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Effect of water deficit at different stages of development on the yield components of cowpea (*Vigna unguiculata* L. Walp) genotypes

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Cowpea cultivation is widespread in West Africa where it is an important source of protein. This study is aimed at determining the effects of water deficit applied at different stages of cowpea development on yield and its components (pod number, seed number, seed yield, aerial biomass yield, harvest index and root biomass of the plant). The experiments were carried out in pots during the rainy season of 2016 under natural conditions of illumination, temperature and relative humidity. Three water regimes were applied to plants at different stages of cowpea development: total suspension of watering at flowering phase (43 days after sowing) (S1); suspension of watering at the beginning of pod formation on the 46th day after sowing (S2); and normal watering as control until harvest (S0). At the water regime level, yield components had higher values in S0 followed by S2. The lowest values were obtained at S1 level. The root to aerial biomass ratios was higher under water deficit than in the control. In conditions of water deficiency, Suvita2, IT96D-610, and ISV128 genotypes gave the highest seed yields and Tiligré the lowest yield. The harvest index showed a genotypic variation according to the water regime. Suvita2 and ISV128 gave the best harvest index in all water regimes. This study may have contributed to the selection of genotypes adapted to drought.

Key words: Cowpea, harvest index, water deficit, yields, Niger.

INTRODUCTION

The frequency of periods of water deficit of variable intensities makes agricultural production very uncertain in Niger, and for proper management of production systems in these areas it is necessary to have a thorough knowledge of the different resistance strategies adopted by the plants under these limiting conditions of water supply.

Cowpea is the main legume crop grown in Niger where

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it plays an important nutritional role for its richness in protein and economic role for the income it generates to producers. Although adapted to semi-arid conditions, drought pockets observed during its development cycle have a negative impact on it production. The choice of varieties adapted to water deficit is important to improve yields in these areas where drought occurs at different stages of plant development. The local varieties which are widely used are late maturing and photoperiod sensitive (Singh et al., 1997) with low yields. According to Singh (1987, 1994), early maturing varieties can escape terminal drought by reducing the length of their development cycle, but when they are expose to intermittent stress, their performance decreases. Varieties that have an average development cycle can be adapted to the climatic conditions of these areas and contribute to increasing agricultural production.

Several physiological and biochemical criteria have been identified in order to distinguish sensitive cowpea varieties from water-stress resistant varieties (Blum, 2011). The effect of water deficit results in morphological (to increase the absorption of water and decreased sweating) and physiological changes (decreased tissue water content, increase in canopy temperature, decreased chlorophyll content and consequent photosynthesis) (Hamidou et al., 2005, 2007). The impact and intensity of water deficit on plants depend on the phenological stage during which this deficit occurs and vary according to the plant. According to Turk et al. (1980), cowpea is more sensitive to water stress during flowering and pod filling. Water stress in the vegetative phase followed by re-irrigation has little influence on the final yield of cowpea seeds (Faisal and Abdel-Shakoor, 2010; Hall, 2012). Although cowpea has the capacity to resist drought more than any legume grown in tropical regions (Hall, 2004; Dadson et al., 2005), a difference between genotypes has been recorded for adaptation to drought (Watanabe et al., 1997; Mai-kodomi et al., 1999).

The physiological and biochemical processes determining the harvesting quality of cowpea under water stress during flowering and pod filling have been widely described by Hamidou (2006) and Halilou et al. (2015). However, there are still shady areas in the choice of yield parameters relevant for the selection of cowpea genotypes at terminal water stress. This study was conducted to evaluate the effect of water deficit at flowering and pod-forming stages on yield components of cowpea.

MATERIALS AND METHODS

Experimental materials

The study involved 5 genotypes whose origin and maturity are presented in Table 1. All genotypes have an intermediate development cycle (90 days).

Method of culture

The trials were conducted at the ICRISAT Sahelian center station (Sadoré, Niger, 13°15'N, 2°18'E) during the rainy season 2016 (August-October) under natural conditions. The plants were grown in 16-L pots pierced at the base. In each pot, 500 g of gravel was deposited at the base to allow for good drainage of water. Each pot was then filled with 17 kg of soil collected at a depth of 20 cm at the station's field. This soil was mixed with organic fertilizer at a ratio of 25 g/kg of soil. The pots were placed on a tarpaulin to prevent the roots from being in contact with the soil.

