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Investigating the Production Potential of Soybean Cultivars Tolerant to Heat Stress from Brazil in Khuzestan Province

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ABSTRACT

Khuzestan province has good potential for oilseed crops production, such as soybeans. At present, however, there are no suitable soybean cultivars in the country that can tolerate the hot conditions of this province well. Therefore, *Gelareh Kalhor Agriculture Company*, in coordination with the Ministry of Agriculture Jihad, has imported four soybean cultivars (BRS391, BRS232, BRS511, and BRS284) from Brazil. This study aimed to compare the yield of imported soybean cultivars tolerant to heat stress with common cultivars in the country (Rahmat, Caspian, and SK-93) in Dezful climate conditions. The experiment was performed in 2021 in a randomized complete block design with three replications. Results of the analysis of variance showed that soybean cultivars had significant effects on the number of branches per plant, pod production per plant, seeds per pod, 1000-seed weight, and seed yield. But, there was no statistically significant difference among the cultivars studied for seed oil and protein contents. The results showed that imported soybean cultivars were able to produce about 25% more pods per plant, 21% more seeds per pod, and 8% higher seed weight, and in total, 20% higher seed yield than common cultivars. Conversely, the potential for branching in common soybean cultivars in the country was about 33% higher than that of the imported cultivars from Brazil. Among the cultivars imported, BRS232 and BRS284 with seed yields of 2793 and 2697 kg ha^{-1}, respectively, showed higher production potential than the other two cultivars.

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1. Introduction

Soybean [*Glycine max* (L.) Merr.] is a high valuable oilseed crop that is produced all over the world. Soybean seeds have a wide application, including animal feed, edible oil and biofuel production, and direct human consumption. In addition, soybeans can be grown and used as a forage crop (Anderson *et al.*, 2019; Mehrban and Fazeli-Nasab, 2017). For the past half-century, soybeans have been ranked third in the world in terms of production after wheat and maize, and second as regards economic value after maize. The total world production of soybeans in 2018 was 348,712,311 tons. Brazil was the largest producer, accounting for 36% of world production (FAO, 2018).

The United States, Argentina, and China are the other major soybean producers. In these countries, in addition to producing high-yielding cultivars, bio- and abiotic stress-resistant genotypes have been developed in soybean breeding programs (Carter Jr *et al.*, 2016; MacMillan and Gulden, 2020). Comparing old and new soybean cultivars, De Bruin and Pedersen (2009) showed that seed yield in new cultivars was indirectly improved by increasing total dry matter and crop growth rate, while the amount of dry matter allocated to seeds was constant. They stated that increasing soybean yield in the future will be possible by (1) increasing the amount and speed of dry matter production and (2) increasing leaf area duration (De Bruin and Pedersen, 2009).

There is a high demand for nutritious soybeans in Iran to enrich livestock and poultry feed. Although soybeans are grown and produced in provinces such as

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Golestan, Mazandaran, Gilan, Ardabil, and Lorestan, and to a lesser extent in several others, domestic production does not meet this growing demand. Currently, a lot of money is spent annually on importing soybeans. Efforts are being made by those involved in the agricultural sector to eliminate or reduce the need to import soybeans.

Due to the country's demand for oilseeds and the need to reduce dependence on imports of this commodity, the policy of the Ministry of Agriculture Jihad is focused on finding new areas and developing soybean cultivation in other areas such as the Khuzestan plain. Khuzestan province has a good potential for oilseed crops production, such as soybeans. At present, however, there are no suitable soybean cultivars in the country that can tolerate the hot conditions of this province well. Therefore, *Gelareh Kalhor Agriculture Company*, in coordination with the Ministry of Agriculture Jihad, has imported four soybean cultivars (BRS391, BRS232, BRS511, and BRS284) from Brazil.

According to the above, this study was conducted to compare the yield of imported soybean cultivars tolerant to heat stress with some common cultivars in the country.

2. Materials and methods

The experiment was performed in 2021 on a field on the outskirts of Dezful (Shahid Motahari town) in northern Khuzestan. For the past 30 years, the mean annual minimum and maximum temperatures and precipitation in Dezful were 16.3, 32.3 °C, and 307 mm, respectively. The region is characterized by a hot semi-arid climate. The cultivars, including four heat-tolerant cultivars imported from Brazil (BRS391, BRS232, BRS511, and BRS284) and three common cultivars in the country (Rahmat, Caspian, and SK-93), were compared in a randomized complete block design with three replications. Rahmat, Caspian, and SK-93 were developed and released by the Agricultural Research, Education, and Extension Organization (AREEO) for planting in temperate northern, warm and humid northern, and warm southern climates, respectively.

