

Full Length Research Paper

Effects of water stress on yield and its components and physiological traits in groundnut

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Groundnut (*Arachis hypogaea* L.) is an important food legume grown worldwide and is a great source of protein for humans and animals. Water stress is the main abiotic constraint affecting groundnut production. 204 groundnut breeding lines were evaluated under water stress and well-watered conditions to assess the effects of water stress on yield and the agro-physiological traits. The study was conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)-Mali experimental site during the 2022 off season in a Latin Square Design. Analysis of variance revealed significant differences between physiological traits, pod yield, and its related traits under both water regimes. Groundnut genotypes ICGV 216020, with superior performance of 2950.34 kg ha⁻¹ for pod yield under water stress, and ICGV 186544 with 3568.13 kg ha⁻¹, pod yield, under well-watered conditions, were identified. Furthermore, groundnut genotypes consistently showing high chlorophyll content values under both water regimes and across sampling dates were ICGV 216249, ICGV 186652 and ICGV 216040. The genotypes ICGV 186607, ICGV 206128, ICGV 216020, ICGV 186652 and ICGV 06424, exhibited the least reduction in pod yield. The results of our study did not show any correlation between chlorophyll content and pod yield under water stress conditions.

Key words: Groundnut, water, stress, drought, tolerance.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.), a crop subject to the effects of climate change, is one of the most important oilseeds cultivated in the world, particularly in arid and semi-arid regions of Africa. It is grown in 108 countries at nearly 30.92 million ha worldwide with a total production

of 54.27 million tons and an average yield of 1755.2 kg ha⁻¹ in 2023, Food and Agriculture Organization Statistics (FAOSTAT, 2023). The global output comes from seasonally, rain-fed areas of warm regions, and tropical, subtropical regions. Developing countries account for

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96.9 % of the world's groundnut area with 93.8 % of total production (Nageswara et al., 2001). According to FAOSTAT (2023), the average yield of groundnut is about 4194.3 kg ha⁻¹ in the USA, 3972.8 kg ha⁻¹ in China, 1246.4 kg ha⁻¹ in Nigeria, and only 919.1 kg ha⁻¹ in Mali. Groundnut provides many benefits including a rich source of digestible protein, high-quality oils, and many functional compounds and elements such as iron and zinc which are important for nutrition and health, especially in children. Groundnut seed contains high-quality edible oil (50%), easily digestible protein (25%), and carbohydrates (20%) (FAOSTAT, 2019). It also provides an important source of fodder for livestock through the haulms and pods (Nyabyenda, 2006).

Africa and particularly Mali is affected by the effects of climate change which resulted in a change in the rainfall regime, marked by a decrease in rainfall, a shift in the start and end of wet seasons, as well as an increase in extreme weather events such as drought, flooding, and heat waves (Birama, 2020). Mali is among the major groundnut producing countries in Africa. Despite the importance of groundnut, yields in Mali have remained low in stark contrast to the crop's potential which can provide more under intensive farming systems such as in the USA (FAOSTAT, 2023). This gap in yield represents a challenge that needs to be addressed through research. Increasing groundnut production is challenged by several constraints including abiotic and biotic stresses. Drought and low soil fertility are the major abiotic stresses limiting tropical groundnut production.

Drought is known to cause substantial reduction in the economic yield of crop plants, a major threat to food security, sustainability of production systems, and the well-being of people living in drought-prone areas. It adversely affects the lives of 2.6 billion people (43 % of the world population) engaged in agriculture (Saxena and O'Toole, 2002). Drought at any stage of crop development affects production, but grain yield losses can be greater if drought stress occurs in the early season, mid-season, and end-of-season. Among the important forms of drought, end-of-season (terminal) drought that affects seed development is more critical (Nigam et al., 2002). Drought is projected to intensify in the years ahead in response to climate change (Acquaah, 2012). According to Derera et al. (2008), groundnut production could probably improve in water-stress-prone areas by additional irrigation. However, in general, groundnut producers in Mali are mainly resource-poor smallholder's farmers, who rely on rainfed systems with little or no access to irrigation facilities and have a limited capacity to adopt high-input technologies.

Groundnut has many mechanisms of response and survival to drought. These include responses involving physiological, agromorphological, and biochemical parameters. Understanding the mechanism explaining the drought tolerance of groundnut varieties to drought is

important for improving production (Hamidou et al., 2007). Previous studies have reported drought tolerance mechanisms and its molecular basis, in groundnut, using physiological, agromorphological, and biochemical parameters (Hamidou et al., 2012; Pasupuleti and Nigam, 2013). Several improved groundnut varieties have been developed in Mali through Institute for Energy Research (IER) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) research collaboration.

Furthermore, the functional significance of the physiological characteristics notably their relationships with yield and its components, are still not established on groundnut cultivars for water stress tolerance, mainly for those grown in Mali. Therefore, developing high yielding groundnut varieties resilient to water stress is critical to support these poor resource subsistence producers. It is also important to understand and establish the functional significance of the physiological characteristics related to yield and its components in elite breeding lines from the breeding programs. This contributes to the improvement of groundnut production in Mali through the identification of drought tolerant varieties.

Therefore, a field experiment was conducted with objectives to:

- (1) Understand the variation for agro-physiological traits in elite groundnut genotypes under water stress and well-watered conditions.
- (2) Identify high-yielding genotypes under stress and optimal conditions.

MATERIALS AND METHODS

Study site

The experimentation was carried out during the off-season of 2022 at Samanko agricultural research station of ICRISAT, located at 25 km South-West from Bamako, in the Sudano-Sahelian zone of Mali; geographically situated between latitude 12°54' W and 8°04' N longitude, 331 m above sea level. The soils at the station are classified as poor in organic matter, light with a pH of 5.0.

