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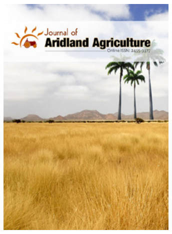

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Performance evaluation of novel safflower (*Carthamus tinctorius* L.) genotypes under salinity stress conditions

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ABSTRACT

Salinity stress is a widespread environmental challenge impacting global crop production. To develop salt-tolerant safflower (*Carthamus tinctorius* L.) cultivars and lines, a factorial experiment was conducted using a randomized complete block design with three replications in Darab Fars during the 2021-2023 crop year. The first factor encompassed seven safflower lines and a novel variety, with Padideh as a control. The second factor involved two levels of irrigation water salinity (0.98 and 7.8 dS m^{-1}). The study assessed multiple traits, including grain yield, biological yield, pod count per plant, seeds per pod, 1000-seed weight, sub-branch count, plant height, harvest index, crude oil percentage, and mineral concentrations (sodium, potassium, chlorine) as well as the potassium-to-sodium ratio. Significant effects of cultivar and irrigation water salinity were observed for all traits ($p<0.01$). Irrigation with saline water significantly reduced yield and its components, except for the number of branches. Saline irrigation increased sodium, potassium, and chlorine concentrations while decreasing the potassium-to-sodium ratio, crude oil percentage, and oil yield. Among the safflower genotypes, Padideh and Mec248 exhibited the lowest and highest yields under saline conditions, respectively. Mec248 demonstrated superior performance under both saline and non-saline conditions, making it the standout line in the study. Parnyan, with moderate yield, showed greater salinity tolerance, as indicated by minimal differences in seed and oil yields under saline and non-saline conditions (10.9% and 14.02%, respectively) and a high potassium-to-sodium ratio in its leaves.

KEYWORDS: Saline irrigation, Crop yield, Mineral concentrations, Salinity stress, Safflower cultivars

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INTRODUCTION

Salinity stress poses a significant challenge to modern agriculture, impeding the growth and development of agricultural products. It is well-documented that more than 800 million hectares of land worldwide are affected by salinity stress to varying degrees, with Iran ranking third after India and Pakistan, harbouring 6.8 million hectares of saline land (Wang *et al.*, 2017; Hazbavi & Silabi, 2021). Salinity stress exerts pressure on agricultural production by inducing both osmotic stress, resulting from salt's impact on water potential, and ionic stress due to the accumulation of toxic sodium ions (Ahmad *et al.*, 2007). In saline conditions, potassium absorption declines, and the sodium-potassium ratio increases, with sodium and calcium ions moving into the cell wall, reducing its elasticity and rendering it rigid. This ionic movement restricts water content, growth, and the movement of sodium and chlorine ions into the plant (El-Hendawy *et al.*, 2005).

Safflower (*Carthamus tinctorius* L.), one of the oldest cultivated plants, plays a vital role in various industries, including food, pharmaceuticals, dyeing, and animal feed (Özçinar, 2021). Safflower exhibits a certain level of salinity tolerance, making it suitable for hydroponic conditions, following crops such as barley, cotton, and sugar beet (Munns, 2009). Although safflower, when exposed to salinity stress, experiences reduced leaf water potential and osmotic potential, tolerant ecotypes exhibit less sensitivity compared to sensitive ecotypes (Javed *et al.*, 2022). However, exceeding a certain salinity threshold can lead to decreased yield and growth (Maggio *et al.*, 2007). Despite its potential, the cultivation of safflower has not seen substantial development, even though native populations and wild types of safflower thrive in Iran, suggesting a rich genetic resource (Khounani *et al.*, 2019).

Southern regions of Iran, such as Darab, have faced escalating salinity problems due to excessive water extraction and the lowering of underground water tables, particularly during hot seasons. This salinity stress disrupts the growth of most agricultural products, making it imperative to explore effective solutions to mitigate its impact. Beyond physical methods, such as desalination, agronomic approaches, including identifying salinity-tolerant cultivars, hold promise. Safflower, a valuable oilseed plant known for its deep roots that allow it to access water and nutrients from the depths, requires relatively low fertilizer input and exhibits some tolerance to drought and salinity. However, most studies on safflower's salinity tolerance have focused on seed germination, lacking comprehensive field assessments. Therefore, this study was conducted to identify high-potential, adaptable, and salinity-tolerant safflower genotypes, addressing this research gap.

