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Comparison of the Yield and Yield Components of Four Imported Soybean Cultivars from Brazil with Domestic Cultivars in Khuzestan

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ABSTRACT

Given the importance of the soybean plant in supplying the country's oil, Gelareh Kalhor Agriculture Company, in cooperation with the Ministry of Agricultural Jihad, imported 4 cultivars of soybeans resistant to heat stress from Brazil and evaluated them in various tests. The present plan has compared the yield and some yield components of imported cultivars with 4 internal cultivars. This experiment was laid out in the form of a randomized complete block design with three replications on a farm on the outskirts of Safi Abad Dezful Research Center in the summer and fall of 2022. For this purpose, imported cultivars including BRS284, BRS232, BRS391 and BRS511 were compared with internal cultivars of Caspian, Rahmat, Saland and SK93. The results showed the superiority of imported cultivars compared to internal cultivars in most traits. Group comparisons between imported and internal cultivars showed that in the traits of the average number of pods per plant, thousand seed weight and yield, imported cultivars were higher than internal cultivars by 20.5, 29 and 35% respectively. The first pod setting height which indicates the harvest efficiency with the combined machine in all imported cultivars was higher than 20 cm. The yield comparison between different cultivars showed that all the imported cultivars had a yield higher than 3000 kg. The highest yield was obtained from the BRS511 cultivar at the rate of 3853 kg, followed by BRS284 (3575 kg) and Caspian (3339 kg). Besides that, the results of the correlation test between different traits with yield showed that the yield has the highest correlation with the average weight of 1000-seed (71%) and with the number of pods per plant (57%). In general, the results of this research revealed that the imported cultivars have a high potential in terms of production and in the future, they can become popular cultivars among farmers.

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1. Introduction

Soybean (*Glycine max* L.) is a vital legume crop. This plant which originated from East Asia, is completely compatible with the regions of temperate, tropical and subtropical and can be prosperously grown in spring as well as in summer seasons. Soybean seeds comprise 18-22% oil and 40-42% high-quality protein relying on environmental and genetic factors (Yoosefzadeh-Najafabadi *et al*., 2021). This plant is a main source of protein, vitamins, fat, energy, polyunsaturated fats, fibers, and minerals, both for humans and animals. On the other hand, it has many uses in industry and medicine, which has made it an important industrial crop in the world. The value of this plant is so high that it presents more than a quarter of the full protein for meals and animal feed in the world (Qin *et al*., 2022). Soybean protein contains high amounts of the amino acid lysine (5%), which is deficient in many plants (Rana *et al*., 2014). This plant together with 5 other species (oil palm, rapeseed, cottonseed, peanut, and sunflower) create 84 percent of the world's oil (Töpfer *et al*., 1995). Together with social improvement and populace boom, the demand for soybean is steadily enhancing. Statistical data show that soybean production in the world has elevated about thirteen times from 1961 to 2017, and this growth is in particular because of improvement activities and an increase in the area under planting

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(Rincker *et al.*, 2014). The global average yield of soybean is 2.8 tons per hectare (Ministry of Agriculture., 2021). The leading producing countries include the United States, Brazil and Argentina, which jointly produce more than 80% of the world's needs (Soares *et al.*, 2015). A good way to achieve high production in soybeans is the type and compatibility of the cultivar with environmental conditions. In this regard, Kumudini et al. (2002) by comparing old and new soybean cultivars, revealed that in new cultivars, high leaf durability during pod filling is an important factor for increasing yield. Breeding activities have led to the introduction of new and high-yielding soybean cultivars. Among the important and influential factors in soybean yield, the number of pods per plant, the weight of 1000-seeds and the number of seeds per pod are paramount (Yoosefzadeh-Najafabadi *et al.*, 2021; Diers *et al.*, 2018). However, most of the soybean growth indicators have a high correlation with increasing the yield of this plant (Ayub *et al.*, 2000; Mandic *et al.*, 2020). Salimi et al. (2021) suggested that among soybean growth traits, the number of seeds per plant and total dry weight has a higher correlation with soybean yield. Berhanu et al. (2021) revealed that soybean yield has a significant correlation with the number of days from germination to 50% of flowering and planting date and 1000-seed weight. In new cultivars, branching with disturbance in the growth of nearby plants and disturbance in harvesting is considered as a negative trait. Although branching is highly related to plant density, no branching or reduced branches are considered in the soybean breeding program. (Pedersen *et al.*, 2004). In general, the characteristics of an ideal cultivar are reported as follows: the desired cultivar should have one or at least two lateral branches, it should be able to be cultivated with a density of 270 thousand plants per hectare, and its height should be between 80 and 110 cm. It should have between 16 and 19 internodes, each node should have 2 to 4 pods and its 1000-seed weight should be between 210 and 230 grams (El-Badawy *et al.*, 2012; Silva *et al.*, 2015; Bihter *et al.*, 2017).