Plant

A total of 204 groundnut genotypes of short maturity group (90 days to maturity) selected among advanced groundnut breeding lines from ICRISAT-Mali were evaluated for drought tolerance under well-watered (WW) (Optimal) and water-stress (WS) conditions. Among the evaluated genotypes, ICGV 06424, ICGV 86124 were used as drought tolerant checks and ICGV 00308 as susceptible check in the groundnut breeding program. Among the evaluated genotypes, 11 genotypes did not germinate in both well-watered and water-stress conditions during the experimentation due to poor germination.

Experiment management

The experiment was laid out in Latin Square Design with three

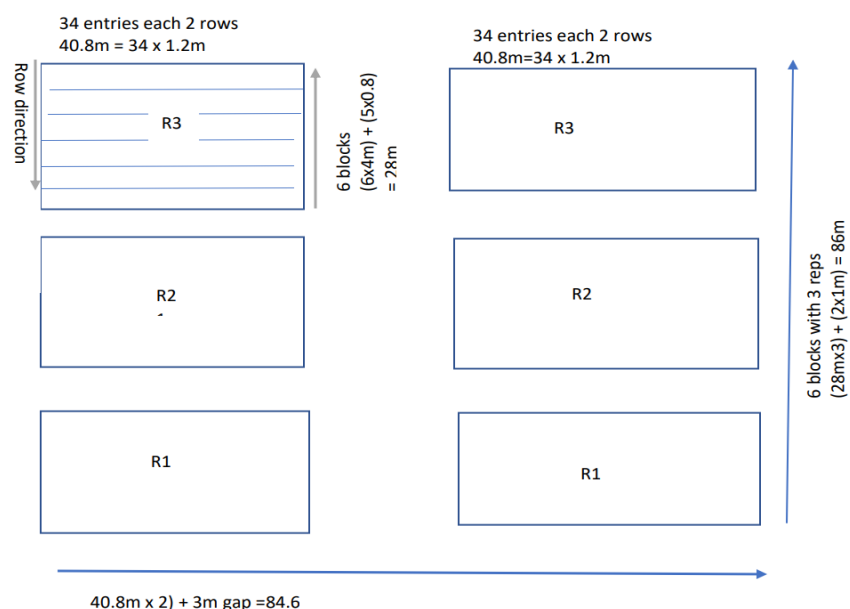


Figure 1. Repeated Latin square experimental design.

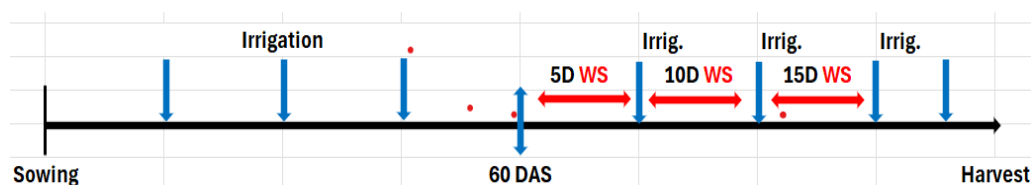


Figure 2. Irrigation schedule: Irrigation, 5 D WS = 5 days of water stress, 10 D WS = 10 days of water stress, 15 D WS = 15 days of water stress, 60 DAS: 60 days after sowing.

replications in the field (Figure 1.). Each plot consisted of two rows of 4 m length with 0.60 m inter-row spacing and 0.10 m between plant spacing within a row. The genotypes were randomized within the block in 34 × 6 row-column arrangement. The well-watered (WW) and water-stressed (WS) experiments were done separately. The two blocks of the WW and WS experiments were separated by an alley of 3m wide to restrict lateral movement of water from the WW block to the WS block and a 1m alley was used between replications. The experimental field was kept free from weeds throughout the study period by hand weeding to prevent weed infestation and competition between plants and weeds.

Irrigation schedule

The irrigation schedule is as shown in Figure 2. The water-stressed environment was irrigated until 60 days after sowing (DAS) and subsequently, irrigation was withheld to gradually expose the genotypes to end-of-season drought from the pod filling until maturity. At 60 DAS, drought stress was imposed for 5 days and irrigation resumed on the 6th day to bring the soil up to saturation. Then, drought stress was imposed for 10 days, followed by irrigation up to saturation. After that, drought stress was imposed for 15 days. After the final stress was applied, both environments were

irrigated at 91 DAS, followed by harvesting at 92 DAS.

This technique is supposed to mimic the end-of-season drought since water is withheld during the critical stage of the reproductive phase. Irrigation continued for well-watered environment until physiological maturity, following irrigation frequency of 2 days per week using overhead sprinklers with freshwater pumped directly from Niger River.

Fertilizer application

Fertilizer was applied in the form of 100 kg ha⁻¹ of DAP (46%P₂O₅, 18% N) during land preparation with 2 to 3 days before sowing (planting). Gypsum at the rate of 400 kg ha⁻¹ was applied 45 days after planting.

Data collection

Climatic data

Cumulative of rainfall and temperature data during the year 2022 is as shown in Figure 3.

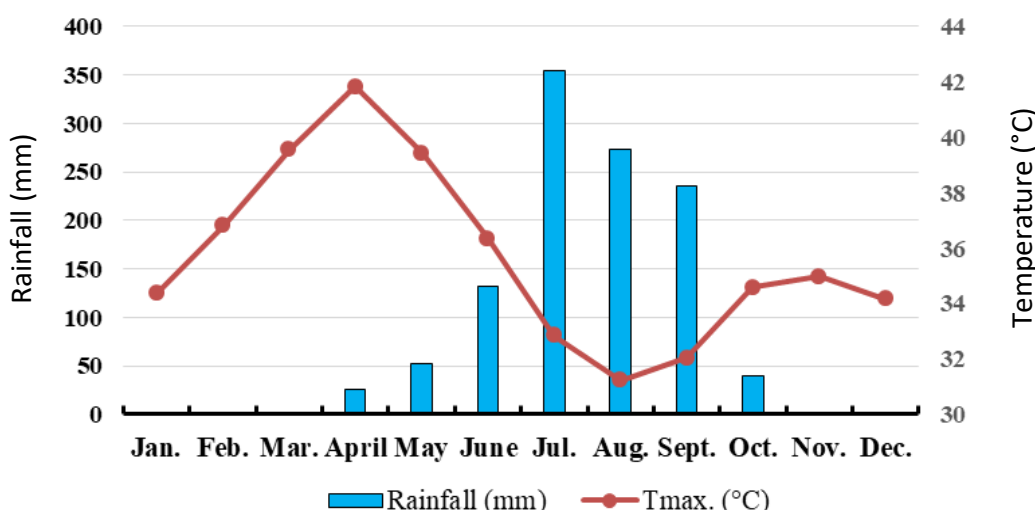


Figure 3. Cumulative of raining and temperature data during the year 2022.