The experimental site was moldboard plowed, disked, and fertilized with 50 kg ha^{-1} of fertilizers of urea CH_4N_2O (46% N), triple superphosphate $Ca(H_2PO_4)_2.H_2O$ (43-44% P_2O_5), and potassium sulfate K_2SO_4 (40-8% P-S). Urea fertilizer was side-dressed at the V_4 and R_1 growth stages at a rate of 50 and 100 kg ha^{-1}, respectively. In addition, 1 kg ha^{-1} of humic acid was used at the R5 stage. These relatively high fertilizer rates were used to minimize underground nutrient competition because, in this study, soybean seeds were not inoculated with any symbiotic strain of nitrogen-fixing bacteria. Likewise, frequent irrigation was performed to minimize competition for water. Irrigation was carried out regularly at intervals of 5-10 days, depending on the temperature conditions, until the end of the soybean growth cycle. In addition, the field was kept free of pests, diseases, and weeds until the end of the season.

Soybean was sown at 40 seeds m^{-2}, at 0.75 m row spacing, on June 26, 2021. Plots were four rows, 7.5 m wide by 20 m long. In addition to recording the time of occurrence of each phenological developmental stage, some soybean growth characteristics, such as plant height, the distance of the first pod from the soil surface, and the number of branches per plant were measured during the growing season.

Seven days after reaching maturity, once seed moisture concentration was below 13%, by removing the margins of the plots, 60 m^2 were harvested from each to measure the seed yield of each studied cultivar. The seeds of each cultivar were then manually separated from the pods and weighed. Soybean yield components of the studied cultivars were also measured by harvesting ten plants from each plot. Seed weight was determined by weighing ten samples of 1000 from each cultivar in each replicate of the experiment. Seed oil and protein concentration (%), as well as profiles of fatty acids of seed oil, were determined for the cultivars studied in the laboratory of the Mahidasht Kermanshah Agricultural Industrial Complex. Analysis of variance was performed using the GLM procedure of the SAS statistical program (SAS Institute, 2001), and the means of treatments were compared using Fisher's least significant difference (LSD) test. Lastly, PROC CORR was used to determine correlations among the response variables across all cultivars studied. All the figures were created using SigmaPlot 14.0 (Systat Software, Inc., San Jose, CA, United States).

3. Results and discussion

The effect of cultivar was significant for plant height the height of the first pod (distance from the soil surface), days to flowering, days to maturity, number of branches per plant, number of pods per plant, number of seeds per pod, 1000-seed weight, and seed yield. But, there was no statistically significant difference among the cultivars studied for seed oil and protein contents (Table 1).

Table 1. Analysis of variance of the effect of soybean cultivar on crop characters, yield and yield components.

S.O.V	D.F	Mean squares										
		Plant height	The height of the first pod node	Flowering time	Seed maturity time	No.of branches per plant	No. of pods per plant	No. of seeds per pod	1000-seed weight	Seed yield	Seed oil	Seed protein
Block	2	41.07^{ns}	1.86^{ns}	0.05^{ns}	1.29^{*}	0.33^{ns}	176.86^{ns}	$0.02n^{s}$	5.51^{ns}	30584.73^{ns}	0.003^{ns}	0.509^{ns}
Cultivar	6	303.52^{**}	76.86^{**}	103.56^{**}	17.38^{**}	1.86^{**}	671.87^{**}	0.22^{*}	586.24^{*}	326141.52^{**}	0.064^{ns}	0.519^{ns}
Error	12	44.96	2.19	0.77	0.29	0.17	40.81	0.04	2.97	22023.06	0.925	1.233
CV (%)		5.75	6.91	1.67	0.42	14.78	10.37	10.84	1.21	6.29	4.69	3.12

ns, * and ** indicate non-significance, significance at the probability level of 1% and 5%, respectively.

3.1. Plant height

The plant height varied between 100.7 (cv. Caspian) and 131.3 cm (cv. BRS511), depending on the cultivar studied (Fig. 1).

3.2. The height of the first pod node

Depending on the soybean cultivar, the distance from the soil surface to the lowest pod node varied from 16.3 cm in cv. BRS232 to 30.3 cm in cv. BRS284 (Fig. 2).