Iran lacks a desirable situation in terms of soybean production, and every year large amounts of currencies are withdrawn from the country for the import of soybeans grain. In 2021, Iran was the 16th country in terms of importing soybeans in the world by importing 1.92 million tons of seeds (tridge, 2021). The demands of the country for oil and the need to lessen the dependency on the import of this product have precipitated the general coverage of the Ministry of Agriculture to move towards encouraging the cultivation of oilseeds in order to supply the required oil. Currently, a cost equivalent to the consumption costs of all universities and higher education centers in the country is spent on importing oilseeds and supplying oil in the country. Therefore, research and development and finding high-yielding cultivars as well as determining areas compatible with existing cultivars are of great importance in. In 2021, Gelareh Kalhor Agriculture Company, in coordination with the Ministry of Agricultural Jihad, imported four cultivars of soybeans from Brazil and is currently researching the performance and stability of these cultivars and comparing the yield and indicators. Their functional values are different in various regions of the country, such as Khuzestan and Mazandaran. In this regard, this project was carried out in order to compare 4 imported cultivars with 4 internal cultivars in the Khuzestan region.

2. Materials and methods

This research was laid out on a farm on the outskirts of Dezful (Shahid Motahari Town) placed in the north of Khuzestan in 2022. Mean annual precipitation and mean annual minimum and maximum temperature for the study area (last 30 years) were 307 mm, 16.3 and 32.3 °C, respectively. The region has a semi-arid climate which receives precipitation below potential evapotranspiration. 15 days before planting, the research site was prepared by using a moldboard plow and after disking the soil, the ground was fertilized with 50 $kg.ha^{-1}$ of urea ((CH4N2O (46% N)), triple superphosphate Ca (H2PO4)2 H2O (43-44% P2O5), and potassium sulfate K2SO4 (40-8% P-S). At the growth stages of the V4 and R1, the urea fertilizer was side-dressed at a rate of 50 and 100 $kg.ha^{-1}$, respectively. Moreover, at the stage of R5, one kg ha^{-1} of humic acid was consumed. In this study, soybean seeds were not inoculated with any symbiotic strain of nitrogen-fixing bacteria. The total size of the agricultural land was 4000 meters and the size of each plot was 20 x 7.5 meters. Each plot included 10 rows and 20 planting lines, and in order to respect the distance between treatments, a distance of 1 meter between the plots inside each block and a distance of

