Macrothink Institute™

Environmental Management and Sustainable Development
ISSN 2164-7682
2016, Vol. 5, No. 2

Effect of Salinity Levels (NaCl) on Yield, Yield Components and Quality Content of Sesame (*Sesamum Indicum* L.) Cultivars

Helale Bahrami (corresponding author)

Department of Agronomy, College of Agriculture

Isfahan University of Technology, Isfahan, Iran

Tel: 61-434-252-433 E-mail: helale.bahrami@gmail.com

Amir Ostadi Jafari

Department of Agronomy, School of Agriculture

Ferdowsi University of Mashhad, Mashhad, Iran

E-mail: amir.ostadi.au@gmail.com

Jamshid Razmjoo

Department of Agronomy, College of Agriculture

Isfahan University of Technology, Isfahan, Iran

E-mail: krazmjoo@cc.iut.ac.ir

Received: April 17, 2016 Accepted: May 7, 2016

doi:10.5296/emsd.v5i2.9852 URL: http://dx.doi.org/10.5296/emsd.v5i2.9852

Abstract

Seeds of ten sesame cultivars (Karaj, Darab, Safiabad, Jiroft, Borazjan, Yellow-white, Felestin, Ultan, Isfahan and Abpakhsh) were sown into soil filled pots in 2008 and 2009. Pots were watered with six levels of salts (0.0038 (tap water as control), 4.89, 8.61, 10.5, 14.54, 17.74 ds.m^{-1} NaCl) until full maturity. Plant height, root and shoot dry weight, yield and yield components, seed oil and protein contents of cultivars were measured. Increasing salinity caused significant reduction in plant height, root and shoot dry weight, yield and yield components, seed oil and protein contents of all cultivars. However, there were significant differences among the cultivars for measured traits for each salinity level. Based on seed oil yield data, Safiabad and Kraj at 0.0038ds.m^{-1}, Safiabad and Ultan at 4.89ds.m^{-1}, Ultan, Safiabad and Darab at 8.61 salinity levels were the superior cultivars. High variability in tolerance to salinity among the tested sesame cultivars suggests that selection of more salt tolerant cultivars for planting or breeding purposes is possible.

Highlights

Effects of contrasting salinity levels (0.0038 (tap water as control), 4.89, 8.61, 10.5, 14.54, 17.74 ds.m^{-1}NaCl) on sesame cultivars were tested. Salinity reduced plant growth and yield and seed oil and protein contents. However, there were significant differences among the cultivars for measured traits for each salinity level.

Keywords: Dry weight, Oil content, Protein content, Salinity stress

1. Introduction

Sesame (*Sesamum indicum* L.) is an important oil seed crop which is widely cultivated in many parts of the world (Morris, 2002). Sesame is widely used in food and in the nutraceutical, and pharmaceutical industry in many countries due to its high oil content, antioxidant and protein contents (Morris, 2002; Koca et al., 2007). Moreover, its amino acid composition is identical to meat, thus its seed protein is superior to that of grain legumes and other oil seed crops (Yahya, 1998). In addition, sesame oil contains sesamin and sesaminol lignans which plays an important role in the oxidative stability and antioxidative activity (Xu et al., 2005). Sesame is used for preparing perfumes and cologne and sesame oil is used as a solvent, oleaginous for skin softener, drugs and in margarine and soap manufacturing (Morris, 2002). Sesame also is used for cancer, cold, diarrhea and cough treatments in many countries (Morris, 2002).

Sesame is cultivated in dry and semi-dry regions of the world where soil and/ or water salinization is common. This crop was reported to tolerate moderately saline conditions (Yousef et al., 1972). Yahya (1998) in several salt culture solutions at seedling stage found that salinity reduced sesame growth. Mahmood et al. (2003) reported that salinity reduced growth, yield, yield components and oil content, but increased protein content of sesame cultivars. However, they found a considerable degree of variability between cultivars for their salinity tolerance. Ramirez et al. (2005) evaluated sesame genotypes for their salt tolerance at germination, vegetative and maturity stages. Germination parameters, growth and yield of the genotypes increased under low salinity level, but decreased under high salinity level. They detected high variability in tolerance to salinity among the genotypes. Gaballah et al. (2007) also reported that low salinity level increased while high salinity level reduced growth parameters of sesame cultivars. The previous reports reviewed here showed that sesame cultivars were subject to salinity stress using sandy soil (Gaballah et al., 2007) and perlite (Koca et al., 2007).

However, to allow for a more realistic response to salt, using field soil is needed for practical use of cultivars under ordinary field soil. Therefore, research is needed for cultivation and selecting salt tolerance cultivars in ordinary soils.

Salt-tolerance sesame cultivars could be an option for salt affected areas. Therefore, identification and selection of the most salt tolerant sesame cultivars would be of great value for agriculture. The reports reviewed here and elsewhere suggest that there is not enough information regarding the effect of salinity level on growth and quality of sesame cultivars of different origin. The present study was initiated to investigate the influence of salinity levels on the yield, yield components and quality of sesame cultivars.