Before sowing, the pots were saturated and allowed to drain for 24 h to reach the field capacity. Field capacity is the amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward movement has decreased. This usually takes place 2 to 3 days after rain or irrigation in pervious soils of uniform structure and texture. The seedlings started out at the rate of 4 seeds of cowpea in pots followed by a two plants seedling on the 14th day after sowing (DAS) and one plant at 23 DAS.

The experimental design (Figure 1) is of a split plot completely randomized with the water regime as the main factor and genotypes grown as a sub-factor and randomized within each 4-repeat subblock. The water regimes are: (1) Regime 0 (S0): Well watering as control, the well watering is to bring each day a quantity of water of 500 ml to the plants to maintain pots at field capacity until harvesting; (2) Regime 1 (S1): Permanent irrigation suspension at 43 DAS corresponding to the stage of 50% flowering; (3) Regime 2 (S2): Permanent irrigation suspension at 46 DAS corresponding to the beginning of pod formation.

The control plants (regime 0) were maintained at field capacity. During subjection to stress, the plants were protected from rainwater by a mobile shed with a translucent roof. Climate data (temperature and humidity) were recorded daily using a thermo hygrometer (Tiny tag Ultra 2 TGU-4500 Gemini Data Loggers Ltd., Chichester, UK) installed next to the test. During the test, mean temperature was 29°C and the relative humidity was 75% (Figure 2).

Data collection

Phenological stages

The following phenological stages were noted per pot: emergence, early flowering date, early date of pod filling and maturity. The stage is noted when 50% of the plants of the same genotype in each subblock have reached the stage.

Yield components and root dry biomass

The harvest consisted of cutting the plant close to the surface of the soil, leaving the roots in the soil. For normally watered plants, as soon as the plant reaches maturity, it is immediately harvested. The date of harvest is mentioned. For stressed plants, the plant is harvested when it shows obvious signs of stress such as dryness, leaf drop and stopped growth. The number of days of stress was noted.

After each harvest, the above-ground biomass (stems + leaves) and the pods were separated, pods were counted and dried in an oven for 48 h at 80°C. Dry samples were weighed using a 0.01 g precision balance to determine dry aerial biomass and pod weight. After decorticating the pods, the total number and weight of seeds/plant were determined.

The cowpea seed harvest index was calculated using the following formula:

Table 1. Origin and earliness of genotypes studied.

Name	Origin	Response to drought
ISV128	ISC Niger[1]	Tolerant
IT93K-503-1	IITA Nigeria[2]	Tolerant
IT96D610	IITA Nigeria[2]	Tolerant
Suvita2	INERA Burkina[3]	Tolerant
Tiligré	INERA Burkina[3]	Susceptible

[1]ISC, ICRISAT Sahelian Centre; [2]IITA, International Institute for Tropical Agriculture; [3]INERA, Institut de l'Environnement et des Recherches Agricoles.

