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Response of okra [*Abelmoschus esculentus* (L.) Moench] to water stress in the soil

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Water stress effects induced by stopping watering at vegetative (S1) and flowering (S2) stages were studied on five varieties of okra [*Abelmoschus esculantus* Moench (L.)]. Parameters such as relative water content, membrane permeability, chlorophyll content and yield of capsules varieties were evaluated. Our results show that water deficiency reduces relative water content of okra leaves. This reduction is more pronounced when water lack occurs at flowering stage of plants and, leakage of electrolytes across cell membranes is increasing. In addition, soil water deficit increased total chlorophyll content of leaves, which is much higher in stressed plants at vegetative stage. At the vegetative stage as to flowering, water deficit also reduces yield of capsules of varieties UAE 1, UAE 40 and UAE 45. This reduction is much important when plants were stressed at flowering.

Key words: Okra, water deficit, physiology, performance.

INTRODUCTION

Okra has long been considered as a marginal crop. It produces very nutritional and dietary capsules. In addition, it has long been used in traditional cooking and particularly in rural areas but nowadays okra is used in dietary habits of urban dwellers (Sawadogo et al., 2009). As tomato and onion, young capsules of okra is used in many dishes because of their binding power and also because they compete in quantity and especially as a more balanced diet. Its mineral, protein and vitamins A and C contents are significant. According to AADI (American Agency of International Development) (2006), okra is very popular in the USA and in European Union countries, EU market is about 637.837 tons, of which Kenya is the main exporter with 37% of the European market with 23 600 tons during 2000. In addition, okra is nowadays a very profitable vegetable for poor communities, especially for women, due to its strong sales potential on rural and urban markets. Indeed, in Burkina Faso, the turnover of the sale of okra from 2000 to 2004 was estimated at 276 125 364 FCFA (DGPSA, 2009). As a medicinal herb, prospective and epidemiological studies have shown that okra capsules contain antioxidants and okra consumption reduces the risk of cardiovascular disease and some cancers (Anonymous, 2009). The richness of okra mucilage content justifies the use of its sauce as diet food for gastric disorders. In fact, the raw consumption of fresh capsules soothe heartburn esophagus.

However, cultivation of okra faces several constraints, and the main one is the lack of rainfall which limits

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severely potential production of different varieties. Indeed, in Burkina Faso, national production decreased from 1.600 tons in 1989 to 726 tons in 1998, representing a decrease of approximately 60%. Faced with this situation, research resistant and / or tolerance varieties to water deficit are a promising prospect.

The goal of this work was to focus on physiological parameters of resistance and to evaluate agronomic performance of okra varieties under water deficit.

MATERIALS AND METHODS

Plant materials and culture conditions

Seeds of five (5) varieties of okra (UAE1, UAE19, UAE22 UAE40 and UAE45) were sown in pots filled with a capacity of 15 L a substrate of sandy-loam texture (13.7% clay, 15.7% silt, 70.6% sand). Two weeks after planting, a singling was performed leaving a plant in each pot. The experiment was conducted in a small greenhouse located at the University of Ouagadougou.

Experiment and application of water stress

The approach in this study was to evaluate the response of okra varieties to water interruption during vegetative stage, and also, their response in a situation of water shortage in the flowering stage. We used a factorial "split-plot" completely randomized device with three conditions of water regime, each with three replicates. Alternatives of water supply are: (i) Regular watering every 48 h until the end of the cycle, the control (T); (ii) stop watering at vegetative stage (S1) of for plants 32 days old during two weeks; (iii) stop watering at flowering stage (50% flowering) during 9 days (S2).

Relative water content (RWC) of the leaves

Measurement of relative turgidity has been determined according to the method described by Barrs (1968). The fourth leaf from apex, cut to the base of blade was weighed immediately for fresh weight (FW). Saturation is obtained by placing the whole leaf in a vial containing 200 ml of distilled water and left in the dark at a temperature of 4°C for 24 h. The weight at full turgidity (WFT) is then determined. The dry weight is obtained by drying the leaves in the oven set at 80°C for 24 h. Relative water content (RWC) is calculated using the formula below.

$$\mathrm{RWC}\,(\%) = \frac{FX - DW}{WFT - DW} \times 100$$

DW is the dry weight.

