Impact of continuous water deficit on the physiological, agronomic and biochemical performance of sesame (*Sesamum indicum* L.) varieties and descendants grown in Burkina Faso

Badoua Badiel*[1], Pascal Adama Kihindo[1], Tchoa Koné[2], Rasmata Nana[1], Razacswendé Fanta Ouédraogo[1], Edmond Dondassé[1], and Zoumbiessé Tamini[1]

[1]*Department of Plant Biology and Physiology, Laboratory of Biosciences, Training and Research Unit in Life and Earth Sciences, Joseph KI-Zerbo University, Ouagadougou 03, Burkina Faso*

[2]*Unit of Plant Physiology, Training and Research Unit in Natural Sciences, Nangui Abrogoua University, Abidjan 02, Côte d'Ivoire*

**Corresponding author email:* badoua.badiel@ujkz.bf

West Africa in general and Burkina Faso in particular are facing climate hazards that are becoming increasingly severe. Periods of drought and a spatiotemporal distribution of rainfall, out of phase with the agricultural calendar, make the already difficult situation more challenging. Thus, the cultivation of varieties resistant to water stress is necessary to sustain production, hence this study aimed at evaluating the physiological, agronomic and biochemical responses of four sesame (*Sesamum indicum* L.) varieties (S-42, Wollega, 32-15 and Humera) and six descendants of S-42 to continuous water deficit. There were three water supply treatments: watering every other day at soil field capacity was the control; water supply at ¾ soil field capacity (moderate deficit) and water supply at ¼ soil field capacity (severe deficit). A randomised complete block design with 30 treatment combinations (ten accessions and three water supply treatments) was used in the greenhouse. The water deficit, whether moderate or severe, caused a reduction in growth, development and water content. Water deficit caused an increase in the foliar content of total chlorophyll, sodium, potassium and magnesium in all the plants of the varieties and descendants, with a greater effect for the severe deficit. Seed number and weight decreased with the intensity of water deficit in all varieties and lines. Moderate water deficit caused the following rates of reduction in capsule yields: SMK-2 (20.4%), SMK-5 (25.8%), SMK-3 (27.3%), Humera (30.7%), S-42 (32.2%), SMK-4 (35.8%), SMK-1 (36.8%), SMK-6 (38.9%), 32-15 (45.3%) and Wollega (61.0%). Severe deficit caused capsule yield reduction of: SMK-2 (46.3%), SMK-5 (46.4%), SMK-3 (52.7%), Humera (78.2%), S-42 (48.6%), SMK-4 (46.0%), SMK-1 (50.7%), SMK-6 (51.0%), 32-15 (76.6%) and Wollega (84.2%). The variety most affected by the water deficit (moderate or severe) was Wollega. The variety S-42 and all the descendants were the most resistant, especially the descendant SMK-2.

Keywords: Sesame, varieties, progenies, resistance, water stress

Burkina Faso is a West African country, with an agriculturally based economy constrained by rather harsh climatic conditions. The poor agricultural performance in 2021 led to a reduced agriculture's contribution to GDP, from 18.9% in 2020 to 16.2% in 2021 (INSD/MEFP 2022). Agricultural production involves a limited range of food and cash crops including sesame (*Sesamum indicum* L.). Sesame is primarily used for its high-quality oil, which comes from 48 - 58% of the seeds; this oil is used in salads, soups, and cold and hot dishes, in China, Korea and elsewhere. Sesame oil is also used in the manufacture of various products such as soaps, insecticides, pharmaceutical products, paints, etc. Sesame seeds are used in the preparation of sauces, fritters, local drinks, bread and croquettes. The sesame paste called "tahini" is very popular in the Arab world. Sesame cake, the main residue after the oil is extracted, is a product of high nutritional and energy value, used for livestock and poultry feed (Hijikata et al. 2018). Sesame is Burkina Faso's second-largest agricultural export after cotton. Sesame production, estimated at 106,674 tonnes in 2021, fell by 51.2% from 2020 and by 30.5% when compared to the 5-year average (CPSA/MAAH 2022). The interest in sesame cultivation in the country, is explained by favourable trends in world markets, and by the fact that sesame remains one of the crops