1.5 meters between the blocks was considered. The experiment was designed as a randomized complete block with 3 replications. For this purpose, four tolerant cultivars imported from Brazil named BRS284, BRS511, BRS232 and BRS391 were compared with four common cultivars including Caspian, Rahmat, Saland and sk93. Planting was done on July 8, 2022, and the field was immediately irrigated. Germination of most of the seeds started on July 12 and on July 15, the whole field turned green. Until the end of the season, the field was irrigated regularly at intervals of 5 to 10 days relying on the temperature and moisture situations of the soil. During the growth of the plants, the field was kept free of weeds. Basagaran® (bentazon) herbicide was used to control broad-leaved weeds and Cycloxidim herbicide (Focus) was used to control narrow-leaved weeds. Uncontrolled weeds were controlled by manual weeding. Similarly, the field was kept free of pests and diseases till the end of the season. For pest control, depending on the conditions and type of pest, Cypermethrin, acetamide, deltamethrin and abamectin pesticides were used for spot control (whiteflies, mites and leaf-eating pests). Measurements and notes of different traits were done regularly from the beginning to the end of the growing season. The parameters of the day from planting to the emergence of seedlings, the emergence of the first and second nodes on the plant, the emergence of the first pod, the emergence of the first flower, the beginning of seed filling and the beginning and completion of ripening were recorded. In addition, before harvesting, the height of the plant and the distance of the first pod from the surface of the ground (characteristic of the combine harvester) were measured. In order to measure the yield, 9 square meters were harvested from each plot after removing the margins and then, the yield was determined by adjusting plot weight to 120 g kg–1 moisture. Seed mass was specified by a random sample of hundred seeds from the harvested seed from every plot. To measure the number of pods per plant, one square meter was harvested from each plot, and after counting the total number of pods (pods larger than 1 cm) and dividing by the number of plants, the number of pods per plant was achieved. To measure the number of seeds in a pod, the average number of pods in 10 plants was used. When a seed diameter was larger than 3 mm, it was counted. Ultimately, by using the GLM procedure of the SAS statistical program, the analysis of variance was carried out (SAS Institute, 2001). The means of treatment were compared by using Fisher's least significant difference (LSD) test. Finally, to determine correlations between the response variables across all cultivars studied, PROC CORR was used and all the figures were created by using Excel 2013.

3. Results and discussion

Table 1 indicates the general characteristics of the cultivars, including days to flowering, days to maturity, flower color, hilum color and growth type. The results of the analysis of variance are given in Table 2. Analysis of variance of seed yield and other parameters associated with yield indicates that the first pod setting height, plant height, number of pods per plant, number of seeds per pod and 1000-seed weight of various soybean cultivars differed significantly at 1 % possibility, whereas the yield of these cultivars varied with each other at 5 percent probability. Nevertheless, statistically non-significant differences were found between these cultivars' parameters with respect to root length. Information on means of parameters belonging to different soybean cultivars are given in Table 3.

Table 1. General characteristics of soybean cultivars

	Cultivar	Growth type	Color of flower	Color of hilum	Day to maturity	Day to flowering
Imported	BRA511	indeterminate	Purple	Cream	130	45
	BRS232	determinate	Purple	Cream	150	50
	BRS284	indeterminate	Purple	Cream	129	46
	BRS391	determinate	White	Cream	125	49
Internal	Caspian	indeterminate	White	Black	130	50
	Rahmat	indeterminate	Purple	Black	120	49
	Saland	indeterminate	Purple	Black	135	55
	SK93	indeterminate	Purple	Black	140	45

Table 2. Mean square of analysis of variance of grain yield and yield components of different soybean cultivars

Source of varitions	Degrees of freedom	First pod setting height (cm)	Root length (cm)	Plant height (cm)	Number of pods plant^{-1}	Number of seeds pod^{-1}	1000-seeds weight (g)	Yield (kg ha^{-1})
Replication	2	10.12	5.90	18.37	12.12	0.012	143.37	1902632
Cultivar	7	45.71**	13.57^{ns}	292.09**	318.1**	0.17**	1705**	1429391*
Error	14	4.27	2.61	0.9	8.55	0.05	41.96	542266

**, * and ns are significant at the 0.01 and 0.05 probability level and non-significant, respectively.

Table 3. Mean comparison of yield and yield components of different imported and internal soybean cultivars in Khuzestan region

