20.03a	8.37a
C*B_5	17.50ab	4.07a	2.17a	54.00b-e	16.33ab	19.67a	5.33a
C*B_6	18.27ab	5.27a	1.47a	44.67de	18.00ab	21.13a	8.10a
C*B_7	17.77ab	3.38a	1.40a	50.33b-e	17.33ab	19.60a	7.47a
C*B_8	13.03ab	4.87a	1.87a	88.33a	25.67a	19.53a	7.67a
C*B_9	12.17b	4.60a	1.50a	50.33b-e	16.67ab	21.00a	7.40a
C*B_{10}	17.93ab	4.67a	1.33a	65.00a-d	18.00ab	20.23a	8.13a
EW*B_1	14.97ab	2.67a	1.57a	58.33a-e	23.33ab	17.17a	6.37a
EW*B_2	14.20ab	4.63a	2.33a	53.00b-e	18.00ab	16.17a	7.10a
EW*B_3	16.67ab	4.03a	2.07a	52.00b-e	16.67ab	19.20a	7.60a
EW*B_4	17.57ab	4.97a	1.40a	34.33e	13.33b	20.27a	6.87a
EW*B_5	18.90ab	4.77a	2.67a	47.00c-e	16.00ab	20.47a	6.97a
EW*B_6	18.37ab	6.10a	1.93a	64.67a-e	22.00ab	18.90a	7.30a
EW*B_7	14.77ab	5.23a	1.83a	68.33a-d	23.00ab	21.67a	7.40a
EW*B_8	16.10ab	4.80a	1.23a	79.00ab	19.67ab	17.70a	6.40a
EW*B_9	17.70ab	4.80a	2.30a	70.33a-d	24.00ab	21.57a	7.43a
EW*B_{10}	17.40ab	5.83a	1.73a	63.33a-e	18.67ab	20.30a	7.57a
DRT*B_1	15.63ab	5.10a	1.67a	80.33ab	26.33a	14.67a	7.30a
DRT*B_2	13.77ab	4.03a	1.93a	71.69a-d	25.00ab	14.20a	5.77a
DRT*B_3	17.33ab	5.53a	1.90a	47.67c-e	17.33ab	19.13a	6.90a
DRT*B_4	15.20ab	3.73a	1.37a	52.00b-e	18.67ab	21.60a	8.00a
DRT*B_5	19.47ab	5.37a	2.37a	60.00a-e	20.33ab	21.47a	7.47a
DRT*B_6	19.93ab	6.00a	2.03a	54.67b-e	18.33ab	20.83a	7.37a
DRT*B_7	21.47a	3.30a	1.50a	79.33ab	25.00ab	21.37a	6.27a
DRT*B_8	17.67ab	4.97a	1.67a	63.33a-e	20.00ab	19.17a	8.17a
DRT*B_9	18.40ab	4.87a	1.83a	53.67b-d	17.67ab	19.90a	7.40a
DRT*B_{10}	14.90ab	4.40a	1.47a	77.33a-c	27.00a	21.40a	7.70a