Physiological and agronomic data

Data on yield, physiological parameters and other important agronomic traits were collected on five randomly tagged plants from each plot.

Days to 50% flowering (50% FL): Plots were regularly monitored to record the date at which 50% of the plants flowered.

SCMR chlorophyll meter reading (SCMR): The chlorophyll content was measured by handholding portable SCMR meter (SCMR 502 Plus, Spectrum Technology, USA). Five plants from each plot were sampled at random in each replication and treatment during the morning period (08:00 h to 12:00 h). Measurement was done on the youngest fully expanded leaflet. Data was collected 3 times (days 65, 75 and 90) at wilting point after drought stress imposition.

Wilting scores (Wscore): Scale of 1 to 5 (1 = good; 5 = poor).

Dry pod yield (DPY gplant⁻¹): Pod yield was determined from pods harvested from five randomly selected plants from each plot in a well-watered and drought-stress environment after air drying to < 10% moisture level and their average is taken as the pod yield per plant.

Shelling percentage (SP): Shelling percentage was determined by taking a sample of about 200 g mature pods per plot. The weights of the 200 pods (PW) and grains after shelling the pods (SW) were used to calculate the shelling percentage (SP) as given in the equation:

$$SP = SW/PW \times 100$$

where SW= seed weight after shelling the 200 g pods; PW = pod weight (200 g).

Hundred (100) seed weight or hundred kernel weight (100 SW g): This was obtained by counting a random sample of 100 seeds taken from the harvested bulk per plots and weighed using

electronic weighing balance.

Dry haulm weight per plot (g): The total produce of each plot was allowed to dry in the field and in driers (during cloudy days) and after drying biological produce was put into cloth bags and weighed.

$$\text{Reduction (\%): RED} = \frac{Y_w - Y_s}{PW}$$

where Ys = yield of the genotype under water stress (WS) condition and Yw = yield of the genotype under well-watered (WW) condition.

Statistical analysis

All statistical analyses were performed using R software version 4.3.0. Analyses of variance (ANOVA) using “agricolae” package were conducted for each water regime separately and combined across water regimes. Residual normality and homogeneity were assessed using the Shapiro-Wilk normality and Bartlett homogeneity tests. Least square difference (LSD) at $p = 0.05$ was used to compare means. The Broad-sense heritability was calculated according to the method of Sarkar et al. (2023) using the formula:

$$H^2 = \frac{\sigma^2 G}{\sigma^2 P}$$

Metan packages in R were used to perform Pearson correlation matrix analysis of the variables. The analyses were conducted on a set of 193 genotypes.

RESULTS

Analysis of variance

The results of the analysis of variance are shown in Table 1. Analysis of variance for pod yield and other agronomic

Table 1. Analysis of variance of agronomic and physiological traits under well-watered and water stress conditions.

Variable	Mean Square									
	Df	DT50	SCMR_65DAS	SCMR_75DAS	SCMR_90DAS	Wscore	HSW	PSH	DHWPP	PYH
Drought-stress condition										
Genotypes	192	5.741**	23.4**	26.4**	24.5**	1.123**	52.7**	89.2**	0.527**	1107312**
Replications	2	13.512**	678.7**	243.3**	775.8**	21.629**	424.9**	740.8**	6.090**	14884398**
Rows	15	6.757**	150.6**	325.0**	44.9**	10.042**	45.6**	138.3**	2.684**	2365507**
Columns	33	3.400**	13.8 ^{ns}	20.5**	14.8*	0.494*	26.9**	26.1 ^{ns}	0.341**	521898**
Residuals	336	1.383	11.5	9.2	9.0	0.315	14.4	34.7	0.177	201599
Well-Water condition										
Genotypes	192	8.426**	20.26**	32.10**	23.1**	1.095**	47.46**	49.6**	0.92**	1240700**
Replications	2	10.119**	110.87**	200.55**	378.2**	9.003**	15.39 ^{ns}	573.5**	41.99**	7678512**
Rows	15	6.602**	49.72**	252.69**	46.2**	2.650**	85.41**	50.8**	4.82**	1080852**
Columns	33	1.584 ^{ns}	11.73*	8.61 ^{ns}	11.8 ^{ns}	0.939**	21.38*	32.3**	0.47 ^{ns}	470684**
Residuals	336	1.612	7.24	8.04	8.9	0.405	13.06	17.3	0.52	258356
Across drought stress and well-water condition										
Genotypes	192	12.177**	31.2**	38**	38.6**	1.48**	81**	108.0**	1.00**	2041988**
Replications	2	15.067**	176.5**	6 ^{ns}	87.2**	5.27**	229**	157.8**	36.79**	4059486**
Rows	15	11.604**	189.3**	210**	48.0**	4.51**	111**	104.1**	6.08**	1479222**
Columns	33	2.576*	10.9	15 ^{ns}	16.9 ^{ns}	0.77 ^{ns}	33**	23.9 ^{ns}	0.42 ^{ns}	343693 ^{ns}
Environment	1	26.858**	900.0**	4290**	508.2**	99.52**	3837**	481.0**	66.81**	36561542**
GenxEnv	192	1.857 ^{ns}	9.8 ^{ns}	18 ^{ns}	8.8 ^{ns}	0.66 ^{ns}	16 ^{ns}	29.5 ^{ns}	0.37 ^{ns}	302305 ^{ns}
Residuals	722	1.603	12.0	18	12.7	0.63	15	31.0	0.44	337160