MATERIALS AND METHODS

Experimental Site

The study aimed to assess the salinity tolerance and performance of newly introduced safflower varieties and lines. A field experiment was conducted in a randomized complete block (CRB) design with three replications during the crop year 2022-23 at the Hasanabad Darab research station. The research station is characterized by an average annual rainfall of 245 mm, evaporation of 2200 mm, minimum winter temperatures of -3 °C, and maximum summer temperatures of 48 °C in July and August.

Experimental Design and Procedures

The experiment examined the performance of various safflower genotypes under different salinity conditions. Eight safflower varieties and lines, including Padideh (control), Goldasht, Parnyan, Golmehr, Isfahan Local, Mec 14, Mec 295, and Mec 248, were studied. The salinity levels consisted of non-saline control (0.98 dS m^{-1}) and saline conditions (7.8 dS m^{-1}). The initial soil analysis was conducted using standard laboratory methods to prepare the field, which was plowed, disked, and leveled (Table 1). Fertilizers applied per hectare, based on guidelines from the Soil and Water Research Institute, included 100 kg of diammonium phosphate, 100 kg of potassium sulfate, and 125 kg of urea.

The planting plan involved safflower seeds being sown in rows 50 cm apart, with 10 cm spacing between plants within each row, across plots consisting of four 3-meter rows. The experimental design ensured meticulous field procedures and accurate data collection for assessing safflower performance under different conditions. The traditional terrace farming method guided the irrigation regime, performed eight times during the growing season, accounting for cumulative rainfall. Approximately 6000 m^3 per hectare was used for irrigation, measured and adjusted using a Parshall Flume to determine precise water amounts.

Salinity treatment began with the second irrigation event and continued until the end of the growing season. Harvesting involved collecting safflower plants from specific sections of each plot, ensuring representative samples. The irrigation water was sourced from two wells with distinct salinity levels, detailed in Table 2. Adhering to local agricultural practices and scientific methodologies ensured consistency and accuracy in the study, allowing a thorough evaluation of safflower genotypes' responses to varying salinity levels and water sources in the regional agricultural context.

Evaluation Criteria and Analytical Procedures

The comprehensive evaluation of safflower plant performance included several key characteristics: Seed Yield (SY, Kg ha^{-1}), Biomass Yield (BY), Number of Pods per Unit Area (No. of pods $plant^{-1}$), Number of Seeds per Pod (No. of seed $pods^{-1}$), Weight of 1000 Seeds (WS), Plant Height, and Number of Sub-Branches (NSB). The Harvest Index (HI) was calculated by dividing the grain yield by the biomass yield. These parameters together provided a detailed understanding of the safflower genotypes' response to different salinity levels, shedding light on their adaptability and productivity in challenging environments. The seed oil percentage was measured using a Minispec MQ20 NMR device, manufactured by Bruker, Germany, at the Karaj Seedling Breeding and Seed Preparation Research Institute. The oil yield was then calculated by multiplying the seed yield by the seed oil percentage.

To assess the concentrations of key ions (sodium, potassium, and chlorine) in safflower leaves, leaf samples were collected, washed, and dried at 68 °C. The dried samples were ground into a fine powder using an electric steel plate mill. One gram of this plant powder was ashed in an electric furnace at 550 °C to remove organic matter, leaving the inorganic minerals. The ash was dissolved in 5 mL of 2 N hydrochloric acid and filtered through Whatman paper no. 42 to obtain a clear solution for ion analysis. Potassium concentration was measured with a Jenway™ PFP7 flame photometer, while chlorine concentration was determined through titration. Additionally, the potassium-to-sodium (K) ratio was calculated to evaluate ionic balance under salinity stress. These precise methods ensured an accurate assessment of safflower characteristics, including oil content and leaf ion concentrations, providing a thorough evaluation of the genotypes' performance under varying salinity conditions.