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grown by the poorest people, particularly women. However, its production is not evenly distributed throughout Burkina Faso, with some regions producing more than others (CPSA/MAAH 2022). Also, sesame yields per hectare remain low, 450 kg/ha in farming areas, compared to approximately 1000 kg/ha on research stations (Rongead 2013). This low production is linked to various constraints, including climatic conditions that are becoming increasingly severe, with periods of drought. It has been reported that a deficit in water supply to sesame plants significantly reduces their yield (Compaoré 2011; Badiel et al. 2017). Increasing national production of this important commodity therefore requires the adoption of drought tolerant/resistant varieties. It is in this context that this study was conducted, the overall objective of which was to evaluate the impact of continuous dry weather conditions on the development and productivity of sesame varieties and their progeny.

Materials and methods

Plant material

The plant material consisted of four varieties and six lines of sesame obtained. The Jaalgon 128 variety of Indian origin was introduced in Burkina Faso under the code of S-42. Variety 32-15 was developed from crosses between S4 (Argentina) and S30 (Brazil) and popularised in Burkina Faso. Two varieties of Ethiopian origin (Humera and Wollega) were introduced in Burkina Faso through the Programme Développement de l'Agriculture (PDA) (Ily 2011). The six progeny; SMK-1, SMK-2, SMK-3, SMK-4, SMK-5 and SMK-6 were obtained by mutagenic selection from variety S-42 at the Institut National de l'Environnement et de Recherches Agricoles (INERA), Kamboinsé, Burkina Faso. The characteristics of the different varieties and their progeny are presented in Table 1.

Table 1: Characteristics of accessions (four varieties and six descendants) of sesame

	Varieties				Descendants					
Parameters	S-42	32-15	Wollega	Humera	SMK-1	SMK-2	SMK-3	SMK-4	SMK-5	SMK-6
SC	White									
FC	White + slight purplish tint		White + purple stripes	White	White + slight purplish tint					
HSLC	Very hairy		Sparse		Very hairy					
DE (DAS)	3									
BF (DAS)	35		42		35					
EF (DAS)	65	67	83		65					
CM (DAS)	84	85	100		84					
CL (DAS)	90		105		90					

Legend: SC: seed colour ; FC : flower colour ; HSLC: hairiness on stem, leaves and capsules; DE: date of emergence; BF: beginning of flowering; EF: end of flowering; CM: capsules maturity; CL: cycle length; DAS: day after sowing.

Experimental site

The experiment was conducted at the experimental station of the UFR/SVT of the Joseph Ki-Zerbo University, located in the centre of the city of Ouagadougou, which is located in a Sudano-Sahelian climatic region at 12°37' N 01°49' W. The plants were grown in pots, in a greenhouse made of fine wire mesh fencing for protection against insects and the roof was made of translucent sheets.

Soil type

Soil was sampled between 0 and 30 cm depth in the vicinity of the greenhouse, and then analysed at the National Soil Bureau (BUNASOLS) to determine its granulometric and mineral characteristics. The soil used was acidic and sandy loam; relatively rich in iron and potassium but relatively poor in organic matter and nitrogen (Table 2).

Table 2: Analytical characteristics of the soil sample

pH	Granulometric composition			MO %	Mineral elements							
	Clay %	Silt %	Sand %		C %	N %	C/N	P ppm	K ppm	Fe ppm	Ca ppm	Mg ppm
5.89	5.88	19.61	74.51	1.556	0.908	0.085	11	5.27	92.57	31.00	2.41	1.47

Sowing

The experiment was conducted from 7 August to 19 November 2015. The seeds of the four varieties and six progenies were sown directly into the pots at a rate of ten per pot, at a depth of about 1 cm. Thinning to one plant per pot was carried out 14 days after sowing.

Water treatments

Three levels of water treatments were applied:

S0: Watering every other day and at soil field capacity

S1: Watering every other day at ¾ soil field capacity (moderate deficit)

S2: Watering every other day at ¼ soil field capacity (severe deficit). This rate is justified by the rapid drying of the soil due to the high temperature and low humidity of the atmosphere in the Sudano-Sahelian zone.

Experimental design

The trial was conducted in a randomised complete block design with 90 pots (four varieties and six progenies x three water treatments with three replicate blocks).