2. Materials and Methods

Seeds of ten sesame cultivars (Karaj (NW of Tehran), Darab (SE of Shiraz), Safiabad (SW of Ahwaz) Jiroft, Borazjan (NW of Bushehr), Isfahan and Abpakhsh (NE of Bushehr) from Central (Tehran), Fars, Khusitan, Kerman, Bushehr, Isfahan and Bushehr provinces, respectively and Ultan, from Russia Yellow-white from Nigeria and Felestin from Palestine) were obtained from Seed and Plant Improvement Institute (Iranian National Gene Bank), Karaj, Iran. Seeds were sterilized with 5% sodium hypochlorite for five min and washed with sterile distilled water 4 times. Then seeds were sown into the pots (40 cm height and 30 diameter filled with 10 kg agriculture soil (texture= clay loam, pH=7.5, N=0.06%, P=21 mg per kg, K= 195 mg per kg, bulk density=1.36 g cm^3, EC= 0.9 dsm^{-1}). Eight seeds were sown per pot and pots were put in the open space under natural sunlight on June 26, 2008 and June 20, 2009. The average minimum and maximum temperatures in 2008 were 18.9/36.9, 19.2/38.2, 14.5/33.6 and 11.3/27.3 °C and in 2009 were 18.8/30.6, 22.8/34.1, 19.9/32.9 and 16.1/29.7 during June, July, August and September, respectively. The average minimum and maximum relative humidity in 2008 were 11/46, 9/32, 8/30 and 11/41% and in 2009 were 10/58, 17/52, 14/53 and 14/56 during June, July, August and September, respectively. Pots were watered with tap water and seedlings were thinned down to four plants per pot. Thereafter, pots were watered with six levels of salts (0.0038 (tap water as control), 4.89, 8.61, 10.5, 14.54, 17.74 $ds.m^{-1}$ NaCl) until full maturity. The salinity levels were reached stepwise, with increments of NaCl, for acclimation to salinity. The initial EC level of the soil was maintained by flushing each pot with the required volume of corresponding treatment solution every 10 days. N fertilizer (200 g N per pot) in the form of urea added to the pots before planting (30% of 200 g N), 4 weeks after planting (30% of 200 g N) and 8 weeks after planting (40% of 200 g N) and about 1.5 L of treatment solution was applied to each pot at 3 day interval. Pots were arranged in a factorial experiment based on a randomized complete block design (RCBD) with four replications. At end of the experiment the EC of the soil for respected salinity levels were 3.9, 5.3, 8.3, 12, 14.6 and 18.4 $ds.m^{-1}$. At full maturity stage, capsules were harvested and number of capsule per plant, number of seeds per capsule, 1000-seed weight, seed yield, and seed protein and oil contents were determined. The seeds protein and oil contents were determined by NRI (Perten 8620 A). The plants were uprooted carefully and washed with distilled water. After recording the fresh masses of both shoots and roots, they were oven-dried at 75 °C for 48 h and dry weight was recorded. Data were analyzed using the MSTAT-C and ANOVA procedures of the SAS system (SAS, Ver 9.1). Comparisons with $P < 0.05$ were considered significantly different.

3. Results

3.1 Plant Height

Plant height was negatively affected by salinity (Table 1). Darab at 0.0038, 8.61 and 17.74 $ds.m^{-1}$ and on average, Safiabad at 8.61 $ds.m^{-1}$, Borazjan at 10.5 $ds.m^{-1}$ salinity levels had the highest height (Table 1). Mahmood et al. (2003) and Koca et al. (2007) also reported that salinity reduced sesame height and there was significant different between the cultivars for this trait. Their results were in accordance with ours. Gaballah et al. (2007) reported that low salinity level increased while high salinity level reduced sesame height and there were significant differences between the cultivars for this trait. Their results were not totally in accordance with ours perhaps due to differences between salinity level, plant genotypes and environmental conditions. In line with our results, reduction in safflower and canola heights was also reported by Bassil and Kaffka (2002) and Bybordy (2010), respectively. Reduction in the plant height could be due to drought stress caused by salt on water adjustment in plant tissues and cell enlargement as well as increase in leaf senescence and abscission (Tester & Davenport, 2003; Manivannan et al., 2007; Jaleel et al., 2008).

Table 1. Effects of salinity levels on plant height (cm) of sesame cultivars.

	Salinity level ($ds.m^{-2}$)						
Cultivars	0.0038	4.89	8.61	10.5	14.54	17.74	Mean
Karaj	64.7 c-f†	55.2 f-k	48.0 k-n	36.7 o-s	34.5 o-t	30.5 q-v	44.9 CD††
Darab	80.0 a	75.7 ab	62.7 c-g	47.5 k-n	41.2 m-p	12.5 yz	53.3 A
Borazjan	71.2 abc	70.7 abc	62.0 c-h	49.7 i-m	32.5 p-u	7.5 z	48.9 B
Safiabad	64.5 c-f	59.7 d-i	63.5 c-f	47.5 k-n	40.2 m-r	7.2 z	47.1 BCD
Jiroft	71.2 abc	70.7 abc	55.5 f-k	40.7 m-q	36.7 o-s	12.5 yz	47.9 BC
Yellow-white	52.0 h-l	49.5 i-m	33.2 p-u	26.7 s-w	15.5 xyz	9.5 z	31.1 G
Felestin	65.2 c-f	57.5 e-k	48.5 j-n	38.5 n-r	30.0 r-v	23.7 u-x	43.9 DE
Ultan	68.2 bcd	58.7 d-j	56.7 e-k	44.0 l-o	25.5 t-w	13.5 yz	44.5 CDE
Isfahan	58.7 d-j	50.2 i-m	36.2 o-s	35.0 o-t	33.7 o-u	20.0 wxy	39.0 F
Abpakhsh	66.0 b-e	52.5 g-l	44.0 l-o	33.5 p-u	26.5 s-w	22.2 v-y	40.8 EF
Mean	66.2 A	60.1 B	51.1 C	40.0 D	31.7 E	15.9 F	

†Means within columns and rows (interaction) with the same letters are not significantly different at the 5% level.

†† Means within column (main effect of cultivar) or row (main effect on salinity level) with the same letters are not significantly different at the 5% level.