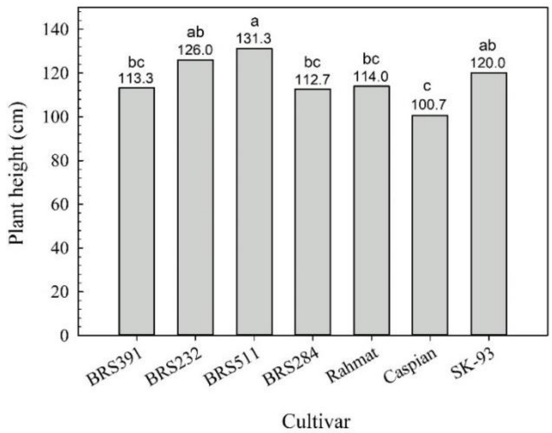

Figure 1. Mean comparison of the effect of cultivar on plant height in soybean.

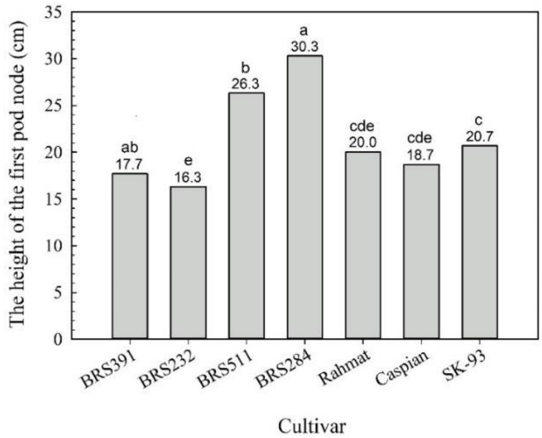

Figure 2. Mean comparison of the effect of cultivar on the height of the first pod node in soybean.

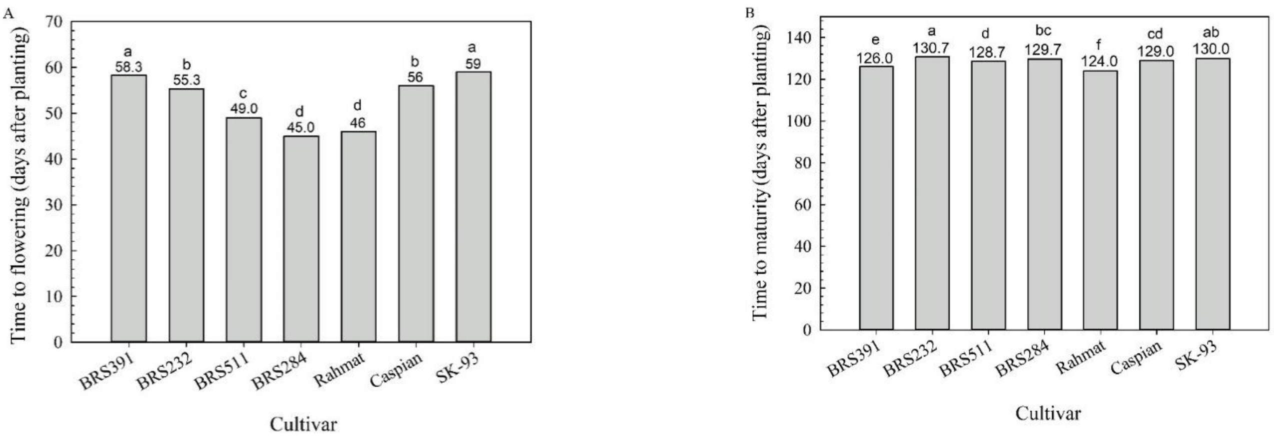

Figure 3. Mean comparison of the effect of cultivar on flowering (A) and seed maturity time (B) in soybean.

3.3. Flowering and seed maturation periods

The time (from planting) to the beginning of flowering in cvs. BRS284 and Rahmat was significantly less than that observed for cv. BRS511. For cv. BRS511, the observed time to flowering was significantly less than that for cvs. BRS232 and Caspian. The cultivars BRS391 and SK-93 commenced flowering later than other cultivars (Fig. 3). The days (from planting) to maturity for soybean cultivars also varied between 124.0 (cv. Rahmat) and 130.7 (cv. BRS232) (Fig. 3).