*Significant at $p < 0.05$; **Significant at $p < 0.01$; ns=no significant; Df: degree of freedom; SCMR_65 DAS, 75 DAS, 90 DAS: Spad chlorophyll meters reading at 65, 75, 90 days after sowing; Wscore: Wilting score; HSW: Hundred seed weight; PSH: Percentage of shelling; DHWPP: Dry haulm weight per plot; PYH: Pod yield per hectare.

traits; hundred seed weight, percentage of shelling and dried haulm weight per plot, physiological trait (SCMR_65 DAS, SCMR_75 DAS, SCMR_90 DAS) plant aspect shown in Table 1, showed that the effects of the genotypes were significant at $p < 0.01$ under both well-watered and water stress conditions. Combined analysis across water stress and well-watered conditions for pod yield, and all the measured traits showed significant difference ($p < 0.01$) for

genotypes and environmental effects. Genotypes $\times$ Environment interaction effect (GEI) was not significant ($p \geq 0.05$) for any traits.

Drought effect on pod yield and related traits

Based on statistical analysis, specifically yield reduction calculations, the best performing genotypes were selected. Therefore, the

performances of 10 top and 10 least yielding genotypes and 3 checks (2 tolerant and 1 susceptible) under drought-stress condition and their performance under well-watered conditions along with their yield reduction percentage are showed (Table 2).

Under well-watered and water stress conditions, significant differences ($p < 0.05$) were present obtained among the genotypes for all the traits. Several genotypes out yielded the checks ICGV

Table 2. Mean performances of 10 yielding and 10 least yielding genotypes under well-watered and drought-stress conditions along with their yield reduction percentage.

Genotype	PYH		RED	Wscore		HSW		DHWPP		PSH	
	WW	WS		WW	WS	WW	WS	WW	WS	WW	WS
Top 10											
ICGV 216020	3202.97	2950.34	7.89	4.17	4.15	39.43	38.13	2.99	2.22	62.57	61.99
ICGV 216106	3385.55	2925.45	13.59	4	4.4	39.84	37.05	2.73	2.28	62.57	67.27
ICGV 206128	3124.72	2900.56	7.17	4	4.52	36.77	35.04	2.76	2.15	58.57	61.51
ICGV 186607	3046.47	2875.68	5.61	4	4.52	33.72	29.88	2.63	2.08	63.07	63.43
ICGV 186435	3098.63	2801.02	9.60	3.32	4.03	32.63	28.46	2.49	2.37	57.57	57.66
ICGV 216040	3463.8	2751.24	20.57	3.32	4.03	36.71	32.83	2.81	2.12	60.57	62.95
ICGV 216249	3437.72	2676.58	22.14	3.49	4.03	31.9	28.75	2.81	2.12	60.07	58.14
ICGV 186652	2863.89	2626.8	8.28	3.66	4.4	36.99	36.88	2.64	2.21	58.57	57.66
ICGV 186544	3568.13	2577.03	27.78	3.83	4.4	38.27	33.92	2.88	2.02	60.07	61.03
ICGV 176331	3020.39	2552.14	15.50	3.83	4.03	39	34.27	2.71	2.18	59.57	67.75
Least 10											
ICGV 216289	1898.81	1631.3	14.09	3.32	4.27	42.55	34.82	2.47	2.19	60.07	61.51
ICGV 196230	2081.39	1606.42	22.82	3.49	4.4	36.64	33.15	2.39	2.37	58.57	55.74
ICGV 206103	1768.4	1581.53	10.57	3.49	4.27	38.12	34.79	2.79	2.27	53.57	57.66
ICGV 196111	2394.39	1556.64	34.99	3.32	4.27	37.07	31.01	2.77	2.31	58.07	55.74
ICGV 196168	1585.82	1481.98	6.55	3.15	3.91	31.24	26.2	2.86	2.59	56.07	56.7
ICGV 206081	1533.65	1457.09	4.99	3.15	3.91	37.1	31.77	2.95	2.4	59.07	60.07
ICGV 196071	1690.14	1407.32	16.73	3.32	4.27	35.98	33.77	2.39	2.35	57.57	55.74
ICGV 196102	1794.48	1382.43	22.96	3.66	3.91	35.29	29.92	3.03	2.36	56.07	55.26
ICGV 196056	1716.23	1357.54	20.90	3.15	4.52	36.11	30.83	2.3	1.52	57.07	56.7
ICGV 196146	1794.48	1282.88	2851	3.32	4.27	37.25	30.84	2.72	1.91	57.07	59.11
Checks											
ICGV 06424	2994.3	2875.68	3.96	3.66	4.03	39.52	37.03	2.71	2.23	62.57	68.23
ICGV 86124	3515.96	2726.35	22.46	3.83	4.15	36.27	33.36	3.01	2.29	60.07	61.7
ICGV 00308	1637.98	1208.22	26.24	3.32	4.52	35.46	35.41	2.33	1.5	59.57	64.87
Grand Mean	2600.1	2244.6		3.7	4.2	36.6	32.9	2.7	2.2	58.9	60.2
CV	21.4	25		20.1	19.9	11.1	12.4	30.9	24.7	7.6	10.3
LSD	773.8	762		0.8	0.8	5.3	5.5	0.7	0.6	5.5	7.6
Heritability	0.8	0.7		0.5	0.4	0.7	0.7	0.3	0.4	0.6	0.6

PYH: Pod yield per hectare, RED: Yield reduction; Wscore: Wilting score; HSW: Hundred seed weight; PSH: Percentage of shelling; DHWPP: Dry haulm weight per plot; WW: well-watered condition; WS: water stress condition; CV: Coefficient of variation, LSD: Least significant difference.