3.2 Root and Shoot Dry Weights

Root dry weight reduced as salinity level increased. Ultan at 0.0038, Abpakhsh at 4.89, 10.5 and 14.54 $ds.m^{-1}$ and 17.74 $ds.m^{-1}$ and on average and Sefiabad at 170.9 mM salinity levels produced the highest root weight (Table 2). Increasing salinity also reduced shoot weight (Table 3). Though differences between the cultivars for each salinity level were not always statistically significant, Safiaba at 0.0038 $ds.m^{-1}$, Jiroft at 4.89 $ds.m^{-1}$ and Abpakhsh on average and at 8.61, 14.54 and 17.74 ds.m^{-1} salinity levels produced the highest shoot dry weight (Table 3). Shoot and root growth inhibition is a common response of plant to salt stress. Mahmood et al. (2003) and Ramireza et al. (2005) found that salinity reduced growth of sesame cultivars. They further showed that high variability in tolerance to salinity between the tested cultivars. Koca et al. (2007) reported that shoot and root of sesame cultivars reduced under an increasing salinity level; however, there were significant differences between the cultivars. They concluded that salt tolerant cultivars produced more root and shoot growth and antioxidative enzyme activities as compared with salt sensitive cultivars. Their results were in line with ours. However, Gaballah et al. (2007) showed that root and shoot weight of sesame cultivars were increased under moderate but reduced under high salt levels. They further showed that cultivars responded differently to salt stress. They concluded that stimulatory effect of moderate salinity level on growth of plant may be due to the improvement of the shoot osmotic status by increasing ion uptake. Their results were not totally in agreement with ours perhaps due differences in the salt levels and plant genotypes. Reduction in the plant shoot and root weights could be due to drought stress caused by salt on water adjustment in plant tissues and cell enlargement as well as increase in leaf senescence and abscission (Tester & Davenport, 2003; Manivannan et al., 2007; Jaleel et al., 2008).

Table 2. Effects of salinity levels on root dry weight (g per plant) of sesame cultivars.

	Salinity level (ds.m^{-2})						
Cultivars	0.0038	4.89	8.61	10.5	14.54	17.74	Mean
Karaj	3.0 b-e†	2.9 b-f	1.8 jkl	0.9 pq	0.5 rs	0.1 uv	1.5 C††
Darab	2.8 c-g	2.7 e-h	1.6 k-n	0.8 pqr	0.3 stu	0.0 tuv	1.4 D
Borazjan	2.6 fgh	2.1 ij	1.5 lmn	0.4 rst	0.3 s-v	0.0 v	1.1 E
Safiabad	3.2 b	3.0 b-e	2.4 hi	1.0 p	0.5 rs	0.0 v	1.7 B
Jiroft	2.5 gh	1.8 j-m	0.9 p	0.4 rst	0.2 s-v	0.0 v	1.0 F
Yellow-white	2.0 ij	1.6 k-n	0.9 p	0.4 stu	0.3 s-v	0.0 v	0.9 F
Felestin	3.2 b	2.7 e-h	1.6 k-n	0.5 rs	0.3 stu	0.0 v	1.4 D
Ultan	3.8 a	3.0 bcd	1.8 j-m	1.1 op	0.6 qrs	0.3 s-v	1.8 AB
Isfahan	2.8 d-g	2.4 hi	1.5 mn	0.9 pq	0.5 rs	0.1 uv	1.3 D
Abpakhsh	3.3 b	3.1 bc	1.9 jk	1.4 no	1.0 p	0.4 stu	1.8 A
Mean	2.9 A	2.5 B	1.6 C	0.8 D	0.4 E	0.1 F	

†Means within columns and rows (interaction) with the same letters are not significantly different at the 5% level.

†† Means within column (main effect of cultivar) or row (main effect of salinity level) with the same letters are not significantly different at the 5% level.

Table 3. Effects of salinity levels on shoot dry weight (g per plant) of sesame cultivars.

	Salinity level (ds.m^{-2})						
Cultivars	0.0038	4.89	8.61	10.5	14.54	17.74	Mean
Karaj	17.7 bcd†	14.7 hi	8.1 qrs	6.1 tuv	5.0 uvw	1.1 z	8.8 E††
Darab	18.9 ab	14.6 hj	9.9 opq	7.9 rst	6.1 tuv	0.5 z	9.6 D
Borazjan	16.3 d-h	10.6 mno	8.5 pqr	6.5 s-v	3.7 wx	0.7 z	7.7 FG
Safiabad	20.1 a	15.2 ghi	11.6 k-o	8.1 qrs	4.7 u-x	1.4 yz	0.1 CD
Jiroft	18.4 abc	17.4 b-e	12.3 j-m	12.3 nop	4.7 vwx	0.4 z	10.6 BC
Yellow-white	15.8 d-i	11.3 k-o	8.3 qrs	6.3 s-v	3.1 xy	0.4 z	7.5 G
Felestin	18.8 ab	16.9 c-g	11.9 k-n	7.7 rst	3.7 wx	0.5 z	9.9 CD
Ultan	18.9 ab	17.3 b-f	12.7 jkl	8.6 pqr	7.4 rst	1.6 yz	11.1 AB
Isfahan	15.7 e-i	12.7 jk	10.8 l-o	6.6 r-u	3.6 wx	0.8 z	8.3 EF
Abpakhsh	16.7 c-g	15.5 f-i	13.8 ij	11.6 k-o	7.8 rst	3.1 wxy	11.4 A
Mean	17.7 A	14.6 B	10.8 C	8.0 D	4.9 E	1.0 F	

†Means within columns and rows (interaction) with the same letters are not significantly different at the 5% level.

†† Means within column (main effect of cultivar) or row (main effect of salinity level) with the same letters are not significantly different at the 5% level.