Permeability of cell membranes

In order to estimate damage of cell membranes under water restriction, the permeability of cell membranes was evaluated through the efflux of electrolytes by method of Clement (2003). Thus, five discs were taken from each leaf (third from the apex) and placed in test tubes containing 10 ml of distilled water. The whole is immersed in a water bath at 45°C for 2 h and conductivity (C1) of solution is measured. Samples are then placed in a boiling water bath for 20 min and then cooled to room temperature. Conductivity of solution is measured again (C2). The percentage of electrolyte's leakage (EL) is calculated by the formula.

$$\mathrm{EL} = \frac{C_1 \times 100}{C_2}$$

Leaf chlorophyll content

Chlorophyll content was determined by the method of Mckiney (1941). Indeed, 100 mg of fresh leaves are crushed in a mortar and chlorophyll extracted is recovered with acetone 80%. After filtration of extract, optical density (OD) is read with a spectrophotometer, respectively 663 and 645 nm. Chlorophyll concentrations are calculated using following formulas.

$$\mathrm{Chl\ a} = 12 \times OD_{663} - 2{,}67 \times OD_{645}$$

$$\mathrm{Chl\ b} = 22{,}5 \times OD_{645} - 4{,}68 \times OD_{663}$$

$$\mathrm{Chl\ a} = 12 \times OD_{663} - 2{,}67 \times OD_{645}$$

$$\mathrm{Chl\ b} = 22{,}5 \times OD_{645} - 4{,}68 \times OD_{663}$$

Total chlorophyll is obtained by the sum of chlorophyll a and b.

Measurement of yield

Capsules yield was evaluated after progressive harvest in each three days. Capsules were cut out and dried in natural conditions. Dry weight was determined by weighing with scales whose detail was 0.01 g.

Statistical analysis

Data are presented as an average of three repetitions ± standard error or the standard deviation. Results were analyzed using the analysis of variance (ANOVA) to estimate the significance of effect on the threshold *P < 0.05* compared to the least significant difference test with Student Newman Keuls. The logical XLSTAT version 7.1 was used for data analysis.

RESULTS

Relative water content of leaves

At vegetative flowering stages, water deficit has reduced relative water content of plants leaves compared to controls (Figures 1A and B). This reduction is relatively higher in stressed plants flowering stage (Figure 1B). Comparisons of means by Newman and Keuls test at P < 0.05 indicate an insignificant varietal effect and water treatment at the vegetative stage (P = 0.64 and 0.06, respectively). But, at flowering, water treatment has highly significant different (P < 0.0001).

Interactions "varieties * water treatment" have shown that at vegetative stage, no significant interaction was found both in the control plants than in those under stress (Table 1).

Instead, at flowering, “varieties * treatment interactions”