06424 and ICGV 86124. Under water-stress conditions, the pod yield ranged from 1282.88 kg ha⁻¹ (ICGV 196146) to 2950.34 kg ha⁻¹ (ICGV 216020), while that of the checks ranged from 1208.22 kg ha⁻¹ (ICGV 00308) to 2875.68 kg ha⁻¹ (ICGV 06424). Under well-watered conditions, it ranged from 1533.65 kg ha⁻¹ (ICGV 206081) to 3568.13 (ICGV 186544) and the checks ranged from 1637.98 kg ha⁻¹ to 3515.96 kg ha⁻¹. The overall mean dry pod yield of all the genotypes evaluated was 2244.6 kg ha⁻¹ and 2600.1 kg ha⁻¹ under water stress and well-watered conditions respectively.

Reduction in dry pod yield due to water stress of the genotypes ranged from 4.99% (ICGV 206081) to 34.99% (ICGV 196111), while that of the checks ranged from 3.96 % (ICGV 06424) to 26.24% (ICGV 00308). Interestingly, the first ten genotypes with high yield performed well under both well-watered and drought-stress conditions.

Wilting score of the genotypes ranged under water stress conditions from 3.91 (ICGV 196102, ICGV 206081, ICGV 196168) to 4.52 (ICGV 206128, ICGV 186607, ICGV 196056), while the checks ranged from 4.03 (ICGV 06424) to 4.52 (ICGV 00308). Under well-watered conditions the lowest score for the wilting was observed for the genotypes ICGV 196056, ICGV 206081 and ICGV 196168 with respectively 3.15, while the maximum score was recorded by ICGV 216020 (4.17); also, the lowest score was recorded by the check ICGV 00308 (3.32) and the maximum score by ICGV 86124 (3.83). The overall mean was 4.2 and 3.7 under water stress and well-watered conditions, respectively.

The hundred seed weight (HSW) of the genotypes ranged from 26.2 (ICGV 196168) to 38.13 g (ICGV 216020) under water stress conditions with the checks ranging from 33.36 (ICGV 86124) to 37.03 g (ICGV 06424). Under well-watered conditions, the lowest HSW was recorded by ICGV 196168 (31.24 g), and the maximum was recorded by ICGV 216289 (42.55 g), while the checks ranged from 35.46 (ICGV 00308) to 39.52 g (ICGV 06424). The overall mean was 32.9 and 36.6 g under water stress and well-watered conditions, respectively. Under water stress conditions, the range in dry haulm weight per plot (DHWP) was from 1.52 (ICGV 196056) to 2.59 g plot⁻¹ (ICGV 196168), while the checks ranged from 1.5 (ICGV 00308) to 2.29 g plot⁻¹ (ICGV 86124). Under well-watered conditions, the lowest performance for DHWP was observed from ICGV 196056 (2.3 g plot⁻¹) genotype and the maximum performance was recorded for ICGV 196102 (3.03 g plot⁻¹), while the checks performance ranged from 2.33 for ICGV 00308 to 3.01 g plot⁻¹ for ICGV 86124. The overall mean varied between 2.2 and 2.7 g plot⁻¹ under water stress and well-watered conditions, respectively.

The overall mean for genotypes evaluated for shelling percentage (SHP) were 60.2 and 58.9% under water stress and well-watered conditions, respectively. Under

water stress conditions, genotypes mean performances for SHP ranged from 55.26 % (ICGV 196102) to 67.75% (ICGV 176331) followed by 67.27 % (ICGV 216106), with the checks ranging from 61.7 (ICGV 86124) to 62.57% (ICGV 06424). Under well-watered conditions, SHP ranged from 53.57% for ICGV 206103 to 63.07% for ICGV 186607, with checks ranging from 59.57% for ICGV 00308 to 62.57% for ICGV 06424.

Drought effect on chlorophyll content

The mean performance of drought effect on SCMR chlorophyll content is showed in Table 3. The general means of SCMR chlorophyll content (SCMR_65DAS; SCMR_75DAS; SCMR_90DAS) under drought-stress conditions were 36.7; 40.9 and 44.9 at 65, 75, and 90 DAS respectively, while under well-watered conditions the SCMR general mean was 34.9, 37.1, and 43.5 at respective 65, 75, and 90 DAS.

At 65 DAS, ICGV 216249 showed the highest SCMR (37.65) followed by ICGV 196146 (37.59), and the lowest performance was recorded by ICGV 196056 (35.2) under water stress conditions. However, under well-watered conditions, the SCMR ranged from 34.15 for ICGV 196056 to 38.48 for ICGV 186435 followed by 36.77 for ICGV 216249. The check ICGV 06424 had the highest SCMR_65DAS with 35.9 and 37.11 under well-watered and water stress conditions, respectively.

Under water stress conditions the genotypes ICGV 196146 (42.11) and ICGV 206081 (41.54) had the highest SCMR_75 DAS and ICGV 176331 (39.8) recorded the lowest performance. Under well-watered conditions, SCMR_75 DAS ranged from 35.54 for ICGV 186544 to 38.94 for ICGV 186435 followed by 38.71 for ICGV 186652. However, the check ICGV 06424 (38.03) and ICGV 86124 (40.65) had the highest SCMR_75 DAS under well-watered and water stress respectively. ICGV 196146 (49.25) followed by ICGV 196168 (47.45) recorded the highest SCMR_90 DAS while the lowest performance was recorded by ICGV 186607 (42.11) under water stress conditions. Therefore, under well-watered conditions, the highest performance was recorded by ICGV 206081 (46.9) followed by ICGV 196168 (46.13) and ICGV 196146 (46.14), while the lowest SCMR_90 DAS was recorded by ICGV 216020 (41.01). However, the check ICGV 06424 (45.76) and ICGV 86124 (46.4) recorded the highest performance under well-watered and water stress, respectively.