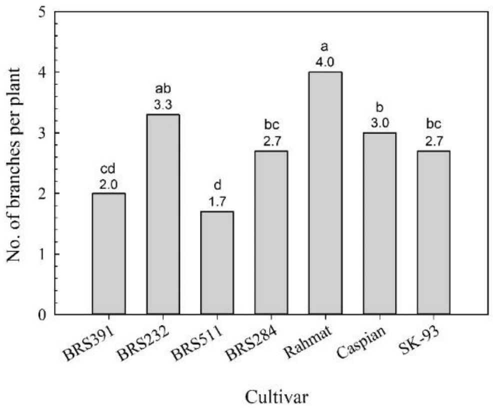

Figure 4. Mean comparison of the effect of cultivar on number of branches per plant in soybean.

3.4. Number of branches on each plant

The average cultivar branches number per plant ranged from 1.7 to 4.0, with an overall average of 2.8 (Fig. 4). The cv. Rahmat had the highest number of branches per plant. However, there was no significant difference between the cv. Rahmat and cv. BRS232 for the number of branches per plant at $\alpha < 0.05$. Also, there was no significant difference between cv. BRS223 and cvs. Caspian, BRS284, and SK-93 for the number of branches per plant at $\alpha < 0.05$. The lowest number of branches per plant was observed in two soybean cvs. BRS511 and BRS391. When comparing the two treatment groups, we found that cultivars imported from Brazil had less potential (33%) for sub-branch production per plant than conventional cultivars. Having a higher branching potential can be valuable in some situations, such as the lack of uniform emergence of seedlings in the field. However, in soybean, since the potential for pod formation on the main stem is considerably higher than the sub-branches, increasing plant density for cultivars with lower branching potential can lead to higher yields of these compared to cultivars with higher branching potential.

3.5. Number of pods per plant

Pod formation potential per plant ranged from 48.4 to 86.3, with an overall average of 61.6, depending on the cultivar studied (Fig. 5). In the Dezful climate, the potential for pod production per plant for cvs. BRS511 and BRS284 was significantly higher than those for other soybean cultivars. There was no statistically significant difference among the other soybean cultivars studied for the number of pods per plant at $\alpha < 0.05$. When comparing the two treatment groups, we found that the potential for pod production in soybean cultivars imported from Brazil, with an average of 69.0 pods plant-1, was about 25% higher than that for the common cultivars in the country.

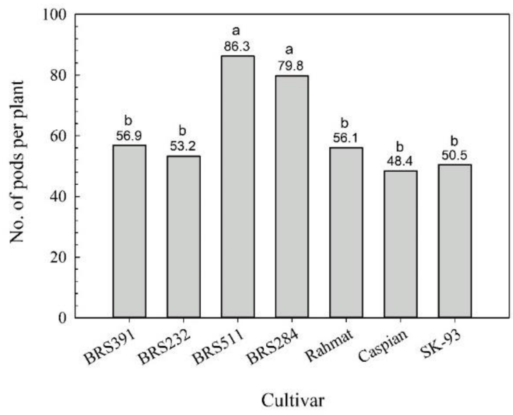

Figure 5. Mean comparison of the effect of cultivar on number of pods per plant in the soybean.

3.6. Number of seeds in each pod

The average number of seeds per pod for cultivars ranged from 1.4 to 2.2, with an overall average of 1.8 (Fig. 6). The cv. BRS284 had the highest number of seeds per pod, but statistically, the number of seeds per pod in this cultivar was not significantly different from that of cvs. BRS232, BRS511, and BRS391 at $\alpha < 0.05$. The cv. Rahmat had the lowest number of seeds per pod, but for this trait, it had no statistically significant difference with the cv. SK-93 at $\alpha < 0.05$. The standard deviation of the number of seeds per pod for different soybean cultivars ranged from 0.13 to 0.30, indicating a high variation in the number of seeds per pod for each cultivar in various replications of the experiment. Anyhow, when comparing the two treatment groups, we found that the number of seeds per pod in soybean cultivars imported from Brazil, with an average of 2.0 seeds pod-1, was about 21% higher than that for the common cultivars in the country. This means that the sensitivity of pollens and stigmas to heat stress during the flowering stage in imported cultivars is less than that of the common cultivars in the country, which has resulted in the formation of more seeds in each pod of these cultivars.