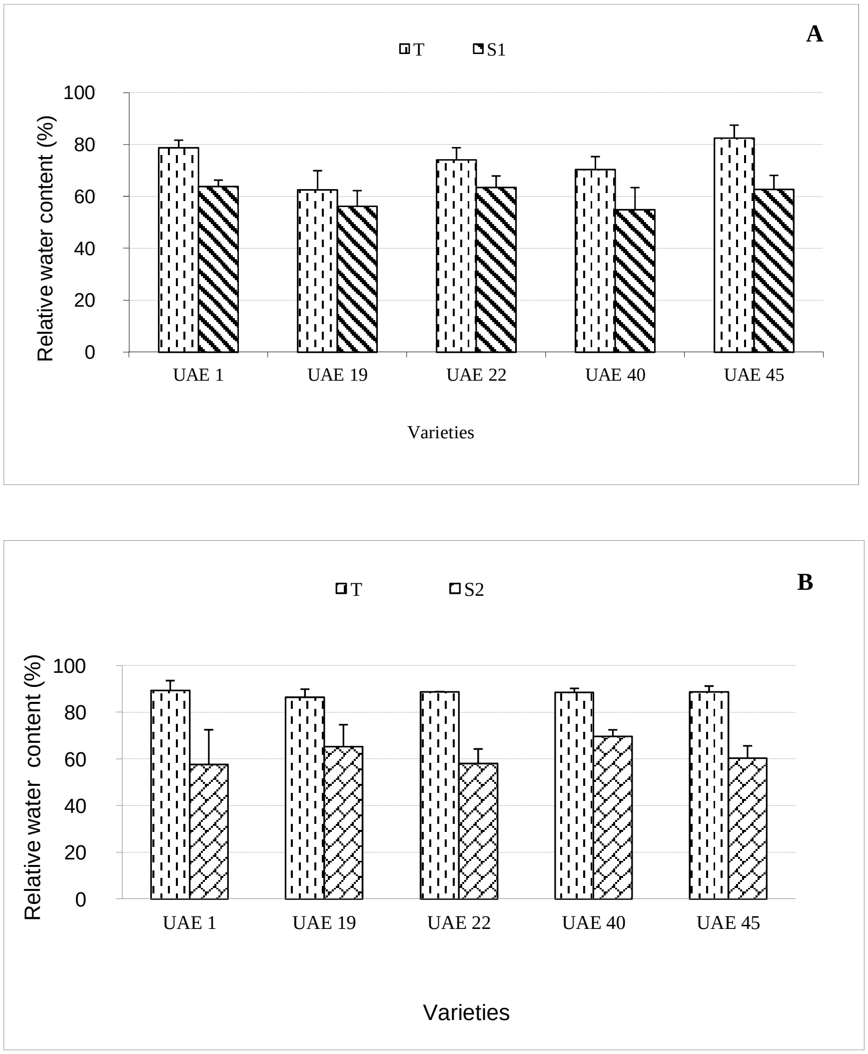

Figure 1. Relative water content of leaves of okra varieties. T = control plants; T1 = stressed plants at the vegetative stage; T2 = stressed plants at flowering.

Table 1. Interaction "varieties * water treatments" on the relative water content.

Varieties	Vegetative stage		Flowering stage	
	T	S1	T	S2
UAE 1	0.213[a]	0.361[a]	0.893[a]	0.675[c]
UAE 19	0.374[a]	0.439[a]	0.904[a]	0.752[abc]
UAE 22	0.259[a]	0.366[a]	0.887[ab]	0.689[c]
UAE 40	0.297[a]	0.351[a]	0.885[ab]	0.896[abc]
UAE 45	0.174[a]	0.373[a]	0.887[ab]	0.702[bc]

T= control; S1= water stress at vegetative stage; S2= water stress at flowering In the same water treatment; averages followed by the same letter are not significantly different and belong to the same statistics.

have significant water and were allowed to distinguish two statistics groups in the control: the first group is represented by varieties UAE 1 and UAE 19 and the second group is represented by varieties UAE 22, UAE 40 and UAE 45. In stressed plants, three statistics groups were distinguished: the first is formed by varieties UAE