Correlation and association among studied traits

Water stress condition

The results of correlations analysis of the characters

Table 3. Physiological mean performance of top 10 and least 10 varieties for SCMR chlorophyll content.

Genotype	SCMR_65DAS		SCMR_75DAS		SCMR_90DAS	
	WW	WS	WW	WS	WW	WS
Top 10						
ICGV 216020	34.46	35.93	37.07	40.58	41.01	45.22
ICGV 216106	36.19	36.56	38.12	40.89	44.08	42.3
ICGV 206128	36.03	36.4	36.64	40.82	43.92	45.59
ICGV 186607	35.36	36.63	37.36	40.83	41.97	42.11
ICGV 186435	38.48	36.62	38.94	40.66	44.84	45.68
ICGV 216040	36.39	36.96	38.65	41.02	42.74	45.59
ICGV 216249	36.77	37.65	38.15	40.93	44.14	45.26
ICGV 186652	36.06	36.87	38.71	41.31	42.24	45.42
ICGV 186544	33.88	36.3	35.54	41.31	43.52	45.06
ICGV 176331	32.62	35.69	35.84	39.8	42.62	43.09
Least 10						
ICGV 216289	35.4	36.6	37.31	41.24	44.61	44.67
ICGV 196230	35.14	35.96	37.58	41.1	44.91	45.42
ICGV 206103	35.68	36.62	36.85	40.67	44.57	44.74
ICGV 196111	35.34	36.18	38.23	41.38	44.23	44.96
ICGV 196168	36.03	37.12	38.23	40.54	46.13	47.45
ICGV 206081	36.06	37.33	38.17	41.54	46.9	45.85
ICGV 196071	33.72	36.3	37.04	41.02	44.15	44.71
ICGV 196102	34.53	36.15	37.7	39.95	45.08	43.38
ICGV 196056	34.15	35.2	37.16	40.61	43.83	44.82
ICGV 196146	36.8	37.59	38.62	42.11	46.14	49.25
Checks						
ICGV 06424	35.9	37.11	38.03	40.1	45.76	45.35
ICGV 86124	33.79	35.85	35.74	40.65	43.87	46.4
ICGV 00308	33.77	35.77	35.6	40.21	41.37	45.17
Grand Mean	34.9	36.7	37.1	40.9	43.5	44.9
CV	8.7	11.3	11.3	11.6	7.5	7.4
LSD	3.6	3.5	4.5	2.9	3.8	4
Heritability	0.5	0.3	0.5	0.1	0.5	0.6

SCMR_65 DAS, 75 DAS, 90 DAS: SPAD chlorophyll meter reading at 65, 75, 90 days after sowing; WW: well-watered condition; WS: water stress condition; CV: Coefficient of variation, LSD: Least significant difference.

studied on 193 groundnut genotypes under stress conditions are showed in Figure 3. A positive and significant correlation was observed between the pod yield and Shelling percentage ($r = 0.29$), hundred seed weight ($r = 0.25$), and wilting score ($r = 0.21$). Pod yield showed a significant negative correlation with SCMR_90 DAS ($r = -0.13$) and percentage of yield reduction ($r = -0.43$). The percentage of yield reduction showed a significant negative correlation with pod yield ($r = -0.43$) and hundred seed weight ($r = -0.16$). The data revealed a highly significant ($p \leq 0.001$) and positive correlation between the different stages of chlorophyll content data collection as follows, SCMR_65 DAS and SCMR_75 DAS

($r = 0.46$), SCMR_65 DAS and SCMR_90 DAS ($r = 0.36$), SCMR_75 DAS and SCMR_90 DAS ($r = 0.26$). SCMR_65 DAS was highly negatively correlated ($p \leq 0.001$) with Hundred seed weight ($r = -0.25$) and moderately correlated with Dry haulm weight per plot and shelling percentage $r = -0.16$ and -0.18 respectively. SCMR_75 DAS was positively correlated with wilting score ($r = 0.31$) and negatively correlated with Dry haulm weight ($r = -0.26$). SCMR_90 DAS was negatively correlated with wilting score ($r = -0.37$), hundred seed weight ($r = -0.18$), shelling percentage ($r = -0.34$) and pod yield ($r = -0.13$) respectively. A positive correlation was observed between wilting score and, hundred seed

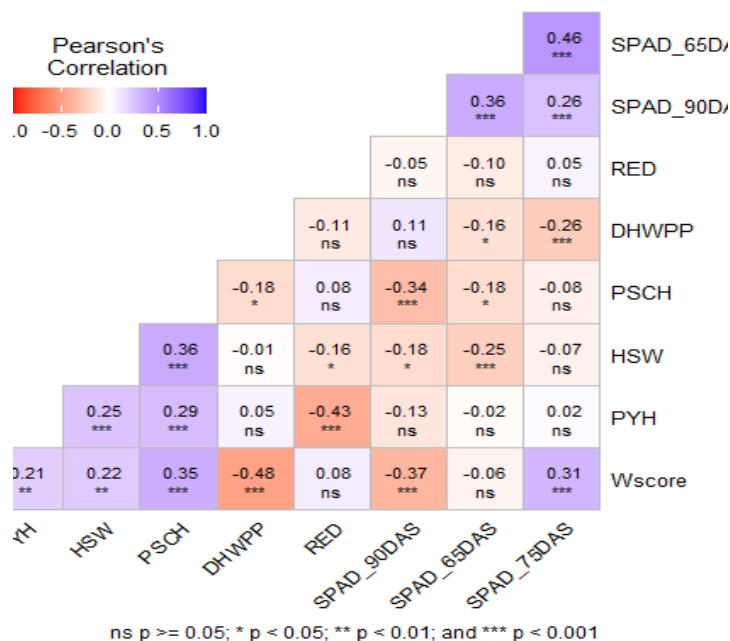


Figure 4. Correlation among characters under water stress conditions.

weight ($r = 0.22$), shelling percentage ($r = 0.35$), and pod yield ($r = 0.21$). Also, it correlated negatively with dry haulm weight per plot ($r = -0.48$).