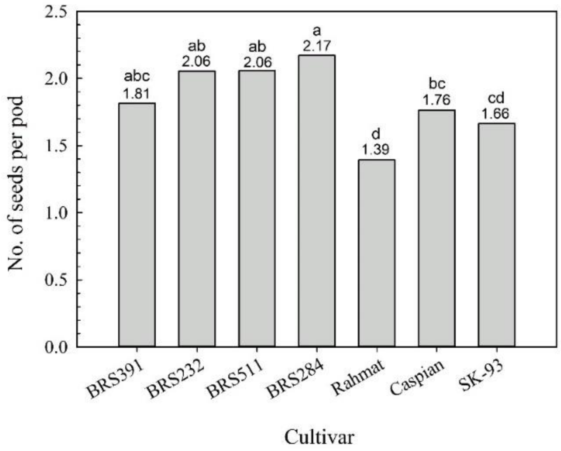

Figure 6. Mean comparison of the effect of cultivar on number of seeds per pod in soybean.

3.7. Seed weight

1000-seed weight averages for cultivars ranged from 132.9 to 172.4 g, with an overall average of 142.4 g (Fig. 7). Seed weight in cultivar BRS232 was significantly higher than the value obtained for cultivar BRS511, for which it was also significantly higher than that for other soybean cultivars. Soybean cvs. BRS391, Rahmat, and SK-93 had the lowest seed weight. By group comparison of treatments, we found that the average 1000-seed weight of soybean cultivars imported from Brazil (147.4 g) was about 8% higher than that of the common cultivars in the country (135.7 g).

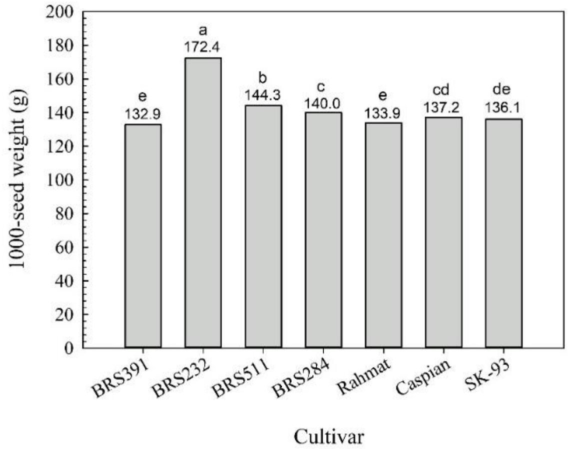

Figure 7. Mean comparison of the effect of cultivar on seed weight in soybean.

3.8. Seed yield

Cultivar yield averages ranged from 1866.7 to 2792.8 kg ha^{-1}, with an overall average of 2339.7 kg ha^{-1} (Fig. 8). The yield of cv. BRS232 was not significantly different from that obtained from cv. BRS284 at $\alpha < 0.05$, but it was significantly greater than that for the other soybean cultivars studied. The seed yield of cv. BRS284 was not significantly different from that obtained from cv. BRS511 at $\alpha < 0.05$, but it had a significantly greater yield than other soybean cultivars. The yields obtained from cvs. Rahmat and SK-93 were also significantly lower than those for the other soybean cultivars. When comparing the two treatment groups, we found that the average seed yield of soybean cultivars imported from Brazil, with an average of 2554.9 kg ha^{-1}, was about 20% greater than that of the common cultivars in the country.

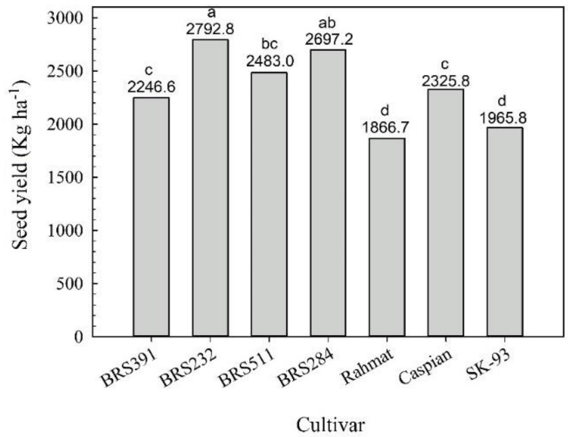

Figure 8. Mean comparison of the effect of cultivar on seed yield in soybean.

3.9. Seed oil

The oil content averages were not affected by the cultivar and ranged from 20.3 to 20.7%, with an overall average of 20.5% (Fig. 9). However, oil yield varied between 383.8 (cv. Rahmat) and 569.4 kg ha^{-1} (cv. BRS232) depending on the studied soybean cultivar (Fig. 9). Also, the average oil yield for cultivars imported from Brazil was about 106 kg ha^{-1} higher than that for conventional cultivars (417.8 kg ha^{-1}).