3.3 Number of Capsule per Plant

On average and for each cultivar, as salinity level increased, the number of capsule per plant decreased (Table 4). Karaj on average and at 0.0038 and 4.89 ds.m^{-1}, Felestin at 17.74 ds.m^{-1} and Safiabad at 8.61, 10.5, and 14.54 ds.m^{-1} salinity levels produced the highest number of capsules per plant (Table 4). Gaballah et al. (2007) also reported that number of capsules per plant of sesame cultivars were increased under moderate but reduced under high salt levels. They further showed that cultivars responded differently to salt stress for this trait. Bybordy (2010) also showed that the numbers of capsules per plant of canola were reduced as salinity level increased.

Reduction in the number of capsule per plant was perhaps due to reduction in the plant height and roots and shoots growth as indicated in Tables 1-3.

Table 4. Effects of salinity levels on number of capsules per plant of sesame cultivars.

	Salinity level (ds.m^{-2})						
Cultivars	0.0038	4.89	8.61	10.5	14.54	17.74	Mean
Karaj	33.3 a†	25.5 bc	14.6 d-g	7.5 m-p	5.0 p-u	2.6 t-w	14.7 A††
Darab	24.3 bc	16.5 de	10.67 h-m	5.6 o-u	3.4 r-w	0.0 w	10.1 C
Borazjan	17.4 d	12.0 f-j	10.87 h-l	9.0 j-o	5.7 o-u	0.0 w	9.2 CDE
Safiabad	25.8 b	22.1 c	14.94 def	9.8 i-n	6.0 o-t	0.0 w	13.1 B
Jiroft	13.4 e-h	11.1 f-k	7.76 l-p	5.6 o-u	3.1 r-v	1.0 vw	7.0 F
Yellow-white	12.5 f-i	10.5 h-m	8.41 k-p	6.5 n-r	3.3 r-v	0.0 w	6.9 F
Felestin	16.6 de	14.2 def	11.79 f-k	6.5 n-r	5.2 p-u	2.9 s-w	9.6 CD

Ultan	17.7 d	14.5 d-g	11.26 g-k	6.4 o-s	2.5 uvw	0.0 w	8.7 DE
Isfahan	14.7 def	11.2 g-k	8.91 j-o	7.1 n-q	5.6 o-u	0.7 vw	8.0 EF
Abpakhsh	16.2 de	12.1 f-j	7.42 m-p	5.0 p-u	3.7 q-v	0.7 vw	7.4 F
Mean	19.2 A	14.9 B	10.6 C	6.5 D	4.4 E	0.7 F	

†Means within columns and rows (interaction) with the same letters are not significantly different at the 5% level.

†† Means within column (main effect of cultivar) or row (main effect of salinity level) with the same letters are not significantly different at the 5% level.

3.4 Number of Seeds per Capsule

The number of seeds per capsule on average and for each cultivar reduced, as salinity level increased (Table 5). Jiroft, Darab, Borazjan and Ultan on average, Jiroft at 0.0038 and 4.89 ds.m^{-1}, Jiroft and Darab at 8.61 ds.m^{-1}, Darab at 10.5 ds.m^{-1}, Safiabad at 14.54 ds.m^{-1} and Felestin at 17.74 ds.m^{-1} salinity levels produced the highest number of seeds per capsule (Table 4). In line with our results, Francois (1996) reported that the number seeds per head of sunflower cultivars were reduced with increasing salinity level. Bybordy (2010) also reported that the numbers of seeds per capsule of canola were reduced under salinity. The decrease in the number of seeds per capsule was perhaps due to reduction in the plant height and roots and shoots growth as indicated in Tables 1-3.

Table 5. Effects of salinity levels on number of seeds per capsules of sesame cultivars.

Cultivars	Salinity level (ds.m^{-2})						Mean
	0.0038	4.89	8.61	10.5	14.54	17.74	
Karaj	56.0 b-h†	52.0 d-i	49.0 e-i	39.0 h-l	30.0 j-n	14.0 n-q	40.0 C††
Darab	72.0 abc	72.0 abc	72.0 abc	72.0 abc	36.0 i-m	0.0 q	54.0 A
Borazjan	72.0 abc	72.0 abc	68.0 a-e	64.0 a-g	48.0 f-j	0.0 q	54.0 A
Safiabad	72.0 abc	64.0 a-g	60.0 a-g	52.0 d-i	51.0 d-i	0.0 q	49.8 AB
Jiroft	78.0 a	74.0 ab	72.0 abc	52.0 d-i	39.0 h-l	11.0 opq	54.3 A
Yellow-white	64.0 a-g	64.0 a-g	59.0 a-g	51.0 d-i	36.0 i-m	0.0 q	45.6 BC
Felestin	72.0 abc	68.0 a-e	64.0 a-g	45.0 g-k	48.0 f-j	28.0 k-o	54.1 A
Ultan	72.0 abc	72.0 abc	68.0 a-e	67.0 a-f	24.0 l-p	0.0 q	50.5 AB
Isfahan	53.0 c-i	52.0 d-i	49.0 e-i	49.0 e-i	48.0 f-j	8.0 pq	43.1 C
Abpakhsh	69.0 a-d	68.0 a-e	67.0 a-f	56.0 b-h	40.0 h-l	16.0 m-p	52.5 AB
Mean	68.0 A	65.8 AB	62.8 B	54.7 C	40.0 D	7.6 E	

†Means within columns and rows (interaction) with the same letters are not significantly different at the 5% level.

†† Means within column (main effect of cultivar) or row (main effect of salinity level) with the same letters are not significantly different at the 5% level.

3.5 1000-Seed Weight

Safiabad produced the maximum 1000-seed weight at all salinity levels and on average except at the 17.74 ds.m^{-1} salinity level where Yellow-white had highest 1000-seed weight (Table 6). In line with our results, Francois (1996) reported that 100-seed weight of sunflower cultivars was reduced with increasing salinity level. The reduction in the 1000-seeds weight was perhaps due to a decrease in plant height and roots and shoot growth as indicated in Tables 1-3.