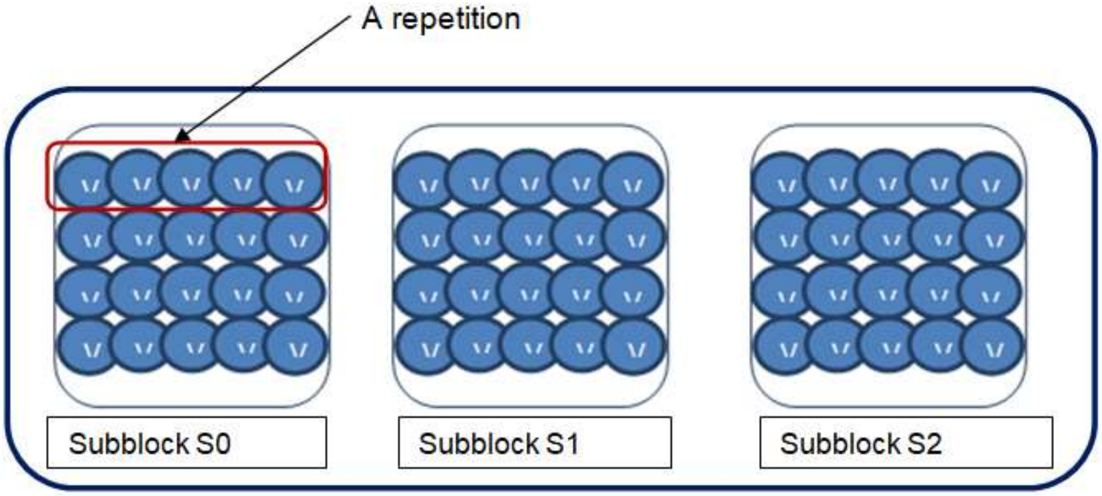

Figure 1. Experimental design. S0, Regime 0; S1, regime 1; S2, regime.

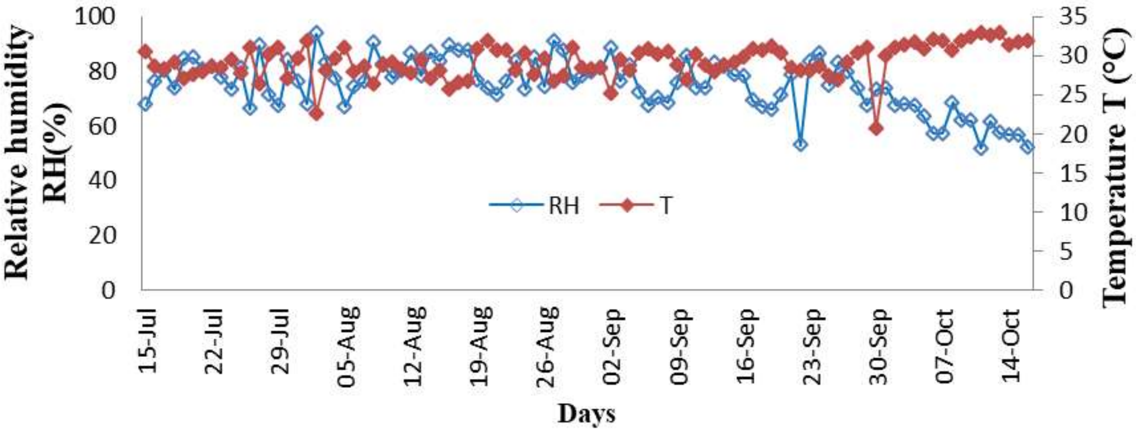

Figure 2. Change in temperature and relative humidity during the test period at Sadoré ICRISAT Sahelian Center.

IR (%) = Dry matter of seeds × 100 / total dry matter.

Total dry matter = Weight pod + Aerial biomass

To determine the root biomass, the soils of each pot were delicately removed through a low water pressure. A fine sieve was placed under the pot to recover any broken roots during the

Table 2. Phenological stages (in number of days after sowing: DAS) of the genotypes studied.

Genotype	Emergence	50% flowering	Maturity
ISV128	3.50±0.58	40.00±1.63	62.00±3.16
IT93K-503-1	3.50±0.58	41.75±1.26	64.50±3.00
IT96D-610	3.00±0.00	40.50±0.58	63.75±2.87
Suvita2	3.75±0.96	40.00±1.16	59.75±2.50
Tiligré	4.00±1.15	42.75±0.96	60.25±2.06
P value	0.46	0.06	0.11

operation. When the total amount of soil is removed, the roots were collected, dried in an oven for 48 h at 80°C and weighed to determine the dry root biomass.

Data analysis

The variance analysis was carried out using the JMP.009 version software. Separation of means for the various parameters measured was carried out by the Student Newman Keuls test at the threshold of α = 5%. To evaluate the effect of genotype, treatment and genotype × treatment interaction, an analysis of variance (ANOVA) by the generalized linear model procedure was performed. Microsoft Office Excel 2007 software was used to perform linear regressions, determine the R^2 and the regression equation. Minitab16 was used to test the significance of linear regression using the Pearson's correlation test.

RESULTS

Phenology

Table 2 shows that there were no significant differences in physiological stages among the genotypes studied. Emergence occurred for all genotypes after 3 to 4 days after sowing (DAS). The stage of 50% flowering was reached between 40 and 42 days after sowing and maturity, between 60 and 64 DAS for all genotypes.