Table 1: The results of physical and chemical analysis of the tested soil

Depth (cm)	EC (dS m^{-1})	pH	T.N.V (%)	O.C (%)	P*	K	Mn	Cu	B	Zn	Fe	Texture
					(mg kg^{-1})							
0-30	1.34	7.90	45.00	0.15	10.00	228.00	3.04	1.40	0.50	0.30	3.00	Loam

*Soil nutrients such as phosphorus, potassium, manganese, copper, boron, zinc, and iron are usable amounts

Table 2: Chemical analysis of irrigation water

Irrigation water	ECw (dS m^{-1})	pH	HCO_3^-	Cl^-	SO_4^-	$Ca_2^{++}Mg_2^+$	K^+	Na^+
			(meq L^{-1})					
NS	0.98	7.60	3.60	5.70	0.51	9.20	0.02	0.61
S	7.80	7.10	27.00	38.00	8.50	56.80	0.34	16.30

NS: Non-salinity, S: Salinity

Statistical Analysis

The data from the experimental study underwent thorough statistical analysis. Initially, an Analysis of Variance (ANOVA) using SAS 9.1 software was conducted to examine variations within and between experimental treatments, revealing the effects of salinity stress and genotype variability on safflower performance. Subsequently, Duncan's multi-range test compared average values of characteristics, offering insights into performance patterns among safflower genotypes under varying salinity conditions. Furthermore, the analysis determined genotypes with the highest seed yield, assessed differences in seed and oil yield, and evaluated the potassium-to-sodium absorption ratio for each genotype. These methods ensured reliable findings, facilitating a comprehensive evaluation of safflower genotype performance under diverse salinity conditions.

RESULTS

Performance

The results, as summarized in Tables 3 and 4, revealed that both the main effects of cultivar and irrigation water salinity significantly influenced all the traits under investigation at the 1% level. The impact of both cultivar and salinity application was statistically significant ($p<0.01$), with the exception of the number of seeds per plant and biomass yield.

Irrespective of the salinity factor, the Mec 248 safflower line exhibited the highest yield, reaching 2763 kg hectare^{-1}. This represented a substantial 71% increase in yield compared to the lowest-yielding cultivar, which yielded 1668 kg hectare^{-1}. These findings highlight the remarkable potential of the Mec 248 safflower line in achieving superior yields, even under the influence of salinity stress, and underscore its significance in safflower breeding and cultivation.

Individual Genotype Performance

The performance of the Mec 248 safflower line demonstrated a significant difference when compared to all other cultivars and safflower lines in the study. Mec 248 displayed remarkable performance, as it recorded the highest values for several crucial traits, including the number of pods per plant, the number of seeds per pod, and the harvest index.

Among other noteworthy genotypes, the Golmehr variety stood out with a remarkable 1000-seed weight of 45 grams, while the Goldasht variety excelled in terms of plant height, reaching 161.5 cm.

For biological performance, the Mec 295 safflower line exhibited the highest values, although it did not exhibit a significant difference from the Mec 248 and Mec 14 lines, as well as the Isfahan local variety. In contrast, the Padideh variety displayed the lowest biological performance among the evaluated genotypes.

Effect of Saline Water on Traits

The application of saline water had a significant impact on several safflower traits. Salinity stress led to a notable decrease in yield, reducing it by 21.4%. Other traits, including the number of pods per plant (15.9%), the number of seeds per pod (15.9%), the weight of 1000 seeds (8.6%), biological performance (13.2%), plant height (32.2%), and harvest index (8.9%), were also adversely affected by saline water. In contrast, the number of sub-branches increased by 5.8% under saline conditions.

Genotype-Salinity Interaction

The interaction between genotypes and salinity conditions revealed that the Mec 248 safflower line displayed the highest yield and harvest index, both under saline and non-saline water conditions, with yields of 3202 and 2324 kg hectare^{-1} and harvest index values of 20.11 and 18.5%, respectively (Tables 3 & 5).