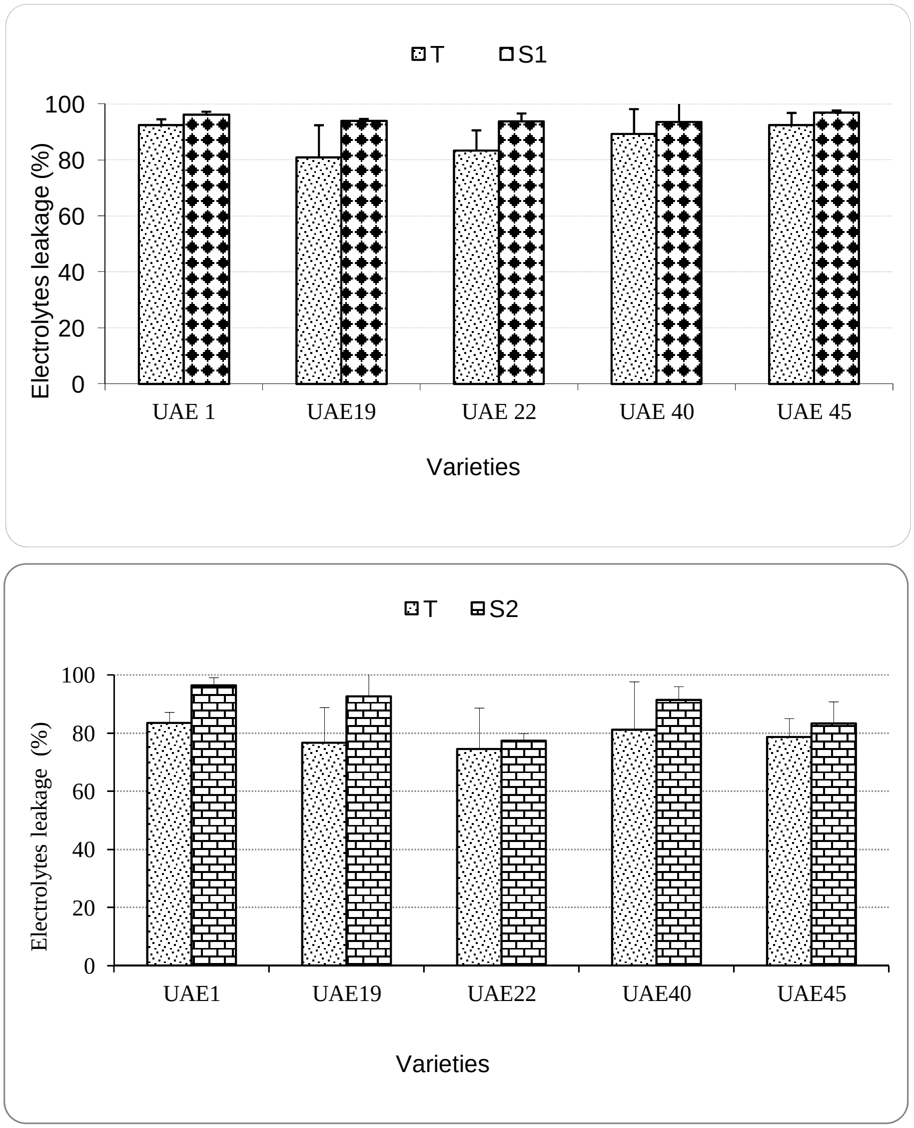

Figure 2. Percentage of electrolytes leakage in the cell membranes. T= control; S1= water stress at vegetative stage; S2 = water stress at flowering.

19 and UAE 40; the second group is represented by the variety UAE 45 and the third group is composed of varieties UAE1 and UAE 22.

Permeability of cells membranes

Permeability of cells membranes evaluated through electrolytes leakage showed an increase in plants stressed at vegetative stage and in those stressed at flowering stage compared to controls (Figures 2A and B). This increase is relatively higher in stressed plants at flowering (Figure 2B). Also, as a result of water stress at flowering stage, varieties UAE 22 and UAE 45 record a small increase in electrolytes leakage compared to other varieties.

The analysis test of variance showed a significant difference (P = 0.016) between varieties under the influence of water deficit at flowering. Regarding water treatments, differences are significant. Indeed, in the vegetative stage, there was a significant difference between control plants (T) and those under stress (S1) with an associated probability (P = 0.003). Moreover, at flowering, the difference between controls (T) and stressed (S2) is significant (P = 0.011).

Chlorophyll content

Chlorophylls *a*, *b* and total content (Table 2) shows that in control plants, chlorophyll *b* (chl *b*) is significantly lower

Table 2. Chlorophyll a, b and total of varieties according to the water treatment.

Parameter	Chlorophyll	UAE 1	UAE 19	UAE 22	UAE 40	UAE 45
T	Chl a	28.31±2.82a	25.57±1.64a	27.34± 2.62a	29.28±2.69a	27.07±1.73a
	Chl b	19.14±1.84a	13.60±1.60bc	8.65±1.66c	16.43±1.43ab	10.98±1.67bc
	Total Chl	47.44±2.47a	39.17±2.06a	35.99±2.12a	45.70±2.85a	38.06±2.38a
S1	Chl a	23.02 ± 2.07a	23.00±2.37a	23.32±2.27a	17.33±2.73a	23.51± .14a
	Chl b	42.31±2.48a	30.81±2.02a	44.00±2.79a	34.66±2.15a	28.62±1.59a
	Total Chl	65.33±3.56a	53.81±2.72a	61.34±3.24a	60.26±3.17a	52.14±3.13a
S2	Chl a	22.51±1.54a	22.70±1.99a	23.70±1.45a	24.64±1.95a	22.55±1.91a
	Chl b	30.33±2.26a	35.76±2.06a	35.48±2.13a	46.54±2.30a	26.09±185a
	Total Chl	52.83±3.94a	58.47±3.98a	59.19±3.11a	71.18±3.88a	48.64±2.50a

T= control, S1= stress at the vegetative stage, S2= stress at flowering stage. For the same water treatment, averages the same row followed by the same letter are not significantly different.

than that of chlorophyll *a* (chl *a*) in all varieties. However, under water stress effect at vegetative stage (S1) as flowering stage (S2), chlorophyll *b* content increased compared to that of controls and is much higher than that of chlorophyll *a*. Moreover, the increase in chlorophyll *b* in stressed plants is accompanied by an increase in *total* chlorophyll.

The analysis of variance shows a highly significant water treatment effect (P = 0.001) and a significant difference between varieties for chlorophyll *b* content. However, for chlorophyll *a* and *total* chlorophyll contents, varietal difference was not significant (P = 0.55).

Capsules yield

Water stress at vegetative stage and that to flowering caused a reduction of capsules yield of varieties UAE 1, UAE 40 and 45. Indeed, capsules yield decrease were respectively 35.5 and 50%, in a variety UAE 1, 14.35 and 50.11% for the variety UAE 40, 16.75 and 50% for variety UAE 45. The reduction is much greater when the water deficit occurs at flowering. Added to this, the reduction of capsules weight of plants stressed. However, varieties UAE 19 and UAE 22 showed a relative increase in the number of capsules per plant, but the average weight of these capsules is lower than that of control plants.