Table 6. Effects of salinity levels on 1000-seed weight of sesame cultivars.

Cultivars	Salinity level (ds.m^{-2})						Mean
	0.0038	4.89	8.61	10	14.54	17.74	
Karaj	2.0 c-k†	2.0 e-l	1.2 n-r	1.2 o-r	0.9 r-u	0.6 t-w	1.3 C††
Darab	2.1 b-i	1.9 g-l	1.8 h-m	1.7 i-n	0.7 s-v	0.0 x	1.4 C
Borazjan	2.5 a-e	2.4 a-g	2.1 b-j	1.8 h-m	1.2 o-r	0.0 x	1.7 AB
Safiabad	2.7 a	2.4 a-f	2.1 b-j	1.8 h-l	1.8 h-m	0.0 x	1.8 A
Jiroft	2.7 a	2.2 a-h	2.0 d-k	1.8 h-m	0.9 r-u	0.2 wx	1.6 B
Yellow-white	2.5 abc	2.1 b-j	1.6 k-p	1.3 n-r	0.5 t-w	0.4 x	1.4 C
Felestin	2.1 b-j	1.9 g-l	1.6 j-o	0.9 rst	1.0 qrs	0.4 v-x	1.3 C
Ultan	2.6 ab	2.5 a-e	1.9 g-l	1.5 l-q	0.5 t-w	0.0 x	1.5 BC
Isfahan	2.5 a-d	1.9 g-l	1.6 k-p	1.5 l-q	1.3 m-r	0.2 wx	1.5 BC
Abpakhsh	2.5 a-e	2.0 f-l	1.8 h-l	1.1 p-s	1.1 o-s	0.4 u-x	1.4 C
Mean	2.47 A	2.1 B	1.8 C	1.5 D	1.0 E	0.1 F	

†Means within columns and row (interaction) with the same letters are not significantly different at the 5% level.

†† Means within column (main effect of cultivar) or row (main effect of salinity level) with the same letters are not significantly different at the 5% level.

3.6 Seed Yield

Though seed yield reduced as salinity level increased, there were significant differences among the cultivars for their seed yield (Table 7). Safiabad on average and at 0.0038, 4.89, 8.61 and 14.54 ds.m^{-1} and Borazjan at 10.5 ds.m^{-1} salinity levels produced the highest yield. Yahya (1998) and Ramirez et al. (2005) found that salinity reduced seed yield of sesame cultivars. They further showed high variability in tolerance to salinity between the tested cultivars. Also in line with our results, Francois (1996) and Bybordy (2010) reported that seed yield of sunflower and canola cultivars were reduced with increasing salinity level, respectively. Moreover, Hebbara et al. (1992) and Hebbara et al. (2003), also in line with our results reported that yield of all of sunflower cultivars decreased as salinity levels increased in the field. In the pot experiment, Hebbara et al. (2003) showed that leaf temperature, stomata conductance and transpiration rate reduced, but osmotic potential increased under salinity. They concluded that a large genetic variation existed among tested cultivars to salinity and they responded differently to salinity. They further showed that various tolerance mechanisms were operating in promising cultivars. Decrease in seed yield was perhaps due to reduction in the plant height, roots and shoots growth, number of capsules per plant, number of seeds per plant and 1000 –seed weight as indicated in Tables 1-5.

Table 7. Effects of salinity levels on seed yield (g per plant) of sesame cultivars.

Cultivars	Salinity level ($ds.m^{-2}$)						Mean
	0.0038	4.89	8.61	10.5	14.54	17.74	
Karaj	3.9 b†	2.6 fg	0.9 q-u	0.3 w-z	0.1 yz	0.0 z	1.3 B††
Darab	3.8 bc	2.3 gh	1.3 m-p	0.7 s-w	0.0 z	0.0 z	1.3 B
Borazjan	3.1 de	2.1 hi	1.5 k-n	1.0 p-s	0.3 t-x	0.0 z	1.3 B
Safiabad	5.1 a	3.5 cd	1.9 ijk	0.9 q-t	0.5 t-w	0.0 z	2.0 A
Jiroft	2.8 ef	1.8 i-l	1.1 o-r	0.5 t-y	0.1 yz	≈ 0.0 z	1.1 C
Yellow-white	2.0 hi	1.4 m-p	0.8 r-v	0.4 v-z	0.0 z	0.0 z	0.8 D
Felestin	2.5 fg	1.8 i-l	1.2 n-p	0.2 w-z	0.2 xyz	0.0 z	1.0 C
Ultan	3.3 d	2.6 fg	1.5 l-o	0.6 t-x	0.0 z	0.0 z	1.3 B
Isfahan	1.9 hij	1.1 o-r	0.7 s-w	0.5 u-y	0.3 w-z	≈ 0.0 z	0.7 D
Abpakhsh	2.8 ef	1.6 j-m	0.9 q-u	0.3 w-z	0.1 yz	≈ 0.0 z	0.9 C
Mean	3.1 A	2.1 B	1.2 C	0.6 D	0.2 E	0.0 F	1.2

†Means within columns and rows (interaction) with the same letters are not significantly different at the 5% level.

†† Means within column (main effect of cultivar) or row (main effect of salinity level) with the same letters are not significantly different at the 5% level.