Impact of water deficit on root biomass and root biomass ratio to aerial biomass of cowpea according to stage of development

When plants were normally irrigated, there were significant differences in aerial and root biomass between genotypes (Table 3). The highest aerial biomass was recorded for Tiligre (32.41 g/plant), followed by IT93K-503-1 (28.14 g/plant). IT96D-610 and Suvita2 had the lowest biomass of 24.57 and 21.35 g/plant, respectively. ISV128 genotype recorded an aerial biomass which is intermediate (26.50 g/plant). IT93K-503-1 and Tiligre genotypes had the highest root biomass yields whereas IT96D-610 and Suvita2 had the lowest yields (Table 3). When the aerial biomass/root biomass ratio was considered, IT93K-503-1 gave the highest value (0.37) and Suvita2 the lowest (0.18).

When water stress was applied at flowering stage (S1), no significant differences were observed among genotypes for root biomass (Table 3). However, significant differences exist for aerial biomass. Tiligre obtained the highest aerial biomass (23.56 g/plant), followed by ISV128 and IT96D-610 (21.19 and 20.19 g/plant, respectively). The other genotypes had lower aerial biomass. At root biomass/aerial biomass ratio, IT93K-503-1 and Suvita2 were the highest with 0.47 and 0.40, respectively (Table 3). Tiligre was the lowest position with a ratio of 0.31.

When water stress was applied at the beginning of pod formation, the yield of aerial biomass of IT93K-503-1 was significantly higher than the other genotypes (25.14 g/plant) (Table 3). Suvita2 had the lowest yield (21.21 g/plant). The other genotypes are intermediate. However, there were no significant differences among genotypes for root biomass yield and root biomass/aerial biomass ratio.

The impact of water deficit on yield components and crop index of cowpea

Table 4 shows yield components and harvest index (HI) of different genotypes for the water regimes applied at flowering and beginning of pod formation. When plants were irrigated normally, the results showed significant differences among the genotypes for the different parameters measured. For example, according to the Newman Keuls test, Tiligré gave the lowest yield (15.73 g/plant) compared to other genotypes with higher yields (19.86 to 21.97 g/plant). IT93K-503-1, IT96D-610 and Suvita2 had the highest number of pods/plant (≥19.50 pods/plant), while ISV128 and Tiligre had the lowest (<16 pods/plant).

IT93K-503-1, IT96D-610, and Suvita2 gave the highest seed number (100 seeds/plant) and Tiligre the lowest (54 seeds/plant). The best seed yield was recorded for ISV128 (17.29 g/plant) and lowest for Tiligre (11.57 g/plant). Suvita2 has the best seed harvest index

Table 3. Effect of water deficit on aerial and root biomass and on the ratio of the root to the aerial portion.

Treatment	Genotype	AB (g)	RB (g)	RB/AB
Normal watering	ISV128	26.50±2.86^{bc}	6.72±1.07^{bc}	0.25±0.03^{bc}
	IT93K-503-1	28.14±3.37^{b}	10.25±0.96^{a}	0.37±0.02^{a}
	IT96D-610	24.57±1.26^{cd}	4.92±0.21^{cd}	0.2±0.01^{cd}
	Suvita2	21.35±0.80^{d}	3.75±0.30^{d}	0.18±0.01^{d}
	Tiligré	32.41±2.31^{a}	8.96±3.21^{ab}	0.27±0.08^{bc}
	Significance	***	***	***
Stress at flowering stage	ISV128	21.19±1.43^{b}	8.10±0.88	0.38±0.05^{bc}
	IT93K-503-1	17.86±0.58^{c}	8.76±3.26	0.47±0.05^{a}
	IT96D-610	20.19±0.74^{b}	7.72±1.34	0.35±0.02^{bc}
	Suvita2	17.66±1.29^{c}	6.88±0.78	0.40±0.05^{ab}
	Tiligré	23.56±1.38^{a}	8.36±0.84	0.31±0.05^{c}
	Significance	***	ns	*
Stress at pod formation	ISV128	23.32±1.46^{ab}	8.14±1.24	0.3±0.04
	IT93K-503-1	25.14±1.46^{a}	8.34±0.84	0.36±0.03
	IT96D-610	22.23±0.99^{bc}	7.26±0.66	0.38±0.09
	Suvita2	21.21±1.56^{c}	7.02±0.72	0.29±0.04
	Tiligré	23.71±1.09^{ab}	7.51±1.21	0.35±0.04
	significance	**	ns	ns

*, **, ***Significant at the probability threshold of 0.05, 0.01 and 0.005, respectively; ns: Not significant (p> 0.05). Numbers with the same letter(s) in the same column are not significantly different from the p<0.05 threshold. AB, Aerial biomass; RB, root biomass; RB/AB, ratio of root biomass to aboveground biomass.