Conversely, the Padideh variety exhibited the lowest yield (1399 kg hectare^{-1}) under saline conditions, and the Golmehr variety displayed the lowest harvest index under saline water conditions.

These results emphasize the remarkable performance of the Mec 248 safflower line, both in terms of overall productivity and tolerance to salinity stress, underscoring its potential value for safflower cultivation under challenging conditions.

Plant Diameter and Plant Height

In the absence of salinity stress, the Mec 248 safflower line excelled in terms of plant diameter, showcasing the highest values among all genotypes. On the other hand, Golmehr stood out for its impressive plant height, displaying the tallest plants in the study under non-saline water conditions.

Yield Differences under Salinity Stress

The data presented in Table 5 shed light on the yield differences observed among safflower genotypes under saline and non-saline water conditions. Notably, Parnyan and Golmehr displayed

Table 3: Analysis of performance variance and its components across investigated treatments

SOV	df	SY	NSP	NPP	WS	BY	Height	NSB	HI
Replicate	2	16013 ^{ns}	3.94^{ns}	1.20^{ns}	1.1^{ns}	2243125^{ns}	99.81**	0.03^{ns}	2.7**
Variety	7	749650**	48.2**	20.4**	295**	7210208**	856.27*	0.33**	15**
Saltiness	1	2998500 **	385**	117**	111**	41626875**	35100**	1.33**	26**
Variety×Saltiness	7	62847 **	2.91^{ns}	4.90**	3.2**	1596399^{ns}	352.37**	0.34**	4.06**
Error	30	23914	3.67	1.64	0.63	1172458	99.81	0.11	0.2
CV (%)		7.42	5.83	7.6	2.4	8.2	2.9	5.3	4.96

SOV: Source of variation, NSP: No. of seed pods, NPP: No. of pods plant, SY: Seed yield, WS: Weight of 1000 seeds, BY: Biomass Yield, NSB: No. of sub-branches, HI: Harvest index, IL: Isfahan local, NS: Non-salinity, S: Salinity, CV: Coefficient of variation, **: significant at 1% level *: significant at 5% level ^{ns}: not significant

Table 4: Comparison of the average main effects of genotype and irrigation water salinity on various characteristics

Cultivars/Lines	The average of the measured characteristics							
	SY (kg ha^{-1})	No. of seed pods^{-1}	No. of pods plant^{-1}	WS (gm)	BY (kg ha^{-1})	Height (cm)	NSB	HI (%)
The Main Factors								
Goldasht	1895^{cde}	27.50^{c}	16.33^{de}	45.00^{a}	12970^{bc}	124.5^{e}	5.900^{ab}	14.61^{c}
Parnyan	2196^{b}	32.67^{b}	16.33^{de}	43.28^{b}	13100^{bc}	127.2^{e}	5.633^{b}	16.77^{b}
Padideh	1668^{e}	32.50^{b}	16.17^{e}	29.08^{f}	11420^{d}	142.8^{c}	6.100^{a}	14.57^{c}
Golmehr	1734de	31.83^{b}	17.83^{cd}	29.95^{ef}	11780^{cd}	161.5^{a}	6.283^{a}	14.76^{c}
IL	1962^{c}	36.17^{a}	18.17^{bc}	27.78g	13320^{ab}	143.8^{bc}	5.600^{b}	14.67^{c}
Mec 14	2148^{b}	32.17^{b}	19.50^{b}	33.62^{c}	13500^{ab}	148.5^{b}	5.933^{ab}	15.94^{b}
Mec 295	2309^{b}	33.50^{b}	19.67^{ab}	30.35^{e}	14620^{a}	135.5^{d}	6.100^{a}	15.85^{b}
Mec 248	2763^{a}	36.67^{a}	21.17^{a}	32.33^{d}	14250^{ab}	145.2^{bc}	5.850^{ab}	19.30^{a}
	The main factor (Irrigation water salinity)							
NS	2334^{a}	35.71^{a}	19.71^{a}	35.45^{a}	14050^{a}	168.2^{a}	5.758^{b}	16.54^{a}
S	1834^{b}	30.04^{b}	16.58^{b}	32.40^{b}	12190^{b}	114.1^{b}	6.092^{a}	15.07^{b}