Measured parameters

These were as follows

- Plant height measured with a ruler.
- The number of capsules per plant and the number of seeds per capsule were determined by manual counting.
- The weight of 1000 seeds was determined by weighing with an electronic balance DENVER AC-1200D of precision 0.001.
- The relative water content (RWC) of the fifth leaf from the top of the main stem was assessed by the following calculation (Barrs 1968):

  RWC (%) = [(FW – DW) / (WFT – DW)] x 100

  RWC = relative water content, FW = fresh weight, DW = Dry weight, WFT = weight of full turgidity
- The 5th leaf from the top of the main stem was used to determine total chlorophyll content (TCC) using the method of Mackinney (1941):

  TCC = Chl a + Chl b in g/kg FL
  Chl a = 12 x (OD 663) – 2.67 x (OD 645)
  Chl b = 22.5 x (OD 645) – 4.68 x (OD 663)
  FL: Fresh leaves
  OD: optical density
  12: constancy associated with optical density at 663 nm for chlorophyll a
  2.67: constancy associated with optical density at 645 nm for chlorophyll a
  22.5: constancy associated with optical density at 645 nm for chlorophyll b
  4.68: constancy associated with optical density at 663 nm for chlorophyll b

- Leaf sodium and potassium contents were determined using a flame photometer with the following procedure: Pipette 0 ml, 2 ml, 4 ml, 6 ml, 8 ml and 10 ml of the 100 ppm solution into 100 ml vials respectively and make up to volume with extraction solution. The final concentrations were: 0 ppm, 2 ppm, 4 ppm, 6 ppm, 8 ppm and 10 ppm of Na-K-Li.

Calculation: The calculation is recorded in the document published by Gueguen and Rombauts (1961).

- The determination of the magnesium content was done using the atomic absorption method.

Procedure:

- Place 1 g of the sample in the air in a capsule
- Add 10 ml of concentrated HNO3. Wet completely
- Place the capsule on a water bath to evaporate the nitric acid
- Repeat the operation twice with 5 ml of nitric acid
- Add 4 ml of concentrated HCl plus 20 ml of distilled water
- Empty the contents of the capsule into a 200 ml flask
- Fill to three quarters of its volume and place on a water bath for about 30 minutes, cool and fill to volume
- Filter into a 300 ml Erlenmeyer flask
- Dilute, if necessary, with the 2000 ppm lanthanum solution.

Calculation:

$$\frac{(L-R) \times K \times TV \times D}{W} = \text{ppm of Mg}$$

L = reading obtained with the sample
R = reading obtained with the blank
K = standard series constant
TV = total volume
D = dilution factor
W = weight of the sample taken

Data processing and analysis

The data were compiled with Microsoft Office Excel 2016. Analyses of variance between the means for each parameter was performed with XLSTAT 2016 software. The comparison of means was performed using the Newman-Keuls test at the 5% threshold.

Results

Analysis of variance of final height, relative leaf water content and total chlorophyll content

Final height of plants

A highly significant difference ($P \leq 0.001$) was observed between accessions under the different watering regimes (Table 3a). The highest mean height was obtained in the variety Wollega (151.1 cm) and the lowest in the descendant SMK-2 (120.4 cm). Also, there was a highly significant difference ($P \leq 0.001$) between the water regimes (Table 3b). The moderate water restriction, watering every other day at ¾ of the soil field capacity, caused an average reduction of 6.7 cm in plant height and the severe water restriction, watering every other day at ¼ of the soil field capacity, caused an average reduction of 14.8 cm, compared to the control of watering every other day at the soil field capacity.

Relative leaf water content

A highly significant difference ($P \leq 0.001$) was observed between accessions (Table 3a). Descendant SMK-6 had the highest average relative water content (77.7%) and variety S-42 had the lowest (73.5%). Also, there was a highly significant difference ($P \leq 0.001$) between the water regimes (Table 3b). The moderate restriction caused an average reduction of 9.1% in relative water content and the severe restriction caused an average reduction of 17.8% when compared to the plants in the control.