(41.26%) and Tiligre had the lowest (24.04%). When stress was applied at flowering (S1), there were also significant differences between the genotypes for the different parameters. The best yield in pods was recorded for Suvita2 (5.36 g/plant) and lowest for Tiligre (1.77 g/plant). Yield for other genotypes (IT96D-610, IT93K-03-1 and ISV128) was between 3.27 and 3.85 g/plant.

When water stress was applied at the beginning of pod formation, genotypes also differed significantly for all measured parameters except seed/plant yield. Genotypes IT96D-610 and Suvita2 have the highest yields of pods, seed/plant number, and harvest index. When water stress was applied to flowering, there was a significant decrease in the aerial biomass of all genotypes relative to the control (Figure 3). This decrease, however, was greater for IT93K-503-1 and Tiligre, 36 and 31%, respectively. When water stress was applied at the beginning of pod formation, there were no significant differences in aerial biomass for the Suvita2, IT93K-503-1 and ISV128 genotypes as compared to the control (Figure 3). However, this difference is very significant for Tiligré and IT96D-610.

Water stress applied at both flowering and early pod formation drastically reduced seed yield as compared to control for all genotypes studied (Figure 4). Tiligre genotype was the most sensitive with a seed yield reduction of 92 and 71% when stress was applied to flowering stage and early pod filling, respectively.

Relationship between seeds weight and harvest index

Correlation analysis of seed weight and harvest index showed a significant positive correlation for the three treatments (Figure 5). The correlation was more significant in the water stress treatments $R^2 = 0.99$ ($p<0.0001$) for S1 and $R^2 = 0.98$ ($p <0.001$) for S2 as compared to control $R^2 = 0.85$ ($p<0.023$).

DISCUSSION

Root weights varied from one genotype to another. When water stress was applied during the flowering phase and the beginning of pod formation, dry root mass was reduced in IT93K-503-1 and Tiligre and increased in Suvita2, ISV128 and IT96D-610. Results similar to those for IT93K-503-1 and Tiligre were obtained by Meftah (2012) on two populations of cowpea Tizi Ouzou and Djanet. Hamidou et al. (2005), studying the effect of water stress on pod formation of two varieties of cowpea

Table 4. Effect of water stress on flowering (S1) and onset of pod formation (S2), yield and its components in cowpea.