The hundred seed weight also showed a positive correlation with shelling percentage ($r = 0.36$), and pod yield ($r = 0.25$) while a moderate negative correlation was observed with yield reduction ($r = -0.16$). Dry haulm weight per plot exhibited a significant negative correlation with SCMR1 ($r = -0.16$), SCMR_75 DAS ($r = -0.26$), wilting score ($r = -0.48$), and shelling percentage ($r = -0.18$). Shelling percentage showed positive and significant correlation with pod yield ($r = 0.29$), hundred seed weight ($r = 0.36$), wilting score ($r = 0.35$), and a significant negative correlation with SCMR_65DAS ($r = -0.18$), SCMR_90 DAS ($r = -0.34$) and dry haulm weight per plot ($r = -0.18$).

Well-watered condition

The results of the analysis of correlations of the characters studied on 193 groundnut genotypes under non-water stress conditions are showed in Figure 4. Under well-watered conditions, a positive correlation was observed between SCMR_65 DAS and SCMR_75 DAS and SCMR_90 DAS with respectively $r = 0.58$, $r = 0.43$, and SCMR1/SCMR3 association $r = 0.48$. Pod yield per hectare was positively correlated with shelling percentage ($r = 0.42$), dry haulm weight ($r = 0.21$), 100-seed weight ($r = 0.14$) and wilting score ($r = 0.30$).

Positive correlations were observed between wilting score and some traits such as 100-seed weight ($r = 0.20$) shelling percentage ($r = 0.36$), and pod yield ($r = 0.30$). Hundred seeds weight showed a positive significant correlation with wilting score ($r = 0.20$), shelling percentage ($r = 0.30$), and pod yield ($r = 0.14$), otherwise, it showed a negative with SCMR_65 DAS and SCMR_75 DAS ($r = -0.22$ and $r = -0.20$).

A positive and significant correlation was observed between dry haulm weight and pod yield ($r = 0.42$), while it showed a negative correlation with SCMR_65 DAS ($r = -0.12$) and SCMR_75 DAS ($r = -0.16$). Shelling percentage showed a positive and significant correlation with 100-seed weight ($r = 0.30$), wilting score ($r = 0.36$), and pod yield ($r = 0.42$), while a significant negative correlation was observed with SCMR_65 DAS ($r = -0.20$), SCMR_75 DAS ($r = -0.20$) and SCMR_90 DAS ($r = -0.37$). Pod yield showed a positive and significant correlation with shelling percentage ($r = 0.42$), dry haulm weight and pod yield ($r = 0.21$), Hundred seeds weight ($r = 0.14$), and wilting score ($r = 0.30$), also it showed a significant negative correlation with SCMR_75 DAS ($r = -0.16$) and SCMR_90 DAS ($r = -0.26$).

DISCUSSION

Genetic variability

Analysis of variance of genotypes for pod yield and other

different traits showed highly significant variation among the genotypes evaluated. The observed significant differences among genotypes indicated the existence of genetic variability in the set of genotypes important as a source of parental materials and thus adaptation under each environmental condition permits the selection of appropriate diverse materials to be used in breeding programs for future improvement. These results are consistent with findings from previous studies that reported for various drought-tolerant genotypes under well-watered and water-stressed conditions where significant differences in pod yield, biomass, shelling percentage, and hundred seed weight were present (Mamadou et al., 2016). This was also confirmed for some traits from studies conducted by Shinde et al. (2010), who that reported significant variations for pod yield, and hundred kernel weight. Similar results were reported, (Ashna, 2014) from studies that found large variation in 14 traits including crop growth rate, hundred kernel weight, pod yield, and other key agronomic traits.

A comparison between two test environments showed significant difference between well-watered and water stress environments. This suggests that the research conditions within and between the two blocks were distinct in their contribution to trait variations within the evaluated set of genotypes. The environmental effect on phenotypes of a particular trait can adversely change the advance upon selection. Therefore, it is essential to conduct extensive testing of the genotypes across diverse research conditions, including water regimes, to confirm their yield performance and stability in each environment. Comparable results were reported for various sets of drought-tolerant groundnut genotypes under both drought stress and well-watered conditions (Belko et al., 2012; Harou et al., 2018; Doumbia et al., 2022; Sanogo et al., 2023).

Drought tolerance

In this study, some promising groundnut genotypes with good performance in pod yield under water stress ICGV 216020 (2950.34 kg ha⁻¹) and well-watered conditions ICGV 186544 (3568.13 kg ha⁻¹) were identified. Interestingly, the top ten high-yielding genotypes performed well under well-watered and drought-stress conditions. We observed a significant and modest decrease in pod yield between genotypes from well-watered to water-stress conditions, with an average pod yield in well-watered conditions being 2600 kg ha⁻¹ and 2244.6 kg ha⁻¹ in water-stress conditions. Pod yield, seed yield, number of seeds per plant, hundred seed weight, and dry biomass significantly decreased under water stress regimes for all groundnut cultivars. The genotypes ICGV 186607, ICGV 206128, ICGV 216020, ICGV 186652, ICGV 06424, and ICGV 206081 exhibited the

least pod yield reduction, suggesting a good level of drought tolerance. Many authors have reported a reduction in groundnut yield under water stress conditions (Clavel et al., 2006; Sultan, 2018; Bacharou Falke et al., 2019; Sanogo et al., 2020).

According to the study conducted by Koolachart et al. (2013), drought-tolerant groundnut genotypes can either have high yield potential under irrigated conditions or low yield reduction under drought. Vorasoot et al. (2003) reported that under water stress, pegging and seed set responses of various groundnut cultivars varied substantially, leading to a large reduction in pod yield, and varied reduction percentage. Alami-Milani et al. (2013) also showed that water deficit significantly reduces the number of pods per plant and the number of seeds per pod and consequently the mass of seeds per plant in lentil (*Lens culinaris* Medick). The findings of Doumbia et al. (2022) on cowpea demonstrate the detrimental impact of water stress on yield components, with reductions exceeding 50%, serving as a strong indicator of the effect of drought stress on cowpea genotypes.