Total leaf chlorophyll content

A highly significant difference (P ≤ 0.001) was observed between accessions (Table 3a). Variety S-42 showed the highest mean (39.0 g/kg FL (fresh leaves) and descendant SMK-6 showed the lowest mean (35.3 g/kg FL). Also, there was a highly significant difference (P ≤ 0.001) between the water regimes (Table 3b). Moderate restriction caused an average increase of 2.2 g/kg FL in chlorophyll content and severe restriction S2 caused an average increase of 5.9 g/kg FL compared to plants in the control.

Table 3a: Analysis of variance of plant height, relative water content and leaf chlorophyll content under different water regimes

Parameters	F	P	Accessions	Effects of water regimes			
				S0	S1	S2	Mean
Final height of plants (cm)	1429.33	< 0.001	Wollega	160	150	143	151.1^{a}
			Humera	155	150	145	149.8^{b}
			32-15	153	148	137	145.9^{c}
			SMK-5	133	127	118	126.2^{d}
			SMK-6	133	127	115	125.0^{e}
			SMK-3	132	126	115	124.5^{ef}
			S-42	132	122	117	123.8^{f}
			SMK-4	131	120	115	122.1^{g}
			SMK-1	127	120	115	120.7^{h}
			SMK-2	125	122	114	120.4^{h}
Relative leaves water content (%)	15.74	< 0.001	SMK-6	87	78.1	68.0	77.7^{a}
			SMK-5	86.0	77.0	68.7	77.2^{ab}
			SMK-4	85.1	75.8	68.0	76.3^{bc}
			32-15	84.0	75.5	68.1	75.8^{cd}
			SMK-2	85.0	75.7	65.9	75.5^{cd}
			Wollega	83.0	74.9	67.4	75.1^{cde}
			SMK-3	83.3	73.9	67.5	74.9^{de}
			SMK-1	83.7	75.0	66.0	74.9^{de}
			Humera	84.5	74.1	63.3	73.9^{ef}
			S-42	83.1	73.3	64.2	73.5^{f}
Total chlorophyll content of leaves (g/kg FL)	13.68	< 0.001	S-42	34.8	40.3	41.8	38.9^{a}
			Humera	36.7	37.3	39.4	37.8^{b}
			SMK-4	31.8	39.8	41.0	37.5^{b}
			32-15	33.1	36.8	41.4	37.1^{b}
			SMK-3	34.6	36.6	38.5	36.6^{bc}
			SMK-2	31.3	37.5	38.1	35.6^{c}
			SMK-1	31.8	36.1	38.8	35.6^{c}
			SMK-5	32.8	35.5	38.2	35.5^{c}
			Wollega	34.3	35.9	36.2	35.5^{c}
			SMK-6	32.3	34.5	39.0	35.3^{c}

Table 3b: Analysis of variance of water regimes effects on accessions

Parameters	F	P	Water regime	Mean
Final height of plants (cm)	1643.15	< 0.001	S0	138^a
			S1	131^b
			S2	123^c
Relative leaves water content (%)	2373.80	< 0.001	S0	84.5^a
			S1	75.3^b
			S2	66.7^c
Total chlorophyll content of leaves (g/kg FL)	252.68	< 0.001	S2	39.3^a
			S1	37.1^b
			S0	33.4^c

S0: watering every 2 days at field capacity; S1: watering every 2 days at 3/4 of field capacity; S2: watering every 2 days at 1/4 of field capacity FL: fresh leaves

Analysis of variance of number of capsules per plant, number of seeds per capsule and 1000 seed weight

Number of capsules per plant

A highly significant difference ($P \leq 0.001$) was observed between accessions (Table 4a). Descendant SMK-5 had the highest mean number of capsules per plant (115 capsules/plant) and variety 32-15 had the lowest mean number (38 capsules/plant). Also, there was a highly significant difference ($P \leq 0.001$) between the water regimes (Table 4b). The moderate water restriction, watering every other day at ¾ soil field capacity caused an average reduction of 43 capsules and the severe water restriction S2, watering every other day at ¼ soil field capacity caused an average reduction of 73 capsules compared to the control regime, watering every other day at soil field capacity.