Treatment	Genotype	AB (g/plant)	Pod N/plant	Pod weight (g/plant)	Seed N/plant	Seed weight (g/plant)	HI (%)
Normal watering	ISV128	26.50±2.86^{bc}	15.25±2.63^{c}	21.97±1.54^{a}	90.00±3.92^{b}	17.29±1.22^{a}	35.71±2.94^{ab}
	IT93K-503-1	28.14±3.37^{b}	22.75±0.96^{c}	20.71±2.72^{a}	100.50±11.12^{a}	15.11±2.54^{ab}	30.9±3.56^{b}
	IT96D-610	24.57±1.26^{cd}	19.75±1.50^{ab}	19.86±2.67^{a}	99.75±2.87^{ab}	14.43±2.10^{b}	32.71±5.67^{b}
	Suvita2	21.35±0.80^{d}	19.50±3.11^{b}	20.36±1.80^{a}	105.50±7.85^{a}	17.24±1.84^{ab}	41.26±2.97^{a}
	Tiligré	32.41±2.31^{a}	13.75±1.71^{c}	15.73±1.62^{b}	54.00±3.37^{c}	11.57±1.42^{c}	24.04±2.98^{c}
Significance		***	**	*	***	**	**
	Mean	26.60±4.31	18.20±3.85	19.72±2.88	89.95±20.04	15.12±2.74	32.93±6.70
Watering flowering stage	ISV128	21.19±1.43^{b}	6.75±0.96^{ab}	3.85±0.56^{b}	43.50±2.12^{a}	2.92±0.58^{ab}	11.52±1.44^{ab}
	IT93K-503-1	17.86±0.58^{c}	3.33±1.53^{b}	3.44±1.07^{bc}	15.50±3.54^{b}	1.79±0.22^{bc}	8.61±1.72^{b}
	IT96D-610	20.19±0.74^{b}	6.00±2.65^{ab}	3.27±0.49^{bc}	28.33±16.56^{ab}	2.70±1.86^{bc}	11.37±7.71^{ab}
	Suvita2	17.66±1.29^{c}	8.75±3.77^{a}	5.36±1.59^{a}	46.50±7.78^{a}	5.17±1.01^{a}	20.66±4.15^{ab}
	Tiligré	23.56±1.38^{a}	4.00±0.82^{b}	1.77±0.63^{c}	10.50±8.23^{b}	0.88±0.10^{c}	4.54±3.15^{b}
Significance		***	*	**	*	*	**
	Mean	20.09±2.53	5.79±2.78	3.56±1.54	27.50±16.86	2.44±1.70	10.83±6.37
Watering pod formation	ISV128	23.32±1.46^{ab}	12.25±1.26^{b}	5.89±0.97^{bc}	47.5±6.86^{ab}	4.91±2.20	16.56±6.31^{ab}
	IT93K-503-1	25.14±1.46^{a}	7.67±0.58^{c}	5.03±0.49^{c}	36.33±5.51^{bc}	3.83±0.33	12.72±1.19^{b}
	IT96D-610	22.23±0.99^{bc}	10.50±1.29^{b}	8.16±0.48^{a}	55.75±6.65^{a}	6.49±1.00	21.33±3.10^{a}
	Suvita2	21.21±1.56^{c}	15.75±0.96^{a}	7.06±2.12^{ab}	53.50±12.58^{a}	5.66±1.81	19.67±4.19^{a}
	Tiligré	23.71±1.09^{ab}	7.25±1.71^{c}	4.32±0.72^{c}	27.00±8.52^{c}	3.34±0.79	11.91±2.74^{b}
Significance		*	***	**	**	ns	*
	Mean	23.01±1.76	10.84±3.40	6.19±1.80	44.72±13.9	4.95±1.79	16.63±5.20^{b}
	Genotypes	***	***	***	***	***	***
	Treatment	***	***	***	***	***	***
	Geno*Treat	**	*	***	**	ns	ns

*, **, ***Significant at the probability threshold of 0.05, 0.01 and 0.005, respectively; ns: Not significant (p> 0.05). Numbers with the same letter(s) in the same column are not significantly different from the p<0.05 threshold. BA, Aerial biomass; Pod N, number of pods; seed N, number of seeds; HI, harvest index.

(Gorom and KN1), found an increase in the dry matter of the root (13.62% For Gorom and 29.74% for KN1).

This study shows that the root biomass/aerial biomass ratios are higher under stress conditions for all genotypes. These ratios were also higher when water stress was applied at the beginning of flowering. The root system was less affected by water stress than aerial biomass. According to Monneveux (1997), the sustained growth of the root system in conditions of water stress is a factor of resistance to water stress. This is due to the fact that when the soil dries on the surface, the roots tend to sink deeper into the soil in search of water (Aziadekey et al., 2014). The growth of the root front would not have been able to discriminate genotypes resistant to those sensitive especially in the condition of terminal stress, but the pattern of water extraction clearly discriminated them (Zaman-allah et al., 2011).