3.10. Seed protein

The average cultivar seed protein contents were between 35.1 and 36.4%, with an overall average of 35.6% (Fig. 10). However, depending on the soybean cultivar studied, protein yield varied between 663.0

(cv. Rahmat) and 994.9 kg ha^{-1} (cv. BRS232) (Fig. 10). Also, the average protein yield of cultivars imported from Brazil was about 181 kg ha^{-1} higher than that of conventional cultivars (728.7 kg ha^{-1}).

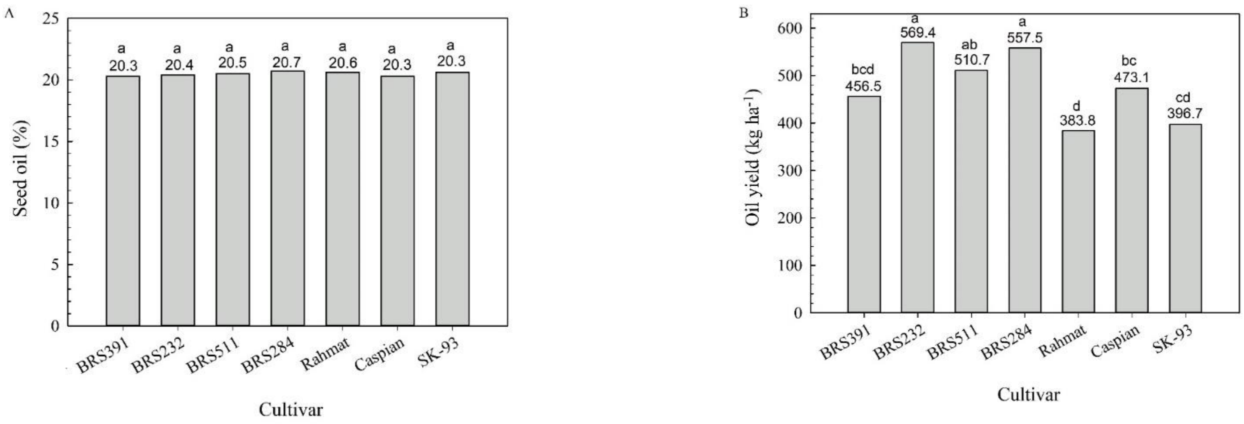

Figure 9. Mean comparison of the effect of cultivar on seed oil (A) and oil yield (B) in soybean.

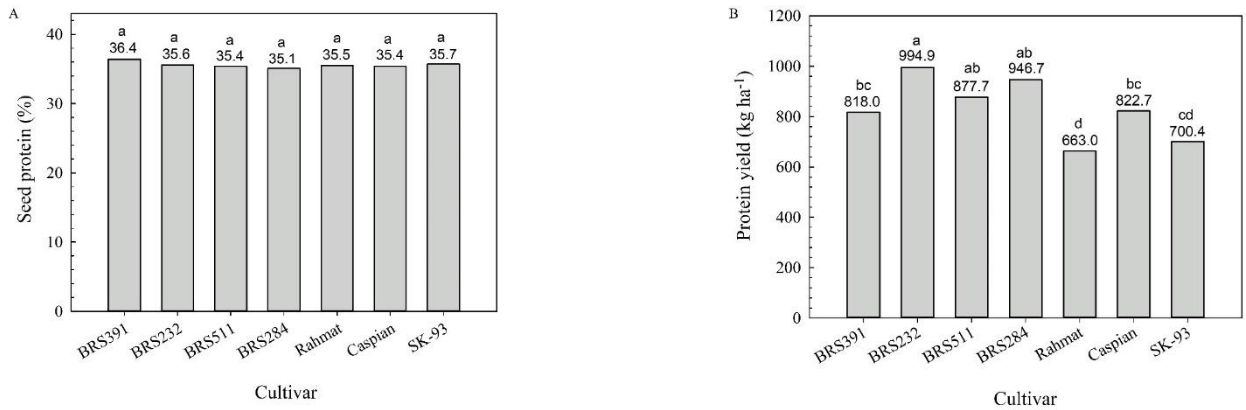

Figure 10. Mean comparison of the effect of cultivar on seed protein (A) and protein yield (B) in soybean.