3.7 Oil Content

Ultan produced the highest oil content on average and at 0.0038, 4.89, 17.74 $ds.m^{-1}$ salinity levels (Table 8). On the other hand, Darab at 8.61, 10.5 $ds.m^{-1}$ and Felestin at 14.54 $ds.m^{-1}$ salinity levels had the highest oil contents. A sharp reduction in oil contents of Borazjan and Jiroft cultivars occurred at 8.61 $ds.m^{-1}$ indicating susceptibility of these cultivars at this salinity level and several folds reduction in oil contents of other cultivars except Darab and Ultan were noted at 10.5 $ds.m^{-1}$ salinity level. These results showed that irrigating sesame cultivars beyond this salinity levels may not produce acceptable seed oil content. On average, reduction in oil content was 11, 47, 66, 85 and 97% under 4.89, 8.61, 10.5, 14.54 and 17.74 $ds.m^{-1}$ salinity level, respectively. Mahmood et al. (2003) also reported that oil content of sesame cultivars was reduced under the salt stress, but reduction was less in salt tolerant cultivars. These results are generally in line with ours. Gaballah et al. (2007) reported that oil content of sesame cultivars were increased under moderate but reduced under high salt levels. They further showed that cultivars responded differently to salt stress for this trait. In contrast with our results, Francois (1996) reported that oil content of two cultivars of sunflower was not significantly affected by salinity; oil content of the third cultivar was slightly reduced. Bassil and Kaffka (2002) also reported that oil content of safflower was not adversely affected by salinity. The contrasting results could be due to salinity level, climate, soil conditions, cultural practices and plant species. Reduction in seed oil content was likely due to reduction in growth parameters, yield and yield components as indicated in Tables 1-7.

Though we did not determine the hull percentage of the seeds, decreases in oil content could be also due to increases in hull percentage caused by enhanced physiological maturity under salt stress as reported by Francois and Bernstein (1964). Oil content of the cultivars ranged from 39.7 to 50.6% under control condition. The ranges of 37 to 63% oil contents for sesame cultivars were reported by others (Khattab and Khidir, 1970; Dhawan et al., 1972; Mahmood et al., 2003). The results showed that the range of oil content of our cultivars was within the ranges reported by others.

Table 8. Effects of salinity levels on oil content (%) of sesame cultivars.

Cultivars	Salinity level (ds.m^{-2})						Mean
	0.0038	4.89	8.61	10.5	14.54	17.74	
Karaj	47.4 a-d†	38.1 ghi	23.1 lm	6.9 p-s	0.7 s	0.6 s	19.4 D††
Darab	47.4 ab	46.8 b-g	40.7 f-i	39.2 jk	3.6 qrs	0.0 s	28.4 B
Borazjan	40.1 e-i	35.6 hij	5.9 qrs	3.5 qrs	0.0 s	0.0 s	14.2 F
Safiabad	39.3 f-i	36.7 ghi	25.0 klm	15.6 no	2.4 rs	0.0 s	19.9 D
Jiroft	41.7 d-h	38.4 ghi	8.5 pqr	5.9 qrs	5.4 qrs	0.0 s	16.7 E
Yellow-white	47.6 a-d	36.6 f-i	27.9 ij	2.1 opq	0.0 s	0.0 s	26.0 C
Felestin	47.6 a-d	43.3 c-g	29.2 jkl	19.7 mn	13.4 nop	3.5 qrs	25.5 C
Oultan	50.6 a	49.2 abc	37.6 ghi	35.3 hij	25.6 klm	0.0 s	33.6 A
Isfahan	45.5 b-f	38.0 ghi	19.3 mn	10.5 opq	4.9 qrs	0.0 s	19.7 D
Abpakhsh	47.9 a-d	46.8 a-e	24.9 klm	16.5 no	5.0 qrs	2.6 rs	24.0 C
Mean	46.1 A	40.9 B	24.4 C	15.6 D	6.8 E	1.1 F	

†Means within columns and rows (interaction) with the same letters are not significantly different at the 5% level.

†† Means within column (main effect of cultivar) or row (main effect of salinity level) with the same letters are not significantly different at the 5% level.

3.8 Protein Content

Protein content of the cultivars ranged from 21.4 to 23.5%, however, protein content reduced with increasing salinity level (Table 9). Desphande et al. (1996) reported that Asian and African sesame cultivars contained 22 to 25% protein. Thus, protein content of tested cultivars was within the range of Asian and African cultivars. On average and at 341.9 ds.m^{-1} salinity level, Ultan produced the highest protein content. However, the highest protein content was recorded in Felestin at 8.61 and 10.5 ds.m^{-1} and Karaj at 0.0038 and 4.89 ds.m^{-1} salinity levels. On average, protein content reduced 0.03, 0.08, 12, 21 and 84% under 4.89, 8.61, 10.5, 14.54 and 17.74 ds.m^{-1} salinity levels, respectively. Mahmood et al. (2003) also reported that protein content of sesame cultivars were reduced under the salt stress, but reduction was less in salt tolerant cultivars. Reduction in seed protein content in our experiment was likely due to reduction in growth parameters, yield and yield components as indicated in Tables 1-7. Though we did not determine the hull percentage of the seeds, decreased in protein content could be also due to an increase in hull percentage caused by enhanced physiological maturity under salt stress as reported by Francois & Bernstein (1964).

In addition, reduction in protein content could be to reduction in K^+ content by Na^+ under salinity stress since protein synthesis requires high concentration of K^+, owing to the K^+ requirements for the binding of tRNA to ribosomes (Blaha, et al., 2000).

Table 9. Effects of salinity levels on protein content (%) of sesame cultivars.