SY: Seed yield, WS: Weight of 1000 seeds, BY: Biomass Yield, NSB: No. of sub-branches, HI: Harvest index, IL: Isfahan local, NS: Non-salinity, S: Salinity. The averages of each column with the same letters do not have a significant difference at the 5% statistical level

the lowest yield reductions, with decreases of 10.9 and 11.9%, respectively, when exposed to salinity stress.

In stark contrast, the Mec 248 safflower line recorded a substantial 27.4% increase in yield when grown under non-saline conditions compared to saline conditions. This significant difference underscores the Mec 248 line's remarkable capacity to maintain high yields in the absence of salinity-induced stress.

Tolerance to Salinity

The yield difference data indicate that Parnyan exhibited the highest degree of tolerance to salinity among all safflower genotypes. Parnyan's ability to maintain yield levels with minimal reduction in the presence of salinity stress positions it as the most resilient and adaptable genotype to challenging saline conditions.

These results highlight the varying responses of safflower genotypes to salinity stress, with Parnyan emerging as the most salt-tolerant variety. This information is valuable for safflower breeders and cultivators seeking to optimize safflower production under diverse environmental conditions.

Seed Oil Yield and Leaf Ion Concentrations

The variance analysis of the effects of different treatments on the percentage and yield of crude oil revealed that both the main effects of safflower variety and salinity had a significant impact on these traits. Moreover, the interaction effect of these two factors was found to be significant solely on the yield of crude oil at the 1% level (Table 6).

The averages of each column with the same letters do not have a significant difference at the 1% statistical level.

Impact of Salinity on Seed Oil Percentage and Yield

When comparing the safflower genotypes under saline water conditions to non-saline water conditions, a consistent trend of decreased seed oil percentage and yield was observed across all examined genotypes. However, it is noteworthy that in the case of the Parnyan variety and the Mec 14 line, this decrease led to a reversal of significance.

Under non-saline water conditions, the highest seed oil percentages were recorded for the Mec 14 and Isfahan local (IL) genotypes, reaching 30.33 and 30.03%, respectively. Conversely, the lowest seed oil percentages were associated with the Parnyan, Goldasht, Golmehr, Padideh, and Mec 248 varieties. However, under saline water conditions, these genotypes exhibited no significant differences in terms of seed oil percentages and were grouped together.

In terms of seed oil yield, the Mec 248 line demonstrated the highest oil yield under non-saline water conditions, totaling 914.27 kg hectare^{-1}. In contrast, the Padideh variety yielded the lowest oil amount when subjected to saline water conditions, with an output of 379 kg hectare^{-1}.

Table 5: Comparison of the average interaction effects of genotype and irrigation water salinity on various characteristics