8TH WEEK

IWS*BA	TLW	NL	NB	PH	TLL
C*B_1	2.37a	191.67e-i	113.33a-e	19.27ab	7.67a
C*B_2	2.37a	187.33e-i	132.00a	16.90ab	7.00a
C*B_3	2.67a	210.00c-g	124.00a-c	23.20a	7.17a
C*B_4	2.73a	143.00ij	101.67c-f	17.10ab	8.23a
C*B_5	2.60a	162.00g-j	124.00a-c	20.53ab	6.40a
C*B_6	2.73a	129.0jk	132.67a	22.47ab	7.93a
C*B_7	2.83a	165.00g-j	102.00c-f	19.20ab	7.73a
C*B_8	3.07a	268.33ab	105.33b-e	20.30ab	7.53a
C*B_9	2.63a	154.00h-j	121.67a-d	18.33ab	8.17a
C*B_{10}	2.43a	124.67jk	98.67d-g	21.80ab	8.00a
EW*B_1	2.47a	195.00e-i	73.00h-k	18.17ab	6.97a
EW*B_2	2.80a	159.00g-j	53.00kl	19.50ab	9.37a
EW*B_3	3.47a	156.00g-j	52.00kl	21.57ab	8.10a
EW*B_4	3.20a	82.67k	27.67m	19.20ab	6.80a
EW*B_5	3.13a	141.00ij	47.00lm	21.63ab	8.30a
EW*B_6	2.87a	175.33f-j	64.67j-l	19.67ab	6.23a
EW*B_7	2.57a	205.00d-h	68.33i-l	22.63ab	6.87a
EW*B_8	2.53a	185.00f-i	80.67f-j	20.93ab	6.40a
EW*B_9	2.83a	228.00b-e	70.33h-l	22.37ab	6.47a
EW*B_{10}	2.77a	150.00ij	58.33j-l	21.13ab	8.23a
DRT*B_1	2.37a	298.33a	119.33a-d	17.13ab	8.36a
DRT*B_2	2.57a	271.33ab	75.33g-k	12.37b	6.80a
DRT*B_3	2.87a	240.67b-e	126.67ab	20.43ab	6.83a
DRT*B_4	2.67a	252.00a-d	92.67e-h	19.57ab	6.37a
DRT*B_5	3.07a	263.67a-c	101.00c-f	22.87ab	7.60a
DRT*B_6	2.93a	255.33a-d	121.67a-d	19.80ab	7.53a
DRT*B_7	2.93a	279.33ab	102.67b-f	17.43ab	6.67a
DRT*B_8	2.70a	263.33a-c	90.33e-i	21.50ab	7.53a
DRT*B_9	2.00a	255.33a-d	101.67c-f	21.73an	6.87a
DRT*B_{10}	2.33a	277.33ab	109.67a-e	22.53ab	7.97a

12TH WEEK

IWS*BA	TLW	NL	NB
C*B_1	3.07a	191.67f-k	130.00a-d
C*B_2	3.37a	187.33f-k	142.00ab
C*B_3	3.37a	210.00d-i	134.67a-c
C*B_4	3.77a	143.00k-l	122.00a-f
C*B_5	3.07a	162.00h-l	134.00a-d
C*B_6	3.50a	129.00lm	142.67a
C*B_7	3.63a	165.00h-l	125.33a-d
C*B_8	4.03a	268.33a-c	126.67a-d
C*B_9	3.83a	154.00j-l	132.33a-d
C*B_{10}	4.00a	124.67lm	118.67b-g
EW*B_1	2.90a	205.00e-j	98.33f-j
EW*B_2	3.40a	169.00h-l	67.33lm
EW*B_3	3.77a	166.00h-l	70.33kl
EW*B_4	4.00a	92.67m	46.00m
EW*B_5	3.40a	151.00j-l	68.33k-m
EW*B_6	2.87a	185.33g-k	78.00j-l
EW*B_7	3.27a	215.00c-h	88.33i-l
EW*B_8	3.23a	195.00f-k	100.67e-j
EW*B_9	3.53a	238.00b-g	91.33g-j
EW*B_{10}	3.50a	160.00i-l	77.33j-l
DRT*B_1	3.90a	293.33a	138.33ab
DRT*B_2	3.23a	271.33ab	97.33g-j
DRT*B_3	3.57a	240.67b-f	140.00ab
DRT*B_4	3.33a	252.00a-e	112.67c-h
DRT*B_5	3.47a	263.67a-d	111.00c-i
DRT*B_6	3.63a	255.00a-e	132.67a-d
DRT*B_7	3.33a	279.33ab	122.67a-e
DRT*B_8	3.43a	263.33a-d	110.33d-i
DRT*B_9	2.97a	255.33a-e	121.67a-f
DRT*B_{10}	3.70a	277.33ab	119.67a-g

Values are means of three replicates. Means with different alphabets in a column differed significantly at 5% level of probability according to Tukey HSD. IWS*BA = Interactions of Induced Water Stress and Bambara Accessions, PH = Plant Height, TLL = Terminal Leaf Length, TLW = Terminal Leaf Width, NL = Number of Leaves, NB = Number of Branches.