DISCUSSION

Whatever the stage of the development cycle, our results show a decrease in relative water content of leaves of all varieties under the effect of water stress. This decline is consistent with that already found by other authors (Mefti et al., 2000; Hamidou, 2006; Zerrad et al., 2006). However, Abdou Razakou et al. (2013) found under water-stressed the highest percentage of relative water content in some varieties of cowpea.

Electrolytes leakage increase in stressed plants corroborates results of Sawadogo et al. (2006), Hamidou (2006), and Mimoun et al. (2007). This increase can be explained by rupture of the membrane delayed, altering selective power of membranes and therefore an increased perme-ability of cellular membranes. According to Stocker (1961), the water shock causes changes or a destruction of chloroplast membranes and release into the cytoplasm of certain enzymes in cellular organelles. Relatively larger increase in stressed plants at flowering stage is con-firmed with the results of Bensalem and Vieira Da Silva (1991) that showed that the percentage of membrane damage increases with age of the plant. In addition, the increase of total chlorophyll observed in stressed plants is related to the increase of chlorophyll *b*. This is probably an adaptation of leaves to water shortages, to better protect photosystems (PSI and PSII) to ensure the photo-synthetic activity on the one hand and on the other hand, increase probability of survival and maintenance of plants production. Deeplata and Rao (2013) state the levels of okra primary metabolites as chlorophyll are strongly affected by genetic and environ-mental factors.

The decrease of fruit yield of varieties UAE 1, UAE 40 and UAE 45 under the effect of water stress at vegetative stage as flowering stage explains by delayed formation of reproductive organs in plants stressed at vegetative stage and a fall flowers buds and flowers seen in those under stress during flowering. These results confirm those found by Konyeha and Alatise (2013) which showed that yield and water use efficiency of okra's crop under high irrigation was highest. Son et al. (2011) in the same idea, showed a reduction in number and weight of capsules in sesame in imposition of water stress. The sharp decline in the yield of capsules in plants stressed at flowering reflects a strong sensitivity to soil moisture deficit during the development phase. Heavy water con-sumption of plants during flowering period was high-lighted by Karam et al. (2002) (Table 3).

However, the increase of capsules number of varieties UAE 19 and UAE 22 under stress effect is a paradox. Gunawardhana and De Silva (2011) found results that indicated that okra has high yield when it grown under high temperature environment with no water stress. Our

Table 3. Yield of capsules and its weight of varieties.

Parameter	UAE 1			UAE 19			UAE 22			UAE 40			UAE 45		
	T	S1	S2	T	S1	S2	T	S1	S2	T	S1	S2	T	S1	S2
N Cap	4.00± 1.53	2.50± 1.00	2.00± 0.71	2.00± 0.58	3.33± 0.58	3.33± 1.53	3.00± 0.58	5.00± 1.73	3.67± 1.53	4.67± 1.53	4.00± 1.00	2.33± 1.53	3.33± 0.58	3.33± 1.00	2.00± 0.33
DW Cap^{-1}	2.55± 0.55	2.41± 0.69	1.07± 0.06	3.04± 0.68	1.38± 0.24	1.94± 0.37	2.06± 0.51	1.16± 0.27	1.63± 0.59	2.68± 0.70	2.31± 0.29	2.14± 0.32	2.13± 0.12	1.86± 0.81	1.88± 0.36

N Cap = number of capsules; DW Cap^{-1} = dry weight of capsules.

results can be explained by tolerance mechanisms that allow these varieties to counteract effects of water shortage.

Sorrells et al. (2000) have shown that increased production in drought conditions depends on the tolerance mechanisms that ensure cellular hydration to allow a favorable water status. Also, variety UAE 22 was identified by Sawadogo et al. (2006) as water stress tolerant because its performance of capsules is slightly reduced under water deficit effect. We had previously found that variety UAE 22 is the most productive under short intermittent water stress than others varieties of okra (Nana et al., 2009).

Conclusion

The ability of okra to tolerate the lack of water depends on strategies to reduce relative water content of leaves and to increase total chlorophyll content. It emerge from permeability of cells membranes, an increase of electrolytes leakage in plants stressed at vegetative stage and in those stressed at flowering stage. However, water deficit led to a reduction in the yield of capsules and weight for varieties UAE 1, UEA 40, UAE 45. Of the two stages of development, flowering stage is most vulnerable to water shortages in okra.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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