3.11. Fatty acid composition

The fatty acid contents for the soybean cultivars studied are shown in Table 2 Linoleic acid showed the predominant average content (51.761%) among all the fatty acids, whereas stearic acid showed the lowest average content (4.69%) (Table 3). The widest range was noticed in oleic acid (21.84–26.97%), followed by linoleic acid (50.35–53.15%), while stearic acid showed the narrowest range (4.56–5.70%). The linolenic acid content exhibited the highest C.V. (10.48%) among the five fatty acids, revealing that the content of this fatty acid had the most abundant variation, which underlies the effect of diverse germplasms on linolenic acid content. Linoleic acid content, contrary to Linolenic acid, exhibited the lowest C.V. (2.08%) among all the fatty acids, which indicates it's less changeable across different germplasms.

Table 2. Fatty acid composition of soybean seed in the studied cultivars.

	Cultivar						
Component	Rahmat	Caspian	SK-93	BRS391	BRS232	BRS511	BRS284
Palmitic acid	10.89	12.68	10.59	12.34	11.47	10.67	10.94
Stearic acid	5.34	4.56	5.70	4.75	5.26	5.11	4.69
Oleic acid	26.97	22.71	24.25	21.84	24.56	26.68	24.72
Linoleic acid	50.35	53.15	52.07	52.31	50.85	50.83	52.73
Linolenic acid	5.80	6.23	6.47	7.68	6.81	6.10	6.17

Table 3. Statistical summary of soybean seed fatty acid composition.

Component	Mean	SD	Range	CV (%)	Min (%)	Max (%)	Skew	Kur
Palmitic acid	11.37	0.84	2.09	7.34	10.59	12.68	0.87	-1.04
Stearic acid	5.06	0.41	1.14	8.12	4.56	5.70	0.31	-1.04
Oleic acid	24.53	1.88	5.13	7.67	21.84	26.97	-0.04	-0.93
Linoleic acid	51.76	1.08	2.80	2.08	50.35	53.15	-0.09	-1.89
Linolenic acid	6.49	0.68	2.06	10.48	5.80	7.86	1.60	2.84

Mean, the content of each fatty acid is expressed as a percentage of total fatty acid content. SD, standard deviation; Range, data range; CV, coefficient of variation; Min, minimum; Max, maximum; Skew, skewness; Kur, kurtosis.

3.12. Relationships between agronomic characters and yield

Our results showed that yield had a positive relationship with the number of seeds per plant (with a correlation coefficient of 0.83), 1000-seed weight (with a correlation coefficient of 0.67), and plant height (with a correlation coefficient of 0.65) (Table 4). Conversely, seed yield had no significant correlation with the number of pods per plant, the number of branches per plant, flowering and ripening time, and the height of the first pod.

Table 4. Pearson correlation coefficients between agronomic characteristics and yield of soybean cultivars.

	Seed yield	No. of seeds per pod	No. of pods per plant	1000-seed weight	Seed oil	Seed protein	No. of branches per plant	Flowering time	Seed maturity time	Plant height	First pod height
Seed yield	1.00										
No. of seeds per pod	0.83**	1.00									
No. of pods per plant	0.40^{ns}	0.50*	1.00								
1000-seed weight	0.67**	0.45*	-0.02^{ns}	1.00							
Seed oil	0.12^{ns}	-0.17^{ns}	0.12^{ns}	-0.04^{ns}	1.00						
Seed protein	-0.07^{ns}	0.05^{ns}	-0.26^{ns}	-0.07^{ns}	-0.17^{ns}	1.00					
No. of branches per plant	-0.20^{ns}	-0.35^{ns}	-0.50*	0.15^{ns}	0.11^{ns}	-0.19^{ns}	1.00				
Flowering time	-0.09^{ns}	-0.11^{ns}	-0.64**	0.08^{ns}	-0.16^{ns}	0.26^{ns}	-0.19^{ns}	1.00			
Seed maturity time	0.25^{ns}	0.33^{ns}	0.77**	-0.22^{ns}	0.21^{ns}	-0.28^{ns}	-0.33^{ns}	-0.67**	1.00		
Plant height	0.65**	0.54*	0.07^{ns}	0.56**	0.02^{ns}	-0.15^{ns}	-0.22^{ns}	0.25^{ns}	0.16^{ns}	1.00	
First pod height	0.37^{ns}	0.39^{ns}	0.46*	0.48*	0.24^{ns}	-0.09^{ns}	-0.20^{ns}	-0.13^{ns}	0.12^{ns}	0.21^{ns}	1.00

^{ns}, * and ** indicate non-significance, significance at the probability level of 5 and 1%, respectively.