3.2. Yield Parameters Table

The Biomass differ significantly (P≤0.05) among the treatments, the Control plot with the highest value (167.60g) was significantly (P≤0.05) different from Excess Watering (134.93g) and Drought (146.73g) respectively (Table 4). Wet pod weight also differ significantly (P≤0.05) among the treatments, the control condition (36.57g) was significantly (P≤0.05) higher than the excess watering (21.67g) and Drought (17.09g) conditions respectively. The same order was observed in the Dry pod weight. Significant difference was also observed in the seed weight per plant, with the Control (8.17g) having the higher significant (P≤0.05) effect over the Excess Watering (5.76g) and Drought (4.22g). However, the control recorded higher values for the other parameters except Pod width and length but there was no significant difference from the other induced water stress conditions.

Table 4. *Effects of Induced Water Stress on the yield and yield components of Bambara Groundnut.*

IWS	Biomass	WPW	DPW	PNpP	SWpP	SNpP	PW	PL	SW	SL
Control	167.60a	36.57a	15.00a	16.87a	8.17a	13.23a	12.33a	17.33a	9.57a	12.20a
Excess Watering	134.93c	21.67b	9.18b	16.40a	5.76b	10.87a	12.40a	17.70a	9.46a	11.90a
Drought	146.73b	17.90c	8.76b	14.83a	4.22c	12.67a	12.27a	17.57a	9.00a	11.77a

Values are means of three replicates. Means with different alphabets in a column differed significantly at 5% level of probability according to Tukey HSD. IWS = Induced Water Stress, WPW = Wet Pod Weight, DPW = Dry Pot Weight, PNpP = Pod Number per plant, SWpP = Seed Weight per Plant, SNpP = Seed Number per Plant, PW = Pod Width, PL = Pod Length, SW = Seed Width, SL = Seed Length.

Table 5 represent the yield parameters across the various accessions, significant ($P \leq 0.05$) difference was observed among the accessions, with B_8 (208.78g) producing the highest biomass, followed by B_3 (181.00g) and B_{10} (175.78g), the least biomass was observed in B_1 (94.22g). The wet pod weight also showed significant ($P \leq 0.05$) difference among the accessions, B_4 (32.33g) was significantly ($P \leq 0.05$) higher than B_2, B_3, B_5, B_7, B_9 and B_{10}, and B_{10} (17.11g) produced the least wet pod weight. The dry pod weight also recorded some significant difference, B_4 (14.83g) was more significant ($P \leq 0.05$) against the other accessions, and B_{10} (5.92g) also recorded the least dry pod weight. Pod number per plant also showed significant difference, B_7 (27.56g) was more significant ($P \leq 0.05$) than the other accessions and produced the highest pod number per plant, while B_{10} (5.22g) produced the least pod number per plant. The accessions showed significant difference, B_6 (9.47g) was more significant ($P \leq 0.05$) than the other accessions and produced the highest seed weight per plant, while B_{10} (3.03) produced the least seed weight per plant. For the seed number per plant, B_7 (20.33) was more significant ($P \leq 0.05$) than the other accessions except B_8 and produced the highest seed number per plant, while B_{10} (4.78) produced the least seed number per plant. On Pod width, B_3 (13.11mm) was more significant ($P \leq 0.05$) than accessions B_5 and B_{10} and produced the highest pod width, while B_{10} (10.78mm) produced the least pod width. On Seed length, B_9 (13.11mm) significantly ($P \leq 0.05$) differ from B_{10} (10.11mm).