Cultivars/lines	The average of the measured characteristics						
	Variety or lines×irrigation water salinity						
	Irrigation water	SY (kg ha^{-1})	No. of pods $plant^{-1}$	BY (kg ha^{-1})	Height (cm)	NSB	HI (%)
Goldasht	NS	2159^{cde}	19.00^{bcd}	13070^{bc}	144.7^{e}	6.033^{abc}	16.54^{c}
	S	1631^{hi}	13.67^{e}	12870^{bcd}	$104.3s^{h}$	5.767^{bcde}	12.68^{f}
Parnyan	NS	2323^{bcd}	18.00^{cd}	13870^{bc}	140.7^{e}	5.233^{de}	16.76^{c}
	S	2069^{def}	14.67^{e}	12330^{cde}	113.7^{g}	6.033^{abc}	16.78^{c}
Padideh	NS	1937^{efg}	17.67^{d}	12100^{cde}	173.0^{bc}	5.633^{cde}	16.02^{cde}
	S	1399^{i}	14.67^{e}	10730^{e}	112.7^{g}	6.567^{a}	13.12^{f}
Golmehr	NS	1843^{fgh}	18.00^{cd}	12700^{bcde}	190.0^{a}	6.367^{ab}	14.56^{e}
	S	1624^{hi}	17.67^{d}	10870^{de}	133.0^{f}	6.200^{abc}	14.95^{de}
IL	NS	2258^{cd}	21.00^{ab}	13900^{bc}	1693.7^{cd}	5.167^{e}	16.22^{cd}
	S	1666^{ghi}	15.33^{e}	12730^{bcde}	118.0^{g}	6.033^{abc}	13.12^{f}
Mec 14	NS	2401^{bc}	20.33^{bc}	14730^{ab}	177.0^{b}	5.833^{bcd}	16.29^{cd}
	S	1896^{efgh}	18.67^{bcd}	12270^{cde}	120.0^{g}	6.033^{abc}	15.59^{cde}
Mec 295	NS	2552^{b}	20.67^{b}	16100^{a}	165.7^{d}	6.100^{abc}	15.85^{cde}
	S	2066^{def}	18.67^{bcd}	13130^{bc}	105.3^{h}	6.100^{abc}	15.85^{cde}
Mec 248	NS	3202^{a}	23.00^{a}	15930^{a}	184.7^{a}	5.700^{cde}	20.11^{a}
	S	2324^{bcd}	19.33^{bcd}	12570^{cde}	105.7^{h}	6.000^{abc}	18.50^{b}

SY: Seed yield, BY: Biomass Yield, NSB: No. of sub-branches, HI: Harvest index, IL: Isfahan local, NS: Non-salinity, S: Salinity. The averages of each column with the same letters do not have a significant difference at the 5% statistical level

Table 6: Comparison of the average interaction effects of genotype and irrigation water salinity on the studied traits

Cultivars /lines	The average of the measured characteristics						
	Variety or lines×irrigation water salinity						
	Irrigation water	Crude oil (%)	Crude oil yield (kg ha^{-1})	Na	K	Cl	K:Na
				Concentration of leaves (mg g^{-1})			
Goldasht	NS	28.37^{cdef}	612.20^{def}	7.500^{g}	10.133^{de}	21.83^{e}	1.356^{d}
	S	26.09^{f}	439.20^{ij}	30.967^{b}	7.100^{f}	34.77^{c}	0.247^{g}
Parnyan	NS	27.57^{def}	640.30^{de}	6.933^{g}	11.267^{bc}	14.67^{f}	1.662^{bcd}
	S	26.60^{f}	550.50^{fgh}	14.867^{ef}	11.300^{bc}	38.50^{b}	0.767^{ef}
Padideh	NS	28.40^{cde}	550.40^{fgh}	5.733^{g}	11.300^{bc}	14.43^{f}	1.971^{ab}
	S	27.03^{f}	379.00^{j}	37.167^{a}	7.567^{f}	36.47^{bc}	0.217^{g}
Golmehr	NS	28.63^{bcd}	527.70^{gh}	6.767^{g}	12.533^{a}	21.63^{e}	1.869^{abc}
	S	26.77^{f}	434.90^{ij}	12.500^{f}	11.800^{abc}	45.17^{a}	0.952^{e}
IL	NS	30.03^{a}	677.60^{cd}	5.833^{g}	10.733^{cd}	14.33^{f}	1.840^{abc}
	S	28.73^{bcd}	479.20^{hi}	15.400^{def}	7.167^{f}	36.33^{bc}	0.468^{fg}
Mec 14	NS	30.33^{a}	728.10^{bc}	5.900^{g}	11.900^{ab}	15.63^{f}	2.089^{a}
	S	29.30^{abc}	554.70^{fgh}	19.367^{cde}	10.133^{de}	34.67^{c}	0.525^{fg}
Mec 295	NS	29.57^{ab}	754.60^{b}	6.800^{g}	11.200^{bc}	15.90^{f}	1.678^{bcd}
	S	27.70^{def}	571.90^{efg}	20.400^{c}	7.633^{f}	29.10^{d}	0.374^{g}
Mec 248	NS	28.57^{bcd}	914.30^{a}	7.500^{g}	11.700^{abc}	12.63^{f}	1.564^{cd}
	S	27.30^{ef}	634.20^{de}	19.967^{e}	9.267^{a}	34.27^{c}	0.464^{fg}