Cultivar	Means Squares					
	Plant height (cm)	First pod setting height (cm)	Number of pods per plant	Number of seed per pod	100- seed weight (g)	Yield (kg)
BRS284	111^{ab}	23.3^{ab}	66.3^{a}	2.31^{a}	158^{a}	3575^{a}
BES511	101.33^{d}	20.67^{bc}	60.66^{b}	1.93^{abc}	159.3^{a}	3853^{a}
BRS232	114^{a}	27.7^{a}	63.6^{ab}	1.76^{bc}	157^{a}	3322^{ab}
BRS391	102^{cd}	23^{ab}	60.33^{b}	1.94^{abc}	134.3^{b}	3232^{ab}
Caspian	107^{bc}	22.33^{ab}	53^{c}	1.73^{c}	103.3^{c}	3339^{ab}
Rahmat	83.7^{e}	15.66^{c}	36.6^{e}	1.7^{c}	98^{c}	1697.3^{c}
Saland	144^{a}	28^{a}	63.3^{ab}	2.13^{ab}	135.3^{b}	2937.3^{ab}
SK-93	103^{cd}	23.33^{ab}	46.66^{e}	1.5^{bc}	136.7^{b}	2100^{bc}

Means with similar letters in each column are not significantly different at 5% level.

3.1. Plant height

The effect of cultivar type on the height of the plant was significant (Table 2). The comparison of the mean values of the plant height confirmed that among all cultivars, Saland has the highest (144 cm) height and Rahmat has the lowest height (83.7 cm), and the differences were significant (Table 3). Among the imported cultivars, the highest height was seen in BRS232 and BRS284 cultivars (114 and 111 cm, respectively) without any significant effect between them. In the next rank, Caspian and SK93 cultivars from Iranian cultivars and BRS391 and BRS511 from imported cultivars showed a height between 101 and 107 cm. A positive correlation has been reported between plant height and yield in soybean cultivars (Diers *et al.*, 2018). Malik et al. 2007 showed a strong correlation between yield with the first pod height, days to 50% flowering and maturity as well as plant height. Fig. 1 shows the average height of different cultivars side by side.

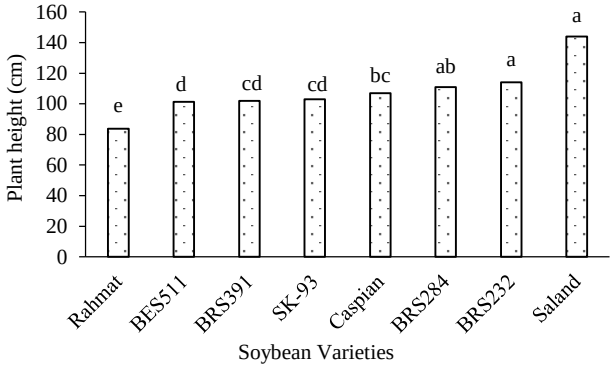

Figure 1. Mean comparison of plant height in different soybean cultivars

3.2. The first pod setting height

The variance analysis table of different traits (Table 2) showed that the cultivar type effect had a significant impact on the first pod setting height. The results of comparing the averages (Table 3) showed that the Saland cultivar, with the formation of the first pod at a height of 28 cm from the ground, is considered the best cultivar in terms of harvesting. In the second place, BRS23 (27.7 cm) had a slight difference with the Saland cultivar without any significant difference. It should be noted that, apart from the Rahmat cultivar, which had the weakest harvestability among cultivars with the formation of the first pod at a height of 15.66 cm, other cultivars formed their first pods at a height higher than 20 cm (Fig. 2). The high combiner properties can increase harvesting efficiency to a great extent. In mechanized harvesting, the pods that are formed near the soil surface are difficult to harvest and, in some cases, they cause seeds to mix with the soil (Kuzbakova *et al.*, 2022). Kang *et al.* (2017) reported that breeding a new type of soybean cultivar with a higher distance of the first pod from the ground can effectively reduce the seed losses while threshing. If the cutter bar level is too low, according to Borowska and Prusiński (2021), the seed yield is highest and significantly positive even with modern harvesters. it can be damaged physically by stones or other debris on the soil surface. As was reported in diverse cultivars of soybean, pods under 15 cm cannot be collected and resulting in net yield loss (Fratini *et al.*, 2007). Overall, the height of the lowest pod setting significantly depends on the type of cultivar, and amount of total rainfall and also enhances with an enhancement in plant density (Sobko *et al.*, 2019).