Table 5. *Effects of Bambara Accessions on the yield and yield components of Bambara Groundnut.*

B. Accessions	Biomass	WPW	DPW	PNpP	SWpP	SNpP	PW	PL	SW	SL
B_1	94.22g	29.00ab	10.06bc	15.44b	5.33b-d	11.11bc	12.78ab	17.44a	9.33a	11.33ab
B_2	146.56cd	20.89cd	7.53cd	15.22b	4.67cd	12.00bc	12.78ab	17.67a	9.33a	12.00ab
B_3	181.00b	25.56bc	11.42a-c	17.33b	4.88b-d	11.89bc	13.11a	17.56a	9.89a	11.89ab
B_4	108.67fg	32.33a	14.83a	14.00b	6.22b-d	11.56bc	12.56ab	18.11a	8.67a	11.33ab
B_5	123.78ef	20.78cd	10.27bc	17.33b	6.24bc	11.44bc	11.22bc	17.33a	9.11a	12.33ab
B_6	134.67de	30.67ab	13.27ab	15.22b	9.47a	12.11bc	13.00a	16.89a	9.22a	12.67a
B_7	168.89bc	26.56b	12.39ab	27.56a	7.50a-c	20.33a	12.56ab	18.11a	10.44a	12.44ab
B_8	208.78a	20.89cd	10.22bc	18.22b	5.30b-d	14.78ab	11.89a-c	17.33a	9.56a	12.33ab
B_9	160.22bc	30.00ab	14.00ab	14.78b	7.94ab	12.56b	12.67ab	18.56a	9.89a	13.11a
B_{10}	175.78b	17.11d	5.92d	5.22c	3.03d	4.78c	10.78c	16.33a	8.00a	10.11b

Values are means of three replicates. Means with different alphabets in a column differed significantly at 5% level of probability according to Tukey HSD. B. A = Bambara Accessions, B_1 =TvSu-1047, B_2 =TvSu-102, B_3 =TvSu-505, B_4 =TvSu-486, B_5 =TvSu-1532, B_6 =TvSu-1531, B_7 =TvSu-1547, B_8 =TvSu-273, B_9 =TvSu-691, B_{10} =TvSu-315, WPW = Wet Pod Weight, DPW = Dry Pot Weight, PNpP = Pod Number per plant, SWpP = Seed Weight per Plant, SNpP = Seed Number per Plant, PW = Pod Width, PL = Pod Length, SW = Seed Width, SL = Seed Length.

Table 6 showed the interactions between the induced water stress and the bambara groundnut accessions. The highest interactive effects on the biomass was observed in C*B_7 (235.67g) and C*B_8 (235.00g) and are significantly ($P \leq 0.05$) higher than EW*B_1 (82.33g) that produced the least interactive effect. Significant was observed in the wet pod weight among the interactions, C*B_9 (48.67g) was more significantly ($P \leq 0.05$) than the other interactions. On dry pod weight, the interaction EW*B_6 was more significant ($P \leq 0.05$) and had the highest dry pod weight (22.50g), while the least interactive effect was observed in EW*B_{10} (2.63g). The interaction EW*B_7 was more significant ($P \leq 0.05$) and had the highest pod number per plant (29.00g), while the least interactive effect was observed in DRT*B_{10} (2.00g). On seed weight per plant, the interaction EW*B_6 was more significant ($P \leq 0.05$) and had the highest seed yield per plant (18.33g), while the least interactive effect was observed in EW*B_{10} (0.77g). On Seed number per plant, the interaction C*B_7 was more significant ($P \leq 0.05$) and had the highest seed number per plant (22.33), while the least interactive effect was observed in C*B_4 (1.33). The interactive effects on pod width, the interaction C*B_1 was more significant ($P \leq 0.05$) and had the highest pod width (14.67mm), while the least interactive effect was observed in DRT*B_{10} (9.00mm). On Seed width, the interaction C*B_7 was significant ($P \leq 0.05$) against C*B_7 (6.33mm) and DRT*B_{10} (6.00mm) and produced the highest seed weight (12.00mm) among the other interactions. On Seed length, the interaction C*B_7, DRT*B_4, DRT*B, and DRT*B_9 were significantly higher ($P \leq 0.05$) when compared with C*B_4 and DRT*B_{10}, however, DRT*B_9 recorded the highest seed length (14.33mm) among the significant interactions.