Chlorophyll content determines the photosynthetic capacity and subsequent plant growth. In the current study, groundnut genotypes showing high chlorophyll content value across water regimes and sampling dates were ICGV 216249, ICGV 186652, ICGV 216040, ICGV 186435, ICGV 206128, ICGV 216040, ICGV 196146, ICGV 196168, ICGV 206081, ICGV 196230. It was observed that the chlorophyll content values at 90 DAS were higher than those obtained at 65 DAS and 75 DAS for the top ten genotypes under both environmental conditions. The genotypes ICGV 196146, ICGV 186435, ICGV 196168, and ICGV 86124 exhibited the highest increase in chlorophyll content at 90 DAS from well-watered to water stress conditions, highlighting their capacity to tolerate drought by maintaining the photosynthetic rate for normal growth and development under moisture stress. Similar observations were previously reported under various environments . (Nigam and Aruna, 2008; Arunyanark et al., 2008; Songsri et al., 2009; Girdthai et al., 2010; Koolachart et al., 2013; Nigam, 2014; Aninbon et al., 2015; Chakraborty et al., 2016; Shinde et al., 2017; Sultan, 2018; Oppong-Sekyere et al., 2019) Plants under mild to moderate water stress, towards the later stage of their lifecycle, may exhibit high chlorophyll content by increasing their photosynthetic efficiency. This response could be an adaptive mechanism to optimize photosynthesis under optimal conditions, ensuring the plant maximizes its production energy to support reproductive processes. For example, Arunyanark et al.(2008), reported that chlorophyll stability is a significant indicator of drought tolerance in groundnut, and genotypes exhibiting higher chlorophyll content under water stress are preferred for breeding programs targeting drought-prone areas. Moreover,

Bennett et al., (2022) observed that drought-tolerant groundnut genotypes maintained higher chlorophyll levels and better physiological performance under water stress conditions. Toudou Daouda et al. (2017) hypothesized that groundnut genotypes with high chlorophyll content have more photosynthetic machinery per unit of leaf area and therefore greater assimilation potential under water stress. Genotypes that showed high values of SCMRs and maintained high biomass production under drought stress may be considered as drought tolerant (Boontang et al., 2010; Coulibaly et al., 2016). Oppong-Sekyere et al. (2019) also observed that chlorophyll content increased in rice during the water stress period but reduced immediately during the first 3 days of rewatering. Numerous studies on groundnut have shown that chlorophyll content is a relatively stable trait strongly correlated with pod yield, which is widely recognized as a reliable indicator of drought tolerance, despite one that is difficult to measure on a large scale (John et al., 2007; Arunyanark et al., 2008; Songsri et al., 2009; Singh et al., 2014; Bennett et al., 2022). The chlorophyll contents measured in this study were not systematically associated with pod yield at different collection stages and yield reduction for water stress tolerance. No significant correlation was observed between pod yield and chlorophyll at 65 and 75 DAS under water stress conditions. A slight negative correlation was observed at 90 DAS. The result partly agrees with previous findings (Balota et al., 2012; Hamidou et al., 2012; Singh et al., 2014). Chlorophyll was not significantly correlated with pod yield although genotypic variability was observed for chlorophyll content (Balota et al., 2012) and Correlation with pod yield was limited to a single year during the dry season 2022. Similar result was reported by Hamidou et al. (2012) and Singh et al. (2014).

The observation in this study could be explained by the fact that the intensity of water stress for genotypic tolerance remained within a moderate range during the systematic field selection trial. Furthermore, the occurrence of unpredictable rainfall and distribution during the trial period (dry season 2022) (Figure 2) may have influenced the expression of genotypic variation. Therefore, chlorophyll content appeared unsuitable for genotypic selection for yield and water stress tolerance of groundnut grown in the semi-arid tropics environment of Samanko.

Conclusions

The study revealed significant genotypic variation in agronomic and physiological traits. This diversity of varietal reactions to imposed water stress offers possibilities for selecting suitable genotypes for better adaptation to drought. The genotypes ICGV 216020 (2950.34 kg ha⁻¹) and ICGV 186544 (3568.13 kg ha⁻¹)

performed well in water stress and well-watered conditions, respectively. Based on yield reduction percentage, the genotypes ICGV 186607, ICGV 206128, ICGV 216020, ICGV 186652, ICGV 06424, and ICGV 206081 exhibited the least pod yield reduction under water stress conditions. Chlorophyll content increased with water stress intensity and period. The genotypes ICGV 196146, ICGV 186435, ICGV 196168, and ICGV 86124 indicated an increase in chlorophyll content at 90 DAS from well-watered to water stress conditions. The results of our study did not indicate a correlation between chlorophyll content and pod yield under water stress conditions. The ideal genotype is the one that will be able to maintain chlorophyll content and high pod yield under unfavorable conditions, therefore chlorophyll content appeared unsuitable for genotypic selection for yield and water stress tolerance in groundnut grown in the semi-arid tropics environment of Samanko. Genetic complexity of drought tolerance, high genotype-environment interactions, lack of accurate phenotypic assessment strategies, and water stress duration and severity under field conditions for pod yield make direct selection difficult. Additional methods such as the use of greenhouses coupled with field trials during the dry season will have to be used to increase the level of drought stress during the terminal stage for validating the reproducibility of the current field evaluation. Furthermore, evaluation of identified promising genotypes in varied rain-fed environments is required to exploit the water stress potential of these lines for climate-smart agriculture. These genotypes could also be used to develop mapping populations for identifying quantitative traits loci (QTLs) and develop molecular markers to improve tolerance to water stress.

CONFLICT OF INTERESTS

The authors have not declared any conflicts of interests.

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