Number of seeds per capsule

A highly significant difference ($P \leq 0.001$) was observed between accessions (Table 4a). Variety Wollega had the highest average number of seeds per capsule (70 seeds/capsule) and variety 32-15 had the lowest average number (51 seeds/capsule). Also, there was a highly significant difference ($P \leq 0.001$) between the water regimes (Table 4b). Moderate restriction caused a mean reduction of 0.82 seeds/capsule and the severe restriction S2 caused a mean reduction of 10.7 seeds/capsule compared to the control.

1000-seed weight

A highly significant difference ($P \leq 0.001$) was observed between accessions (Table 4a). Variety 32-15 had the highest average 1000-seed weight (3.08 g) and descendant SMK-4 had the lowest average 1000-seed weight (2.31 g). Also, there was a highly significant difference ($P \leq 0.001$) between the water regimes (Table 4b). Moderate restriction caused an average reduction of 0.66 g and severe restriction caused an average reduction of 1.02 g compared to the 1000 seed weight of the control S0.

Reduction of capsule yield

Table 5 shows the impact of the two levels of water stress on the capsule yield of the four varieties and six lines of sesame. It shows that for all the varieties and descendants, the intervention of water stress with watering every other day at 3/4 of the field capacity caused a reduction in capsule yield of about 35%. However, the variety Wollega was the most vulnerable with a reduction of more than 60%, contrary to the descendant SMK-2 in which the reduction was only about 20%.

Water stress with watering every other day at ¼ of the field capacity at flowering stage caused an overall reduction of about 58% in all varieties and descendants. At this stage, the variety Wollega was still the most vulnerable with an average reduction of 84% as opposed to the SMK-2, SMK-4 and SMK-5 descendants where the reduction was only about 46%.

Table 4a: Analysis of variance of number of capsules per plant, number of seeds per capsule and 1000 seed weight under different water regimes

Parameters	F	P	Accessions	Effects of water regimes			
				S0	S1	S2	Mean
Number of capsules/plant	1107.18	< 0.001**	SMK-5	151	112	81	115^{a}
			SMK-2	147	117	79	114^{a}
			S-42	152	103	78	111^{b}
			SMK-3	150	109	71	110^{b}
			SMK-6	149	91	73	104^{c}
			SMK-1	144	91	71	102^{cd}
			SMK-4	137	88	74	100^{d}
			Humera	101	70	22	64^{e}
			Wollega	82	32	13	42^{f}
			32-15	64	35	15	38^{g}
Number of seeds/capsule	20.11	< 0.001**	Wollega	74	73	63	70^{a}
			Humera	72	71	49	64^{b}
			S-42	66	65	58	63^{b}
			SMK-3	66	65	56	62^{b}
			SMK-6	66	6	56	61^{b}
			SMK-5	64	64	54	61^{b}
			SMK-2	63	63	55	61^{b}
			SMK-4	64	64	54	61^{b}
			SMK-1	64	63	54	61^{b}
			32-15	55	53	46	51^{c}
Weight of 1000 seeds (g)	12.98	< 0.001**	32-15	3.56	3.12	2.56	3.08^{a}
			Humera	3.38	2.85	2.35	2.86^{b}
			SMK-6	3.10	2.56	2.21	2.62^{c}
			S-42	3.01	2.45	2.03	2.49^{cd}
			SMK-3	3.03	2.37	2.01	2.47^{cd}
			SMK-2	2.98	2.28	1.98	2.41^{cd}
			Wollega	3.09	2.23	1.89	2.40^{cd}
			SMK-1	2.99	2.22	1.96	2.39^{cd}
			SMK-5	2.95	2.14	1.91	2.33^{cd}
			SMK-4	2.88	2.19	1.87	2.31^{d}

Table 4b: Analysis of variance of water regimes effects on accessions

Parameters	F	P	Water regime	Mean
Number of capsules/plant	5096.47	< 0.001	S0	128^{a}
			S1	85^{b}
			S2	55^{c}
Number of seeds /capsule	116.15	< 0.001	S0	65^{a}
			S1	64^{a}
			S2	55^{b}
Weight of 1000 seeds (g)	185.69	< 0.001	S0	3.09^{a}
			S1	2.44^{b}
			S2	2.08^{c}

S0: watering every 2 days at field capacity; S1: watering every 2 days at 3/4 of field capacity; S2: watering every 2 days at 1/4 of field capacity

Table 5: Rates of reduction (%) in capsule yields of the four varieties and six descendants subjected to water deficit with watering every other day at 3/4 of the field capacity (moderate stress) and to water deficit with watering every other day at 1/4 of the field capacity (severe stress) in greenhouse.

