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Original Article

Effect of Water Deficit on Grain Yield and Yield Components Ispaghula (*Plantago ovata* Forssk.)

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Abstract

Drought is the major limiting factor of plant growth and productivity in many regions of the world. To determine the response of different ecotypes of ispaghula (*Plantago ovata* Forssk.) to drought stress, a field experiment was conducted at the Research Institute of Forests and Rangelands, Tehran, Iran in 2018. The experimental design was a split plot based on a randomized complete block design (RCBD) with three replications. The main factor included drought stress at three levels control (D1), drought stress after flowering stage with supplemental irrigation in the filling stage (D2), and post-flowering drought stress (D3). The second factor contained eight ecotypes of *Plantago ovate,* including Dehloran (3328), Alborz (3968), Markazi (14592), Dashtestan (21228), Hormozgan-1 (31536), Hormozgan-2 (31563), Ghaen (37496), and Sarbisheh (38917). The results showed a significant effect of drought stress and ecotypes for all traits ($P<0.01$). The interaction between ecotypes and drought stress was not significant for yield and yield components. Ispaghula ecotypes showed similar responses to drought stress. The highest grain yield with an average value of 720 kg/ha was obtained in ecotype 3328 and it was considered as the best ecotype to cope drought stress conditions. Ispaghula grain yield decreased by an average of 11.02% and 23.65% with drought stress D2 and D3 in comparison with control (D1), respectively. A significant difference between D2 and D3 were observed, so that the grain yield of D3 was 11.26% lower than D2. Regardless of the drought stress level, ecotype Dehloran (3328) produced the highest grain and was recommended for breeding improved varieties. Considering drought the ecotype Dehloran (3328) that had a good yield under normal irrigation conditions produced the least yields than other ecotypes.

Keywords: Drought Stress, Medicinal Plants, ispaghula, Grain Production

Introduction

Production of medicinal and aromatic plants is increasing in the world, due to their association with health benefits [1]. Medicinal plants are economically important that widely are used raw and processed in traditional and modern medicine. According to World Health Organization (WHO), medicinal plants are an accessible, affordable, and culturally appropriate source of primary health care for more than 80% of developing countries [2].

Plantago is the largest genus within the Plantaginaceae family comprising approximately 275 annuals and perennial species distributed all over the world. For centuries, *Plantago* species have been used in folk medicine because of their diverse properties [3]. Some species are particularly valuable in the nutraceutical and pharmaceutical industries due to the mucilaginous product (*psyllium*) derived from the seed husk, which has been used as a functional food and dietary supplement to improve intestinal health [4]. The value of *Plantago* seeds is due to the quantity and quality of mucilage in the

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surface layers of shell and grain [5]. *Plantago* is especially distributed in India, Iran, Pakistan, and Bangladesh [6].

The two most important species of this genus are *P. psyllium* and *P. ovata* Forssk. In Iran, they are called Asfarzeh, which have wide uses in industry and pharmacy. Ispaghula (*P. ovata* Forssk.) is an annual species that originated from arid and semi-arid zones and is used widely in traditional and industrial pharmacology. Seeds and husks of ispaghula are also used widely in pharmacology as laxatives. Interest in ispaghula has risen primarily due to its use in high fiber breakfast cereals and from claims that it is effective in reducing cholesterol [7]. The seed coat contains mucilage and hemicellulose which cause a strong swelling of seeds. Mucilaginous compounds found in medicinal raw material contain xylose, rhamnose, arabinose, galactose, and uronic acids as well as sugars (planteose, glucose, and fructose), oil, phytosterols, aucubin, monoterpene, and triterpene alkaloids. Seeds of the ispaghula are used as a protective and coating drug and also as a purgative. Ispaghula seeds have also been found to reduce the level of cholesterol [31].

Drought is one of the most important limiting factors of plant growth worldwide and it is the most common environmental stress that has limited the production of approximately 25% of the world's land. Due to the situation in Iran, which is located in an arid and semi-arid region, and the existence of water crisis in these areas, the selection of plants that adapted to these conditions is important and requires evaluation and selection the drought-tolerant varieties with low water requirement [8]. Many of the processes that happen in plants, both directly and indirectly, depending on the presence of water. Water stress has various effects on the metabolism, morphology, and physiology of the plant, including reduced leaf area, stimulation of leaf-fall, turbulence reduction and consequently decreased cell development and organ growth [9], stomatal closure in response to Abscisic acid [10], photosynthetic limitations [11], increased degradation of carbohydrates, proteins, nucleic acids and osmotic regulation [12] and decreased absorption of nutrients and elements [13].