The application of water stress during flowering and at the beginning of pod formation led to a significant decrease in seed yields and its components. Reduced yield were more severe when stress was applied to flowering stage than early pod formation. The number of pods in a non-limiting water condition is higher than stressed condition. Water stress therefore affected flowering and also increased the rate of abortion of flowers and pods. In addition to the yield reduction, a difference in size between the seeds of the control and stress plants was observed. The results are in agreement with those of Turk et al. (1980) who reported that the intervention of water stress during the flowering phase and the pod filling phase reduces the number of pods per plant and the size of the seeds. This reduction in pod numbers and seed size can be explained by the acceleration of foliar senescence and the shortening of

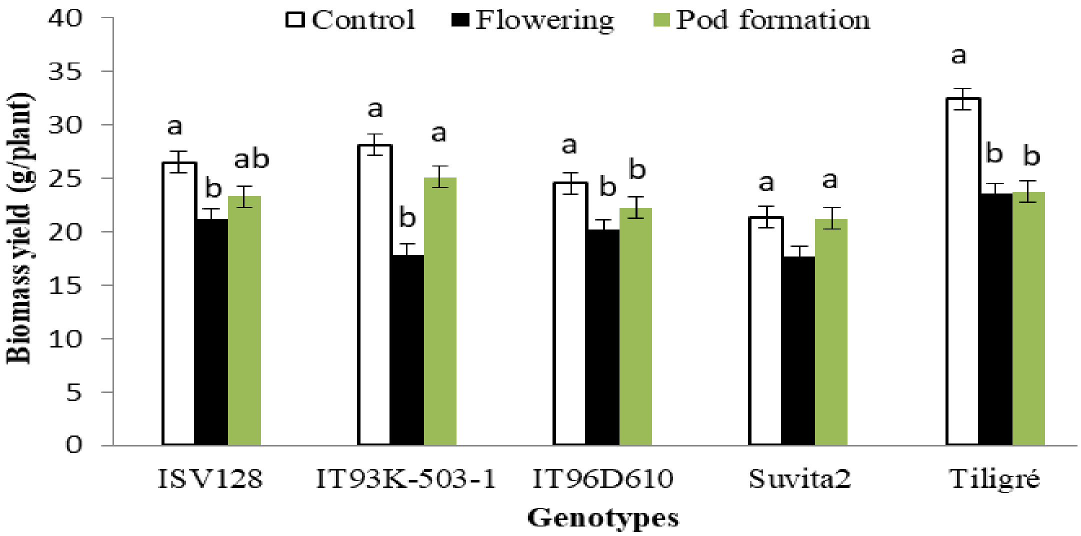

Figure 3. Comparison of aerial biomass yields of genotypes according to the period of application of stress: beginning of flowering (S1), beginning of pod formation (S2) and control (S0).

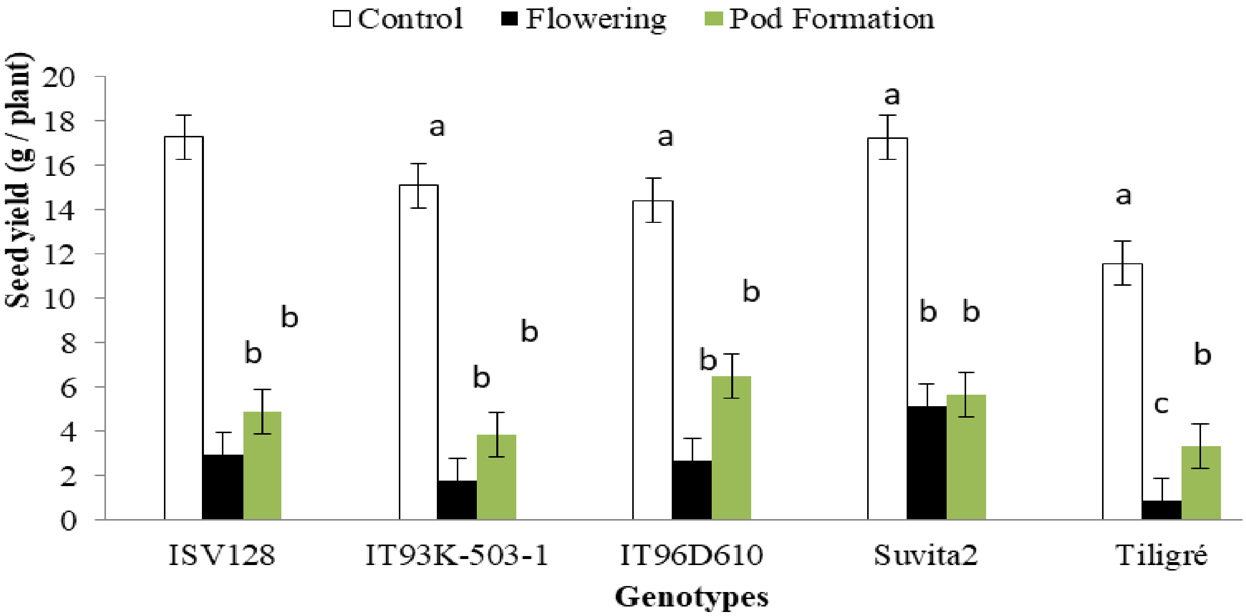

Figure 4. Comparison of seed yields of genotypes according to the period of application of stress: beginning of flowering (S1), beginning of pod formation (S2) and control (S0).