IL: Isfahan local, NS: Non-salinity, S: Salinity

Notably, the Parnyan variety displayed the lowest difference in oil yield between saline and non-saline water conditions, with a minor reduction of 14.02%, followed closely by the Golmehr variety with a decrease of 16.64%. Other genotypes, including Mec 14, Mec 295, Goldasht, Isfahan local (IL), Padideh, and Mec 248, exhibited larger variations in oil yield under these conditions, with differences ranging from 21.24 to 30.63%.

Effect of Salinity on Leaf Ion Concentrations

In all safflower genotypes, the use of saline water resulted in a statistically significant increase in sodium concentration within plant leaves. Conversely, under non-saline water conditions, all genotypes exhibited no significant differences, and they were grouped together.

The highest and lowest sodium concentrations in the leaves under saline water conditions were recorded for the Padideh and Golmehr cultivars, respectively, with values of 37.17 and 12.5 mg per gram of dry matter (mg g of dry $matter^{-1}$).

Furthermore, the highest potassium and chlorine concentrations, amounting to 11.8 and 45.17 mg per gram of dry $matter^{-1}$, respectively, were attributed to the Golmehr variety when grown under saline water conditions.

Regarding the potassium-to-sodium ratio, it was found to significantly decrease in all genotypes under saline water conditions. Golmehr and Parnyan displayed the highest potassium-to-sodium ratios under saline water conditions, while the Padideh and Goldasht cultivars exhibited the lowest ratios.

These results illuminate the multifaceted effects of salinity stress on safflower, impacting seed oil characteristics and leaf ion concentrations. They underscore the importance of selecting and breeding safflower genotypes that exhibit tolerance to salinity while maintaining desirable seed oil attributes.

DISCUSSION

The results of this study clearly indicate that different safflower cultivars exhibit distinct performance under both saline and non-saline conditions. These disparities can be attributed to variations in key performance components, such as the number of pods per plant, number of seeds per pod, and the weight of 1000 seeds. These natural variations arise from genetic differences among cultivars, as each possesses a unique yield potential. This observation aligns with the findings of Ehsanzadeh and Baghdad-Abadi (2003), who also reported significant differences in safflower cultivars concerning the number of pods per plant, number of seeds per pod, weight of 1000 seeds, and overall yield.

Salinity stress had an adverse impact on yield and various yield components in all safflower varieties, although the extent of this reduction varied among different cultivars. The outcomes of previous studies by Feizi *et al.* (2010), Singh *et al.* (2014) and Yeilaghi *et al.* (2015) further underline the decrease in safflower yield and its components in response to irrigation water salinity. In this study, only the Parnyan and Golmehr cultivars exhibited significant tolerance to salinity, with no significant differences in performance under both saline and non-saline water conditions (Parnyan 9.10% and Golmehr 9.11%).

The decline in yield under saline water conditions resulted from reductions in key yield components, including the number of pods per plant (15.9%), the number of seeds per pod (15.9%), and the weight of 1000 seeds (8.6%). Beke and Volkmar (1995) similarly attributed the reduced safflower yield to decreases in the weight of 1000 seeds, the number of seeds per pod, and the number of pods per plant under saline conditions. Furthermore, salt stress led to an increase in the number of sub-branches; however, some of these branches failed to develop and produce leaves, leading to a significant decrease in the number of leaves under saline conditions.