Table 6. *Interactive Effects of Induced Water Stress and Bambara Accessions on the yield and yield components of Bambara Groundnut.*

IWS*BA	Biomass	WPW	DPW	PNpP	SYpP	SNpP	PW	PL	SW	SL
C * B_1	94.67jk	38.00a-c	10.33c-j	16.00b-h	7.33b-f	10.33a-e	14.67a	18.33a	10.00a-c	12.67a-c
C * B_2	124.00g-k	39.00a-c	10.67c-j	22.33a-e	7.33b-f	17.33a-d	13.00ab	18.33a	10.00a-c	12.33a-c
C * B_3	216.67ab	36.33b-d	18.00a-c	26.67a-c	7.33b-f	16.67a-e	13.67ab	18.33a	10.33a-c	12.33a-c
C * B_4	127.67f-k	37.67a-c	21.00ab	3.00ij	6.00c-f	1.33e	11.67a-c	16.00a	6.33bc	8.00c
C * B_5	157.67d-h	32.00c-f	15.00a-d	21.33a-f	9.33bc	18.33a-c	11.33a-c	18.00a	9.00a-c	13.00ab
C * B_6	165.00c-g	36.67bc	13.33b-f	15.33c-i	8.33b-e	12.33a-e	11.67a-c	16.33a	10.33a-c	12.67a-c
C * B_7	235.67a	34.00c-e	15.67a-d	28.33ab	9.00b-d	22.33a	12.33a-c	16.67a	12.00a	14.00a
C * B_8	235.00a	25.00d-h	12.00c-h	13.67d-j	6.67c-f	13.33a-e	12.00a-c	17.33a	9.67a-c	12.67a-c
C * B_9	154.33d-h	48.67a	21.67ab	12.67e-j	13.33ab	11.67a-e	11.00bc	16.67a	9.00a-c	12.67a-c
C * B_{10}	165.33c-g	38.33a-c	12.33c-g	9.33f-j	7.00b-f	8.67a-e	12.00a-c	17.33a	9.00a-c	11.67a-c
EW * B_1	82.33k	20.00g-j	5.33f-j	13.00e-j	1.67f	7.33a-e	11.67a-c	16.67a	8.67a-c	11.33a-c
EW * B_2	123.0g-k	16.00h-l	8.33d-j	14.67c-j	4.67c-f	10.67a-e	14.00ab	18.33a	9.33a-c	12.67a-c
EW * B_3	174.33b-e	18.00g-k	5.33f-j	12.67e-j	2.50d-f	8.67a-e	11.33a-c	14.67a	9.00a-c	11.00a-c
EW * B_4	85.33jk	34.67c-e	11.33c-i	15.00c-i	7.00b-f	12.33a-e	13.67ab	20.00a	10.00a-c	12.00a-c
EW * B_5	84.00jk	19.67g-j	10.67c-j	24.00a-e	7.00b-f	12.67a-e	11.00bc	17.00a	9.00a-c	11.67a-c
EW * B_6	115.00h-k	46.33ab	22.50a	26.00a-d	18.33a	20.67ab	13.00ab	17.67a	10.33a-c	12.00a-c
EW * B_7	164.00c-g	29.00c-g	13.33b-f	29.00a	9.33bc	16.67a-e	13.00ab	19.00a	10.33a-c	13.00ab
EW * B_8	183.67b-d	13.00i-l	6.33e-j	17.33a-g	3.00c-f	9.67a-e	11.67a-c	17.33a	9.67a-c	12.67a-c
EW * B_9	170.67b-f	13.00i-l	6.00e-j	8.00g-j	3.33c-f	7.00b-e	13.33ab	19.33a	9.33a-c	12.33a-c
EW * B_{10}	167.00c-g	7.00kl	2.63j	4.33h-j	0.77f	4.00c-e	11.33a-c	17.00a	9.00a-c	10.33a-c
DRT * B_1	105.67i-k	29.00c-g	14.50a-e	17.33a-g	7.00b-f	15.67a-e	12.00a-c	17.33a	9.33a-c	10.00a-c
DRT * B_2	192.a-d	7.67kl	3.60h-j	8.67f-j	1.70ef	8.00a-e	11.33a-c	16.33a	8.67a-c	11.00a-c
DRT * B_3	152.00d-i	22.33f-i	10.93c-j	12.67e-j	4.80c-f	10.33a-e	14.33ab	19.67a	10.33a-c	12.33a-c
DRT * B_4	113.00h-k	24.67e-h	12.17c-h	24.00a-e	5.67c-f	21.00ab	12.33a-c	18.33a	9.67a-c	14.00a
DRT * B_5	129.67e-j	10.67k-l	5.13f-j	6.67g-j	2.40d-f	3.33c-e	11.33a-c	17.00a	9.33a-c	12.33a-c
DRT * B_6	124.00g-k	9.00j-l	3.97g-j	4.33h-j	1.73ef	3.33c-e	14.33ab	16.67a	7.00a-c	13.33a
DRT * B_7	92.00jk	16.67h-l	8.17d-j	25.33a-e	4.17c-f	22.00a	12.33a-c	18.67a	9.00a-c	10.33a-c
DRT * B_8	200.67a-c	24.67e-h	12.00c-h	23.67a-e	6.23c-f	21.33ab	12.00a-c	17.33a	9.33a-c	11.67a-c
DRT * B_9	155.67d-h	28.33c-g	14.33a-e	23.67a-e	7.17b-f	20.00ab	13.67ab	19.67a	11.33ab	14.33a
DRT * B_{10}	195.00a-d	6.00l	2.80ij	2.00j	0.97fg	1.67de	9.00c	14.47a	6.00c	8.33bc