Accessions	Moderate stress	Severe stress
S-42	32.2	48.6
32-15	45.3	76.6
Wollega	61.0	84.2
Humera	31.0	78.2
SMK-1	36.8	50.7
SMK-2	20.4	46.3
SMK-3	27.3	52.7
SMK-4	35.8	46.0
SMK-5	25.8	46.4
SMK-6	38.9	51.0
Mean	35.4	58.1

Analysis of variance of leaf potassium, sodium and magnesium content

Leaf potassium content

A highly significant difference ($P \leq 0.001$) was observed between accessions (Table 6a). Descendant SMK-4 showed the highest mean (30.2 g/kg dry matter, DM) and variety Wollega showed the lowest mean (24.1 g/kg DM). Also, there was a highly significant difference ($P \leq 0.001$) between water regimes (Table 6b). Moderate restriction caused an average increase of 1.2 g/kg DM in potassium content and the severe restriction caused an average increase of 4.4 g/kg DM in potassium content compared to the control.

Leaf sodium content

A significant difference ($P = 0.016$) was observed between accessions (Table 6a). Descendant SMK-6 had the highest mean (0.33 mg/kg DM) and Humera had the lowest mean (0.13 mg/kg DM). Also, there was a highly significant difference ($P = 0.004$) between water regimes (Table 6b). Moderate restriction caused an average increase of 0.04 mg/kg DM in sodium content and severe restriction caused an average increase of 0.10 mg/kg DM in leaf sodium content compared with the average sodium content of plants in the control regime.

Leaf magnesium content

A highly significant difference ($P \leq 0.001$) was observed between accessions (Table 6a). Descendent SMK-6 line showed the highest mean (2.51 g/kg DM) and Humera variety showed the lowest mean (1.31 g/kg DM). Also, there was a highly significant difference ($P \leq 0.001$) between water regimes (Table 6b). Moderate restriction caused an average increase of 0.24 g/kg DM in magnesium content and severe restriction caused an average increase of 0.05 g/kg DM in leaf magnesium content of the plants in control (S0). The increase in leaf mineral content due to drought implies a resistance strategy. In water-deficit situations, plants fight for survival by accumulating more Mg and K in their leaves. Magnesium is a constituent of chlorophyll, promoting its synthesis and activating enzymes, in particular those responsible for protein synthesis. Potassium increases cell pressure, regulates the plant's water economy, reduces evaporation and thus increases drought resistance.

Table 6a: Analysis of variance of leaves potassium, sodium and magnesium content under different water regimes

Parameters	F	P	Accessions	Effects of water regimes			
				S0	S1	S2	Mean
Foliar potassium content (g/kg DM)	31.27	< 0.001	SMK-4	28.4	29.2	32.8	30.1^{a}
			SMK-1	26.1	28.4	33.0	29.2^{b}
			Humera	26.1	29.2	32.3	29.2^{b}
			S-42	27.7	26.9	29.2	27.9^{c}
			32-15	25.4	28.4	29.2	27.7^{c}
			SMK-3	26.1	26.9	29.2	27.4^{c}
			SMK-2	24.6	24.6	32.3	27.1^{c}
			SMK-5	24.6	26.1	27.7	26.1^{d}
			SMK-6	23.1	25.4	27.7	25.4^{d}
			Wollega	23.8	22.3	26.1	24.1^{e}
Foliar sodium content (mg/kg DM)	2.53	0.016	SMK-6	0.27	0.35	0.36	0.33^{a}
			32-15	0.19	0.22	0.51	0.31^{a}
			S-42	0.24	0.28	0.26	0.26^{ab}
			SMK-5	0.20	0.25	0.30	0.25^{ab}
			SMK-4	0.18	0.23	0.29	0.23^{ab}
			Wollega	0.18	0.22	0.29	0.23^{ab}
			SMK-3	0.16	0.22	0.25	0.21^{ab}
			SMK-1	0.18	0.20	0.23	0.20^{ab}
			SMK-2	0.14	0.21	0.25	0.20^{ab}
			Humera	0.15	0.12	0.11	0.13^{b}
Foliar magnesium content (g/kg DM)	83.44	< 0.001	SMK-6	2.36	2.82	2.36	2.51^{a}
			SMK-2	2.18	2.67	1.86	2.24^{b}
			SMK-5	2.10	2.15	2.32	2.19^{b}
			SMK-1	2.15	2.19	2.18	2.17^{b}
			SMK-4	1.89	2.25	2.37	2.17^{b}
			S-42	2.09	2.28	1.93	2.10^{bc}
			SMK-3	1.76	2.11	2.15	2.01^{c}
			Wollega	1.30	2.08	2.17	1.85^{d}
			32-15	1.83	1.88	1.39	1.70^{e}
			Humera	1.61	1.23	1.08	1.31^{f}