3.3. Number of pods per plant

The effect of cultivar type on the number of pods per plant had statistical significance (Table 1). The comparison of the mean values of the number of pods per plant showed that the imported cultivars BRS284 and BRS232 created the highest number of pods per

plant, 66.3 and 63.6, respectively. Also, Saland, BRS391 and BRS511 cultivars were not significantly different from the BRS232 cultivars by producing 63.3, 60.3 and 66.66 pods, respectively. Among the remaining Iranian cultivars, Rahmat produced the least pods per plant by producing 36.6 pods (Fig. 3). It should be noted that the number of pods per plant is a main component of the yield, which directly affects the yield of the plant. The number of pods per plant in soybean plants has the largest share among soybean yield components (Mandic *et al.,* 2020). Consistent with Egli et al. (2013), soybean yield is often related to the number of pods per area. Kahlon et al. (2018) showed that in soybean plants, increasing the pod number enhances the soybean yield. According to Mandic et al. (2020), the number of pods per plant, accompanied by the plant height and the first pod setting height is considered the essential soybean-yielding components.

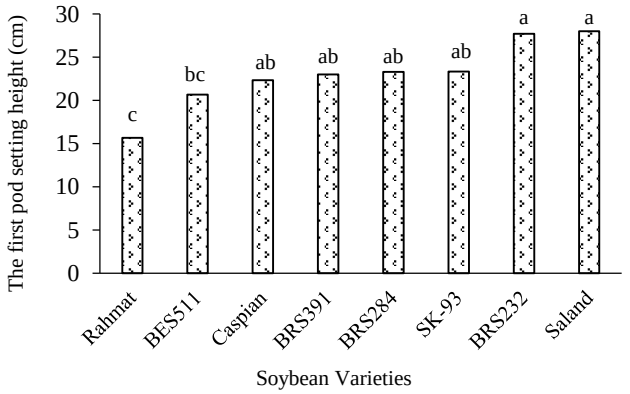

Figure 2. Mean comparison of the first pod setting height in different soybean cultivars

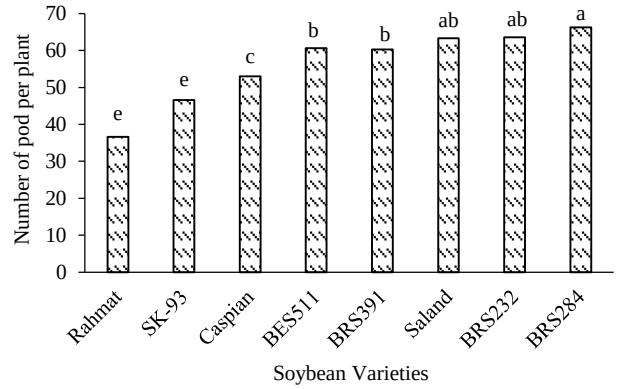

Figure 3. Mean comparison of Number of pod per plant in soybean cultivars

3.4. Number of seeds per pod

The results of comparing the average seed number of different cultivars revealed that cultivar BRS284, had the highest number of seeds with 2.32, and cultivar SK93 had the least number of seeds per pod with 1.5 seeds. After BRS284, Saland (2.13), BRS391 (1.94), BRS511 (1.93) and BRS232 (1.76) had the highest number of seeds per pod. Junior et al. (2017), calculated the number of seeds in the pod in the cultivar BRS284, 2.37, which is consistent with the results of this experiment. The number of seeds in a pod is one of the three components of yield, along with the number of pods in a plant and the weight of 1,000 seeds that make up the yield. Boehm et al. (2019) represented that some yield components including the numbers of pods per plant, number of seeds per pod and seed mass have a conclusive impact on soybean yield. Board et al. (1999) stated that correlations between seed number with yield are nearly two times stronger than that of the effect of seed weight in soybean. Gaspar and Conley (2015) as well as Wells (1991) indicated a positive correlation between seed number and seed yield (r = 0.98), whereas there was not a significant correlation between seed and yield. Fig. 4 shows the number of seeds per pod in different cultivars.