Reducing the height of the lowest pod node could lead to more pods and seeds per plant and higher yields (Qin *et al.*, 2017). However, there are harvesting difficulties with short stature grain legume crops, where basal pods are close to or touching the soil surface. Typically in mechanized harvesting, the lower the pod node distance from the soil surface, the higher the seed yield losses. In Iran, mechanized soybean production has been realized for ploughing and planting, but harvesting and weeding are still relatively manual. Improvements to mechanization at planting and harvesting, with particular attention to the height of the lowest pod, will benefit soybean productivity.

The length of the growing period is an important ecological adaptation for soybean traits and determines the scope of soybean varieties suitable for planting (Egli, 2008). A longer growing period generally increases biomass accumulation and, thereby, seed yield potential, but this has not occurred in any of the regions. Rather, a longer growing period increased the probability of lower temperatures (< 18 C) at the seed-filling stage, which resulted in a reduced seed-filling rate and a higher rate of pod abortion (Qin *et al*., 2017).

Rameeh et al. (2020) compared the yield of 22 soybean lines in Dezful and reported that the average number of pods per plant was between 31 and 54, which is consistent with the average observed for common cultivars in the country.

Studies in Canada have shown significant differences in seed weights among soybean cultivars (Wang *et al*., 2016; Wu *et al*., 2015) which are compatible with our results.

Sabokdast et al. (2008) identified a range for oil content between 19.5 and 21.4%, with an average of 20.3% for soybean in Karaj, which relates well to our values. Vaezirad et al. (2009) reported a range of 21.4 to 22.6%, with an average of 22.0% for different soybean cultivars, which is slightly higher than that for cultivars studied here.

Sabokdast et al. (2008) identified a range for protein between 31.3 and 34.2%, with an average of 33.1% for soybean in Karaj, which is slightly less than our values. Likewise, Vaezirad et al. (2009) observed a range of 26.3 to 29.7%, with an average of 27.7% for soybeans in Zanjan. It was suggested (Qin *et al*., 2014) that high latitudes in China are more conducive to soybean oil accumulation and that low latitudes are more conducive to protein formation. The oil content of soybeans from 19 provinces in China increased from southern to northern China, whereas the protein contents decreased (Li *et al*., 2004). The oil and protein content observed in our experiment was lower and higher than that reported in previous studies for the more Northern provinces, respectively (Vaezirad *et al*., 2009).

In general, the lower level of saturated fatty acids than unsaturated fatty acids in the present study was consistent with those previously reported (Abdelghany *et al*., 2020; Clemente and Cahoon, 2009; Fehr, 2007; Sabokdast *et al*., 2008). The observed stearic acid, palmitic acid (11.37%), and oleic acid (24.53%) levels in this study were high in comparison with previously reported by Sabokdast et al. (2008), while levels of linoleic acid (6.49%) and linolenic acid in this study were lower than those reported in previous studies (Abdelghany *et al*., 2020; Sabokdast *et al*., 2008). The content of unsaturated and saturated fatty acids observed in the present study was higher and lower, respectively, compared to that reported (Sabokdast *et al*., 2008) for the previous work in temperate climates. This can be ascribed to the effect of the more light-intensity and warmer climate of Khuzestan on the duration of oil synthesis.

Some studies have shown that genetic improvement occurs in soybean by increasing the number of seeds per pod and 1000-seed weight (Wang *et al*., 2016; Wu *et al*., 2015). In our study, the yield was positively related to 1000-grain weight and the number of seeds per pod, which is compatible with previous studies (Hao *et al*., 2000; Sun *et al*., 2001).

4. Conclusion

Overall, the results showed that soybean cultivars imported from Brazil into the Dezful climate had about 25% more pods per plant, 21% more seeds per pod, and 8% more seed weight than conventional cultivars. Conversely, the country's common soybean cultivars had 33% more branching than those imported from Brazil. Considering that seed yield had a significant positive relationship with the number of seeds per pod and 1000-seed weight, imported cultivars also yielded 20% more than the country's common soybean cultivars. Among the cultivars imported, BRS232 and BRS284 with seed yields of 2793 and 2697 kg ha^{-1}, respectively, showed higher production potential than the other two cultivars.

Conflict of interests

All authors declare no conflict of interest.

Ethics approval and consent to participate

No human or animals were used in the present research.

Consent for publications

All authors read and approved the final manuscript for publication.

Availability of data and material

All the data are embedded in the manuscript.

Authors' contributions

All authors had an equal role in study design, work, statistical analysis and manuscript writing.

Informed consent

The authors declare not to use any patients in this research.

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