Values are means of three replicates. Means with different alphabets in a column differed significantly at 5% level of probability according to Tukey HSD. IWS*BA = Interactions of Induced Water Stress and Bambara Accessions, WPW = Wet Pod Weight, DPW = Dry Pot Weight, PNpP = Pod Number per plant, SWpP = Seed Weight per Plant, SNpP = Seed Number per Plant, PW = Pod Width, PL = Pod Length, SW = Seed Width, SL = Seed Length.

4. Discussions

Among the treatments, the Control plot with the highest value on the yield components, Biomass (167.60g), Wet Pod Weight (36.57g), Dry Pod Weight (15.00g) amongst others and was significantly ($P \leq 0.05$) different from Excess Watering and Drought, where the drought recorded the least. The drought-induced reduction in pod weight in bambara groundnut was achievable due to a combination of stomatal closure and reduced leaf area, which might reduce water loss but also restrict photosynthetic capability and carbon fixation efficiency during seed filling. Under drought stress (30–15% soil water availability), a reduction in gs from 0.25 to 0.05 mol H_2O m^{-2} s^{-1} resulted in a decrease in instantaneous carboxylation efficiency in two Jatropha curcas accessions [21]. Unlike other legumes like pea, chickpea, and mungbean (Vigna radiata), bambara groundnut does not redistribute dry matter during the pod filling stage, as bambara groundnut lacks important vegetative structures like large and highly compressed stems to store carbohydrates before redistributing assimilates to the seed, according to Mwale et al. [22]. Lower photosynthetic levels of plants during the pod filling stage owing to drought stress could contribute to a drop in seed output in bambara groundnut plants [22]. Combining the responses of bambara groundnut plants to the interactive effects of induced water stress and bambara accessions, though C*B_8 and C*B_9 out-performed other interactions in Biomass and Wet Pod Weight respectively, however, the interactions EW*B_6 and EW*B_7 (accessions under excess watering conditions) recorded significant ($P \leq 0.05$) higher Dry Pod Weight and Pod Number/Plant, which could potentially be selected as candidates for future breeding programmes and can be included in climate change adaptation strategies [23].

5. Conclusions

The effects of drought stress on bambara groundnut development and yield vary depending on the severity of the stress. In general, bambara groundnut tolerates low soil moisture content to a high degree; nevertheless, prolonged drought during the flowering stage results in low yield. Due to increased floral abortion caused by high water stress, drought stress affects the number of seeds and pods produced. Dry pod weight, pod number per plant, seed length, and seed weight per plant are the parameters that could be selected for improvement in bambara groundnut under stress.

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