Table 6b: Analysis of variance of water regimes effects on accessions

Parameters	F	P	Water regime	Mean
Foliar potassium content (g/kg DM)	152.99	< 0.001	S2	29.9^{a}
			S1	26.7^{b}
			S0	25.6^{c}
Foliar sodium content (mg/kg DM)	6.07	0.004	S2	0.29^{a}
			S1	0.23^{ab}
			S0	0.19^{b}
Foliar magnesium content (g/kg DM)	38.70	< 0.001	S1	2.17^{a}
			S2	1.98^{b}
			S0	1.93^{b}

S0: watering every 2 days at field capacity; S1: watering every 2 days at 3/4 of field capacity; S2: watering every 2 days at 1/4 of field capacity

Discussion

Temperature and relative humidity measures during the study showed that the plants experienced high temperature and low relative humidity. This atmospheric dryness recorded during the trial compounded the effect of the applied water deficit. Continuous water deficit can occur in a natural environment with low but regular rainfall during all or part of the crop cycle. This phenomenon is quite regular in the tropics.

In the four varieties and six descendants of sesame studied, plant height decreased compared to controls when water stress was moderate (watering every other day at ¾ of field capacity). This decrease was more important under severe water stress (watering every other day at ¼ of the field capacity). This reduction in height can be explained by both the reduction in assimilative surfaces and a slowdown in photosynthesis related to the water deficit (Badiel et al. 2017; Kihindo, 2016). Diallo (2009) reported that continuous water deficit markedly reduced the growth and development of rice. This is because the imposition of water stress on the entire developmental cycle of the plant causes a permanent lack of water. This results in insufficient hydromineral nutrition and a reduction in radial and vertical growth and development. When the water deficit is severe and permanent, it has a more significant and negative impact on the growth and development of plants. The varieties Wollega and Humera were the most affected by the effect of the permanent water deficit, whether it was severe or moderate. On the other hand, the variety S-42 and the descendants (especially SMK-2) were less affected.

The relative water content of the four varieties and six progeny decreased as the water deficit increased. All accessions were sensitive, but differently, to variations in soil water availability. This may be attributed either to differences among accessions in the ability of roots to absorb water from the soil, or to the ability of stomatal control of water loss through evaporative surfaces. The water supply capacity of the plant has a key importance on stomatal function (Zufferey et al. 2011). Although abcissic acid appears to be a major player in stomatal control under water stress, leaf water potential is also involved (Tardieu and Simonneau 1998; Comstock 2002). The decrease in relative water content is more rapid in susceptible varieties than in resistant varieties. This can also be attributed to differences between accessions in the power of accumulation of metabolites and osmotic adjustment for the maintenance of cell turgor and physiological activities (Bayoumi et al. 2008). Boutraa et al. (2010). Thameur et al. (2011) and Huseynova (2012). Thameur et al. (2012) showed that genotypes that maintain high relative water content in the presence of water stress are tolerant genotypes. As such the SMK-6 descendant was found to be the most tolerant in contrast to the Humera variety which was the least tolerant to severe and continuous water insufficiency.