Overall, the negative impact of salinity stress on plant growth and performance can be attributed to reduced water absorption, ion toxicity due to excessive sodium and chlorine uptake, and nutritional imbalances (Isayenkov & Maathuis, 2019). Salinity stress is also associated with oxidative stress, primarily caused by the production of reactive oxygen species (ROS) (Isayenkov, 2012). It is important to note that different plant species and even different varieties of the same plant can exhibit varying levels of salinity tolerance. The plant's ability to adapt or tolerate high salt concentrations in its growth environment plays a pivotal role in its salinity tolerance (Parihar *et al.*, 2015). Salinity tolerance involves various physiological and molecular mechanisms, encompassing osmotic resistance, ionic resistance, and tissue resistance (Roy *et al.*, 2014).

Crude oil percentage and yield exhibited a significant decrease in all safflower genotypes under salinity influence. The smallest reduction in oil yield under saline conditions was observed in the Parnyan and Golmehr cultivars, indicating their superior tolerance to salinity. Salinity stress, which causes physiological changes like increased sodium absorption and decreased potassium, calcium, and sulfur uptake, not only affects plant growth and performance but also impacts oil production. The reduction in oil content varied among genotypes depending on their salinity tolerance. While a slight increase in oil content may occur in low salinity conditions, the findings of Harrathi *et al.* (2012) and Yeilaghi *et al.* (2012) corroborate the results of this study.

An increase in the concentration of sodium and chlorine in the leaves of plants grown with saline water, coupled with a decrease in potassium concentration and the potassium-to-sodium ratio, reflects the impact of environmental salinity on nutrient uptake. Salinity-exposed plants typically accumulate higher concentrations of sodium and lower concentrations of potassium (de Lacerda *et al.*, 2003; Harrathi *et al.*, 2012). Moreover, the high concentration of Na^+ and Cl^- in the soil solution disrupts the activity of nutrient ions, leading to inappropriate ion ratios, including Na^+/Ca^{2+}, Na^+/K^+, Ca^{2+}/Mg^{2+}, and Cl^-/NO^{3-}. This condition makes the plant susceptible to osmotic stress, ion toxicity, nutrient imbalances, and yield reduction (Greenway & Munns, 1980). The varying ratios of potassium to sodium absorption among different genotypes are noteworthy, with the highest ratio associated with Golmehr and Parnyan and the lowest with Padideh and Goldasht cultivars. Some researchers propose that a high potassium-to-sodium ratio is a crucial criterion for enhancing a plant's salinity resistance. Ashraf (2004) suggests that a high potassium-to-sodium ratio in plants subjected to salinity stress is an essential selection criterion for determining salinity resistance. In essence, plants with a high potassium-to-sodium ratio under salt stress exhibit greater resistance to salinity.

CONCLUSION

In this comprehensive investigation of the effects of irrigation water salinity on various safflower genotypes, several critical findings have emerged. It is evident that salinity stress leads to a decrease in yield, along with a reduction in most yield components and oil yield across all genotypes. However, the susceptibility of different safflower genotypes to salinity varies significantly. Salinity-induced changes in nutrient absorption further underscore the genotype-dependent nature of this response, with increased sodium and chlorine absorption coupled with decreased potassium uptake and potassium-to-sodium ratio. These alterations are not uniform across all genotypes.

Collectively, the comprehensive dataset obtained in this study allows us to draw several noteworthy conclusions. Foremost, the Mec 248 line stands out as a superior genotype with substantial potential. Its remarkable performance, unaffected by the type of water used, positions it as a standout choice among the various safflower genotypes. Additionally, Parnyan, characterized by moderate yield, demonstrates impressive salt resistance. This conclusion is supported by its minimal disparity in seed and oil yields between saline and non-saline conditions, despite a lower potassium-to-sodium absorption ratio under saline conditions.

This study's findings offer valuable insights for safflower cultivation under conditions of salinity stress. By identifying genotypes that exhibit higher salt tolerance and maintain relatively stable performance under saline conditions, it becomes possible to make informed decisions when selecting safflower cultivars for regions with elevated salinity. Furthermore, the research underscores the importance of considering specific genotypes and their response to environmental stressors, as this knowledge can significantly impact agricultural practices and crop productivity.

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