Cultivars	Salinity level ($ds.m^{-2}$)						Mean
	0.0038	4.89	8.61	10.5	14.54	17.74	
Karaj	23.5 ab†	23.6 a	21.1 a-g	20.0 a-j	18.8 a-j	8.8 no	17.9 B††
Darab	20.0 a-j	19.4 a-j	17.9 e-j	17.0 g-j	15.3 jk	0.0 p	15.9 C
Borazjan	21.4 a-g	20.0 a-j	19.0 a-j	18.1 c-j	16.1 h-k	0.0 p	15.8 C
Safiabad	23.0 abc	20.5 a-i	20.4 a-i	19.0 a-j	15.9 ijk	0.0 p	17.0 BC
Jiroft	20.3 a-i	20.0 a-j	18.2 c-j	17.6 f-j	15.3 jk	3.8 op	15.9 C
Yellow-white	20.5 a-i	20.3 a-i	19.2 a-j	19.1 a-j	12.5 kl	3.3 p	15.3 C
Felestin	22.8 a-d	22.2 ab	22.1 a-f	20.9 a-h	19.9 a-j	2.9 op	18.7 AB
Oultan	23.3 ab	22.7 a-e	21.7 a-g	22.0 a-f	20.5 a-i	0.0 p	20.2 A
Isfahan	20.7 a-i	19.1 a-j	18.7 b-j	17.9 d-j	17.4 f-j	11.0 lm	15.7 C
Abpakhsh	20.9 a-g	21.8 a-g	19.8 a-j	19.0 a-j	19.0 a-j	8.0 mn	18.3 B
Mean	21.7 A	21.1 B	19.9 B	19.1 B	17.2 C	3.5 D	

†Means within columns and rows (interaction) with the same letters are not significantly different at the 5% level.

†† Means within column (main effect of cultivar) or row (main effect of salinity level) with the same letters are not significantly different at the 5% level.

4. Discussion

In saline environments, NaCl is often the most injurious and predominant salt. Salt stress causes a variety of negative consequences. Salt causes ionic imbalances because Na^+ and Cl^- increase, whereas K^+, Ca^+, $NO3^-$ and P reduce under salinity condition (Yahya, 1998; Khan et al., 2000; Tester & Davenport, 2003; Jaleel et al., 2008). That is due to the competition of Na and Cl with other ions in the uptake (Bhandal & Malik, 1988; Aziz & Khan, 2001). Moreover, salinity has deleterious effect on many cellular systems due to excess Na and Cl ions. Metabolic toxicity of Na is largely caused by competition with K for binding sites of protein components essential for cellular process where Na cannot substitute the role of K (Kook et al, 2009). Salinity also induces reduction in chemical activity of water causing a loss of cell turgor which inflicts hyper osmotic shock on plants. Moreover, salinity causes lesser availability of nutrients along with lower translocation of photosynthesis from source to sink area under salt stress as suggested by Manivannan et al. (2007), Sankar et al. (2007) and Farooq et al. (2009). In addition, salinity was reported that caused reduction in protein synthesis, water uptake, chlorophyll content, oxygen evolution, carbon fixation and photosynthesis (Srivastava et al., 2008). Consequently, salinity causes ionic imbalance, has deleterious effect on cellular system and osmotic stress, thus reducing protein synthesis, chlorophyll content, photosynthetic rate, nutrient and water availability. Therefore, reduction in sesame height, yield components, seed yield and oil and protein contents under salt could be due to a decrease in cell division, enlargement, differentiation and growth, wilting and closure of stomata caused by osmotically driven removal of water from cells and reducing water uptake by roots as result of above mentioned effects of salinity (Flowers et al., 1991; Tester & Davenport, 2003.

5. Conclusion

Sesame response to increasing salinity included reduced plant height, root and shoot growth, yield components, seed yield, and seed protein and oil contents, but reduction in oil content was more than protein content.

High variability in tolerance to salinity among the tested sesame cultivars was observed indicating that selection of more salt tolerance cultivar for planting or breeding purposes is possible.

Based on oil yield data (seed yield x oil percent), Safiabad and Kraj at 0.0038 $ds.m^{-1}$, Safiabad and Ultan at 4.89 $ds.m^{-1}$, Ultan Safiabad and Darab at 8.61 $ds.m^{-1}$ salinity levels were superior cultivars.

At the 10.5 $ds.m^{-1}$ salinity levels or higher, oil yield of all cultivars were too low suggesting that beyond this salinity level cultivation of these cultivars may not be possible.

Acknowledgement

The authors are grateful to Mrs. A. M. Rice of Columbus, Ohio, USA for editing the manuscript.

References

Aziz, I., & Khan, M. A. (2001). Experimental assessment of salinity tolerance of Ceriops tagal seedlings and spalling from the Indus delta, Pakistan. *Aquatic Botany, 70*, 259-268. http://dx.doi.org/10.1016/S0304-3770(01)00160-7

Bhandal, I. S., & Malik, C. P. (1988). Potassium estimation, uptake and its role in the physiology and metabolism of flowering plants. *International Review of Cytology, 110*, 205-254. http://dx.doi.org/10.1016/S0074-7696(08)61851-3

Bassil, E. S., & Kaffka, S. R. (2002). Response of safflower (*Carthamus tinctorius* L.) to saline soils and irrigation: II. Crop response to salinity. *Agricultural Water Management, 54*, 67-80. http://dx.doi.org/10.1016/S0378-3774(01)00148-2

Blaha, G., Stelzl, U., Spahn, C. M. T., Agrawal, R. K., Frank, J., & Nierhaus, K. H. (2000). Preparation of functional ribosomal complex and effect of buffer conditions on tRNA position observed by cryoelectron microscopy. *Methods in Enzymology, 317*, 292-309. http://dx.doi.org/10.1016/S0076-6879(00)17021-1

Bybordy, A. (2010). Effect of salinity on yield and components characters in canola (*Brassica napus* L.) cultivars. *Notulae Scientia Biologicae, 2*, 81-83.

Desphande, S. S., & Salunkhe, D. K. (1996). Sesame oil. In: *Bailey's Industrial Oil and Fat*

Products. (Eds YH Hui). New York: International publication. 457-497

Dhawan, S., Singhvi, S. C., & Silmot, M. M. (1972). Studies in the quality of sesamum seed and oil. 1. Varietal differences in the quantity and quality of oil. *Journal of Food Science and Technology, 9*, 23-25.

Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., & Basra, S. M. A. (2009). Plant drought stress: effects, mechanisms and management. *Agronomy for Sustainable Development, 29*, 185-212. http://dx.doi.org/10.1051/agro:2008021

Flowers, T. J., Hajibaghri, M. A., & Yeo, A. R. (1991). Ion accumulation in the cell walls of rice plants growing under saline conditions-evidence for the Oretli hypothesis. *Plant, Cell and Environment, 4*, 319-325. http://dx.doi.org/10.1111/j.1365-3040.1991.tb01507.x

Francois, L. E., & Bernstein, L. (1964). Salt tolerance of safflower. *Agronomy Journal, 54*, 38-40. http://dx.doi.org/10.2134/agronj1964.00021962005600010012x

Francois, L. E. (1996). Salinity effects on four sunflower hybrids. *Agronomy Journal, 88*, 215-219. http://dx.doi.org/10.2134/agronj1996.00021962008800020016x

Gaballah, M. S., Abu Leila, B., El-Zeiny, H. A., & Khalil, S. (2007). Estimating the performance of salt-stressed sesame plant treated with antitranspirant. *Journal of Applied Sciences Research, 9*, 811-817.

Hebbara, M., Vishwanath, D. P., Naganagoud, A., Basavaraj, B. (1992). Interrelationship between soil salinity and crop yields on vertisol. *Journal of the Indian Society of Soil Science, 40*, 888-889.

Hebbara, M., Rajakkumar, G. R., Ravishankar, G., Raghavaiah, C. V. (2003). Effect of salinity stress on seed yield through physiological parameters in sunflower genotypes. *Helia, 26*, 155-160. http://dx.doi.org/10.2298/HEL0339155H

Jaleel, C. A., Gopi, R., Manivannan, P., & Panneveerselvam, R. (2008). Soil salinity alters the morphology in *carthamus roseus* and its effects on endogenous mineral constituents. EurAsia. *Journal of Biosciences, 2*, 18-25.

Khan, M. A., Ungar, I. A., Showalter, A. M. (2000). Effect of salinity on growth, water relations and ion accumulation of the subtropical perennial halophyte, *Atriplwx griffithii* var *stocksii*. *Annals of Botany, 85*, 225-232. http://dx.doi.org/10.1006/anbo.1999.1022

Khattab, H. A., & Khidir, M. O. (1970). Oil and protein content of local sesame types. *Journal of Food Science and Technology, 2*, 8-10.

Koca, H., Bor, M., Ozdemir, F., & Turkan, I. (2007). The effect of salt stress on lipid peroxidation, antioxidative enzymes and proline content of sesame cultivars. *Environmental and Experimental Botany, 60*, 344-351. http://dx.doi.org/10.1016/j.envexpbot.2006.12.005

Kook, H. S., Park, T. I., Khatoon, A., Rehman, S., & Yun, S. J. (2009). Avoidance of sodium accumulation in the shoot confers tolerance to salt stress in cultivated barley. *Pakistan Journal of Botany, 41*, 1751-1758.

Mahmood, S., Iram, S., Ather, H. R. (2003). Intra-specific variability in sesame (*Sesamum indicum* L.) for various quantitative and qualitative attributes under differential salt regimes. *Pakistan Journal of Science and Industrial Research, 14*, 177-186.

Manivannan, P., Abdull Jaleel, C., Sankar, S., Kishorekumar, A., Somasundaram, R., Lakshmanan, G. M. A., & Pannceerselvam, R. (2007). Growth, biochemical modifications and proline metabolism in *Helianthus annus* L. as induced by drought stress. *Colloids and Surfaces B: Biointerfaces, 59*, 141-149. http://dx.doi.org/10.1016/j.colsurfb.2007.05.002

Morris, J. B. (2002). *Food, industrial, nutraceutical and pharmaceutical uses of sesame genetic resources*. Janick J, Whipkey VA. 153-156.

Ramireza, R., Gutierrez, D., Villafane, R., & Lizaso, J. I. (2005). Salt tolerance of sesame genotypes at germination, vegetation and maturity stages. *Communications in Soil Science and Plant Analysis, 36*, 2405-2419. http://dx.doi.org/10.1080/00103620500253324

Sankar, B., Jaleel, C. A., Manivannan, P., Kishore Kumar, A., Somasundaram, R., & Panneerselvam, R. (2007). Drought induced biochemical modification and proline metabolism in *Abelmoschus esculentus* (L.) moench. *Acta Botanica Croatica, 66*, 43-56.

Srivastava, A. K., Bahargava, P., Thapar, R., Rai, L. C. (2008). Salinity-induced physiological and proteomic changes in *Anabaena doliolun*. *Environmental and Experimental Botany, 64*, 49-57. http://dx.doi.org/10.1016/j.envexpbot.2007.12.012

Tester, M., & Davenport, R. (2003). Na^+ tolerance and Na^+ transport in higher ojants. *Annals of Botany, 91*, 503-527. http://dx.doi.org/10.1093/aob/mcg058

Yahya, A. (1998). Salinity effects on growth and on uptake and distribution of sodium and some essential mineral nutrients in sesame. *Journal of Plant Nutrition, 21*, 1439-1451. http://dx.doi.org/10.1080/01904169809365494

Yousif, Y. H., Bingham, F. T., & Yemanos, D. M. (1972). Growth, mineral composition and seed oil of sesame (*Sesamum indicum* L.) as affected by NaCl. *Soil Science Society of America Journal, 36*, 450-453. http://dx.doi.org/10.2136/sssaj1972.03615995003600030025x

Xu, J., Chen, S., & Hu, Q. (2005). Antioxidant activity of brown pigment and extracts from black sesame (*Sesamum indicum* L.) seed. *Food Chemistry, 91*, 79-83. http://dx.doi.org/10.1016/j.foodchem.2004.05.051