Total chlorophyll content was higher in the water-stressed plants compared to the unstressed (control) plants. This increase was greater in the severely stressed plants than in the moderately stressed plants. The increase in total chlorophyll content in these sesame accessions can be attributed to an osmotic adjustment that limited the reduction in cell turgor pressure and allowed protection of membranes and enzyme systems (Belhassen et al. 1995). This maintenance of cell turgor, which is the basis for the preservation of several physiological functions, prevented the closure of stomata, thus enhancing photosynthesis by increasing the chlorophyll content (Bammoun 1997).

Moderate water stress caused an increase in leaf sodium, potassium and magnesium content in most plants of the stressed accessions compared to unstressed plants and this increase was greater under severe stress. These results suggest that the intensification of the water deficit is accompanied by a progressive accumulation of these mineral elements by the plants of these sesame accessions. These different mineral elements are essential for the normal growth and development of the plant and they also contribute to the different resistance mechanisms to water deficit developed by the plants (Zaid 2006). Although potassium is not a constituent element of carbohydrates, lipids or proteins, it acts as an activator of different enzymes. It increases cell pressure, regulates water economy in the plant, reduces evaporation and thus increases drought resistance (Zaid 2006).

Potassium is the main ion in cytoplasmic solutions because of its fundamental roles in passive and active transmembrane exchange processes in cells and in improving the efficiency of chlorophyll assimilation (Zaid 2006). It is known that magnesium is a constituent of chlorophyll, it promotes its synthesis and activates enzymes, particularly those responsible for protein synthesis.

Sodium (Na) accumulation in leaves can cause toxicity in glycophytes (Shabala et al. 1998; Yousfi et al. 2010). This form of excess Na sequestration in leaves indicates the lowering of osmotic potential (Morant-Manceau et al. 2004). High potassium (K) levels lead to a relatively high K/Na ratio that influences photosynthesis, a key ratio for plant tolerance to drought (Munns et al. 2006). From this point of view, it could be said that the four varieties and six descendants of sesame responded well to the water deficit by accumulating more of these minerals with the intensity of the stress.

Both severe and moderate water stress negatively affected capsule yield per plant, number of seeds per capsule and seed mass. In all accessions, moderate water stress caused an average reduction in capsule yield of about 35%. The variety Wollega was the most vulnerable with a reduction of more than 60%, contrary to the descendant SMK-2 in which the reduction was only about 20%. Severe water stress caused an average overall reduction of about 58% in all varieties and descendants. At this level, Wollega was also the most vulnerable variety with an average reduction of 84%, while SMK-2, SMK-4 and SMK-5 only showed reductions of about 46%. These results corroborate those of many other authors including Tantawy et al. (2007), Hassanzadeh et al. (2009) and Compaoré (2011) on sesame and Mawuli et al. (2014) on cowpea. Severe water stress affects factors related to seed formation including photosynthesis and assimilate translocation. Photosynthesis, the primary factor of total production is often disrupted by water deficit which induces stomatal closure. The impact of water deficit depends on its intensity, the phenological stage during which it occurs but also on the genotype of the plant (Sawadogo et al. 2006). Moutinho-Pereira et al (2004) attributed most of the yield losses under dry conditions to the decrease in photosynthesis alone (Moutinho-Pereira et al.

2004). However, this causal link remains difficult to establish. For example, shoot growth (especially secondary) is rapidly affected by very moderate levels of water deficit while photosynthesis is still little or not modified (Lebon et al. 2006) and photosynthesis products tend to accumulate (Cramer et al. 2013).

Conclusion

Adaptation to water deficit resulted in reduced plant growth and development in all sesame varieties and descendants studied. The more severe the stress, the less growth and development. Regardless of sesame variety or descendant, chlorophyll content increased with the intensity of water deficit. Plants of all four varieties and six descendants proved to be resistant to the lack of water by maintaining leaf water contents at relatively sufficient levels to ensure their minimum development. Moderate water deficit caused an increase in leaf sodium, potassium and magnesium contents in most plants of the accessions and this increase was even greater under the severe deficit. The water deficit, whether severe or moderate, negatively affected the yield of capsules per plant, the number of seeds per capsule and seed weight. In summary, it can be stated that S-42 and the descendants are more tolerant of continuous water deficit compared to Wollega, Humera and 32-15.

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