the seed filling period under the effect of water stress (De Souza and Da Silva, 1987). The terminal stress thus reduced the transfer of leaf assimilates to the seeds. The size of the seed is therefore directly related to the duration and/or filling rate (Sofield et al., 1977). A long filling time is often indicative of optimal photosynthetic activity as is the case with the control plants; whereas a high filling rate is indicative of the effects of water stress (Bahlouli et al., 2008).

The seed yield/harvest index relationship was much higher for water stress than non-limiting water condition. This strong correlation is explained according Jose et al. (2008) by the fact that some varieties of cowpea under water stress show a high harvest index following a large

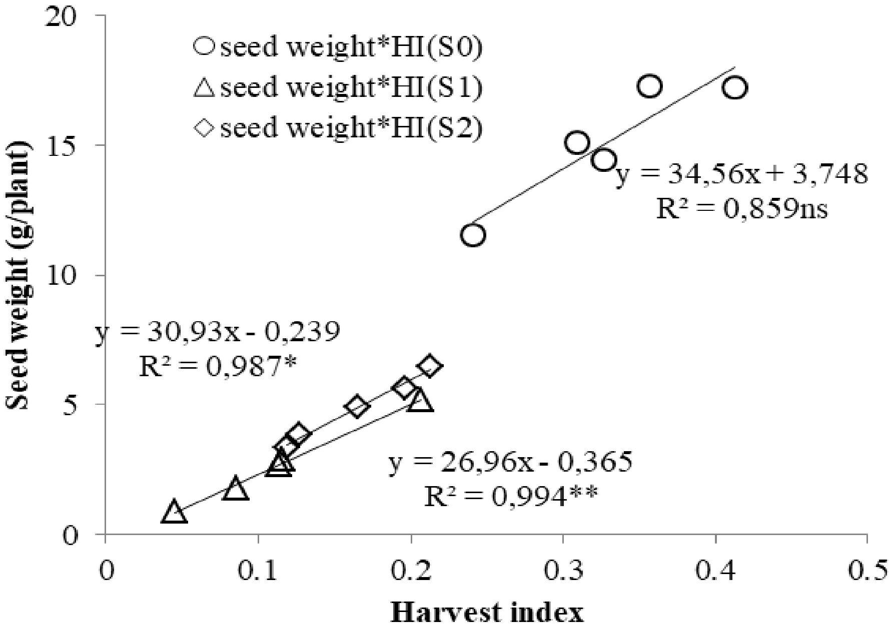

Figure 5. Seed weight relationship with harvest index for the three treatments.

mobilization of photosynthetic assimilates for the production and filling of seeds. Results show that the diminution of aerial biomass was followed by decrease pod production and filling under water stress. This low production of aerial biomass increases the relation of the harvest index and the yield of seeds under water stress conditions. This result is in agreement with those of Halilou (2016) who reported that in non-limiting water conditions, some varieties tend to favor a high production of aerial parts disproportionate to seed production, which reduces the relationship between harvest index and seed yield. Suvita2, ISV128 and IT96D-610 gave the highest harvest index for all the treatments which shows that this genotype assures better management of the assimilates on water stress condition.

Conclusion

This study did not allow the discrimination of genotypes on the basis of yield of seeds in conditions of water stress on pot experiment. The results show that yields decrease as conditions become constraining. Water stress was more severe when applied at flowering stage. Ideal genotype is the one that gave a higher harvest index under water stress. Suvita2, ISV128 and IT9D-610 genotypes recorded the highest seed yield and harvest index under water stress conditions would be more suitable and could contribute to combat food insecurity in Niger where climatic conditions are unfavorable for agriculture.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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