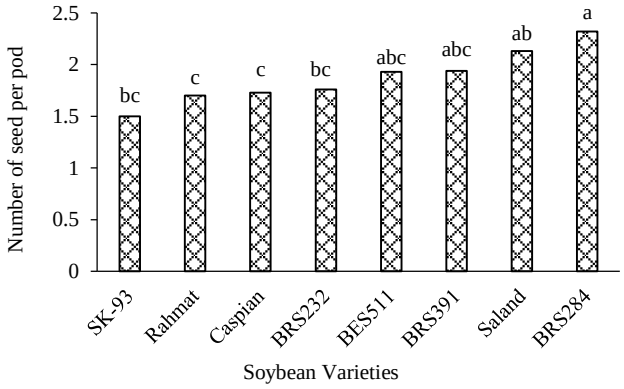

Figure 4. Mean comparison of number of seed per pod in soybean cultivars

3.5. 1000-seed weight

The average comparisons of different soybean cultivars are given in Table 3. The results of this trait showed that the imported cultivars BRS511, BRS284 and BRS232 produced the highest weight of 1000-seeds by producing 159.3, 158 and 157 grams, respectively. SK-93 cultivars with a weight of 136.7 grams per thousand seeds and BRS391 cultivars with a weight of 134.3 grams were ranked next. Also, the weight of 1000-seed of Saland, Caspian and Rahmat cultivars was 103.7, 103.3 and 85.3 grams, respectively. In the group comparison of cultivars, the

weight of 1000 seeds in imported cultivars were 22% higher than internal cultivars. Seidel et al. (2021) reported the weight of 1000-seed of BRS284, BRS511 and BRS391 cultivars as 150.9, 145.2 and 148.5 grams, respectively. Bateman et al. (2020), found a significant positive correlation between seed yield and 1000-seed weight. The 1000-seed weight in different cultivars is shown in Fig. 5.

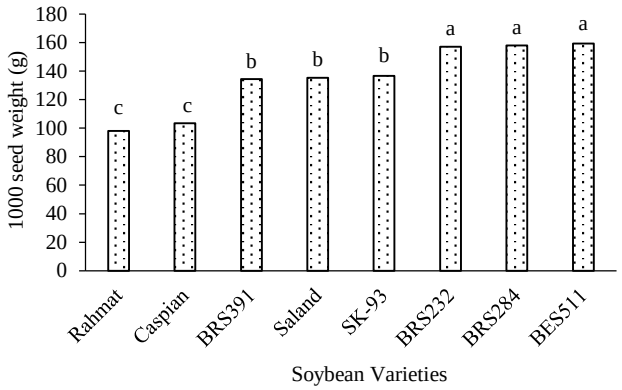

Figure 5. Mean comparison of 1000-seed weight in different soybean cultivars

3.6. Seed yield

A comparison of the average yield of different soybean cultivars in the Khuzestan region is given in Table 3. The obtained results indicate a significant superiority of yield in imported cultivars compared to internal cultivars (except for Caspian and Saland). Based on the results, the cultivar of BRS511 with a yield of 3853 kg showed the highest yield among all the cultivars. The cultivar BRS284 was ranked second with a yield of 3575 and the Caspian stood third with a yield of 3232 kg per hectare. Regarding the cultivar BRS284, Junior et al. (2017) stated that in addition to having a higher protein percentage, this cultivar also shows high yield stability in different cultivation dates. Also, BRS232 and BRS391 yielded more than 3000 kg, and there was no significant difference between them with BRS511. On the other hand, the yield of the remaining Iranian cultivars, including Saland, SK93, and Rahmat, was 2937, 2100, and 1697 kg, respectively. Group comparison between imported and internal cultivars showed that imported cultivars were 28% superior to internal cultivars. Yield is of the top issue for soybean growers. In the last 60 years, yields have increased by 60 percent. Through this period, more than 3900 cultivars of soybean have been released by plant breeders worldwide. One of the ways to improve the overall yield is to introduce high-yielding cultivars. Imported cultivars showed high yield potential in different regions and experiments. Fig. 6 shows the yield of different cultivars.

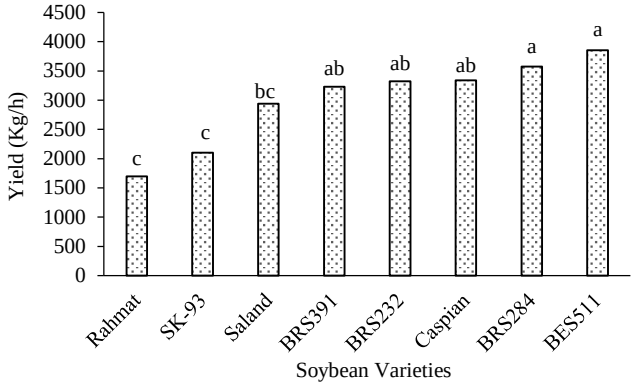

Figure 6. Mean comparison of yield in different soybean cultivars

3.7. Correlation coefficients

The correlation between the averages obtained from different parameters with yield indicated that the highest correlation was found between yield and the weight of 1000 seeds at the rate of 71%. Also, between the yield and the number of pods per plant, 57 percent of correlation was seen. On the contrary, no significant correlation between yield and the number of seeds per pod, the height of the plant and the first pod setting height were found. In this regard, Akhtar and Sneller (1996) showed the number of pods has the highest correlation with yield. Berhanu et al. (2021) also reported that soybean yield has a significant correlation with the number of pods per plant, the number of sub-branches, the number of seeds per pod and the height of the plant. According to Akram et al. (2016), significant positive correlations were seen between yield and the number of pods per plant (0.988) as well as the number of seeds per plant (0.94) and 100-seed weight (0.634). On the other hand, yield per plant experienced a negative correlation with days to first and 50% flowering and maturity, as well as plant height and the number of seeds per pods. According to Wei and Molin (2020), the number of seeds per soybean pod had 92 percent correlation with yield. Our result is consistent with the results of previous researchers who also found that the number of pods and seeds to be the most important plant traits that help to the improved the economic yield of soybean crops (Ayub *et al.*, 2000; Board *et al.*, 2003; Liu *et al.*, 2005)

Table 4. Correlation coefficients of grain yield with yield components in different soybean cultivars in Khuzestan region

	Yield (kg)	1000 seed weight (g)	Number of pods per plant	Number of seed per pod	Plant height (cm)	First pod setting height (cm)
Yield (kg)	1					
1000 seed weight (g)	0.705**	1				
Number of pods per plant	0.571**	0.611**	1			
Number of seed per pod	0.092ns	0.311ns	0.251ns	1		
Plant height (cm)	0.403ns	0.435*	0.812**	0.325ns	1	
First pod setting height (cm)	0.182ns	0.319ns	0.64**	0.35ns	0.85**	1

**, * and ns are significant at the 0.01 and 0.05 of probability level and non-significant, respectively.

4. Conclusion

In this experiment, the efficiency of 4 imported soybean cultivars was compared with 4 internal cultivars. The general results of the experiment pointed out the superiority of imported cultivars compared to domestic cultivars in most of the measured traits. Group comparison of the average yield in imported cultivars was 3495 kg and in internal cultivars was 2518 kg, which shows a 28% advantage in imported cultivars compared to domestic cultivars. In this regard, among the imported cultivars, BRS511 and BRS284 and among the internal cultivars Caspian and Saland were introduced as the best cultivars. In general, the results of this experiment showed that the imported cultivars, in addition to having a high yield potential, have better combining and harvesting efficiency than internal cultivars. Overall, the result of this research confirmed that in the future, these cultivars can replace the old soybean types as high-potential 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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