According to Rahimi *et al*., the amount of proline accumulation in ispaghula increased under water stress conditions, which it indicates its resistance to drought stress [7]. There are reports which indicate the resistance of some medicinal plants as ispaghula to water stress [14], however, *P. psyllium* L. is susceptible to water stress [15]. Najafi in his study on ispaghula observed that 7-day irrigation intervals had the highest grain yield and with decreasing irrigation intervals, plant height, and spikes number per plant, straw yield and grain yield increased [16]. So, in many cases moderate water stress could enhance the content of active substances in medicinal plants, otherwise, water stress in growth and development stages is extremely affected on active substances [17]. Rahimi *et al*. also found a significant decrease in leaf chlorophyll of *P. ovate* under drought stress conditions [18]. In general, the purpose of this experiment was to investigate the effect of drought stress on grain yield and yield components of this species. This research was done to increase economic yield and with desirable quality to be able to meet the domestic needs of the pharmaceutical industry.

Material and Methods

This study was carried out at the experimental farm of Research Institute of Forests and Rangelands, Tehran, Iran (latitude, 35°48′ N, longitude, 51°00′ E, Elevation, 1320 m above sea level) in 2018. The soil of the experimental site was sandy (Table 1). Climate records (20-yr) from a Karaj meteorological station indicate a mean annual total precipitation of 235 mm with relative humidity (68%). The mean annual temperature at this nearby site was 16°C.

A split plot design based on Randomized Complete Block Design (RCBD) with three replications was conducted. The first factor was drought stress at three levels (control-D1, drought stress after flowering stage with a supplemental irrigation in the filling stage D2 and post-flowering drought stress- D3). The second factor was eight Ecotypes of *P. ovate*, including: Ilam-Dehloran (3328), Alborz (3968), Markazi (14592), Bushehr-Dashtestan (21228), Hormozgan-1 (31536), Hormozgan2 (31563), South Khorasan-Ghaen (37496) and South Khorasan-Sarbisheh (38917).

Table 1 Physical and chemical properties of the soil before the experiment.

Depth (cm)	Sand (%)	Clay (%)	Silt (%)	Soil texture	K (mg/kg)	P (mg/kg)	Organic Carbon (%)	EC (ds/m)	pH
0-15	45	25	30	Loam	197.6	10.2	0.57	0.22	8.5
15-30	53	21	26	Silty Clay Loam	178.6	8.7	0.68	0.19	8.4

Table 2 Topographical characteristics of the ispaghula ecotypes to be tested

Place (ecotypes)	Longitude	Altitude	Elevation (m, above sea level)
Ilam-Dehloran (3328),	47° 26′ E	32° 69′ N	213
Alborz (3968)	50° 97′ E	35° 82′ N	1300
Markazi (14592)	49° 7′ E	34° 08′ N	1743
Bushehr-Dashtestan (21228)	51° 20′ E	29° 26′ N	80
Hormozgan-1 (31536)	56° 27′ E	27° 18′ N	20
Hormozgan2 (31563)	56° 27′ E	27° 18′ N	20
South Khorasan-Ghaen (37496)	59° 18′ E	33° 73′ N	1432
South Khorasan-Sarbisheh (38917)	59° 81′ E	32° 59′ N	1839

The experimental plot was 3×2 m^2. Seeds were sown manually at a row distance of 50 cm in 0.5 cm depth at the date 19 April 2018. The distance between the plants in the row was 30 cm. Irrigation was applied every 7-day interval up to the flowering stage, then the drought stress was applied. During the growing season, weeds were controlled manually many times if necessary. In this experiment nitrogen and phosphorus fertilizers were added with a dose of 100 kg/haurea (46% N) and 150 kg/hatriple superphosphate (19.8% P), based on soil test and fertilizer recommendations for ispaghula before sowing, respectively.

After biological maturity, 10 plants were randomly sampled from each plot for measuring plant height, spike length, spikes per plant, seeds number per spike, and 1000 seeds weight and averaged as mean of the plot. Grain yield was measured from each plot after removing two side rows as border effects [18]. Analyses of variance (ANOVA) were conducted using SAS procedures [19] and means were compared using LSD test at α=0.05.

Results and Discussion

Analysis of variance showed that the main effect of ecotype was significant (*P*<0.01) for all traits (Table 3). Moreover, the main effect of drought stress was also found to be significant for plant height, spike length, spikes per plant, number of seeds per plant spike and grain yield (*P*<0.01), and 1000-seed weight (P<0.05). Interaction between ecotypes and drought stress was not significant for yield and yield components (Table 3).

In all ispaghula ecotypes, drought stress reduced plant height by 15.78%. Reduction of plant height could be due to the reduction in photosynthesis area, decreased chlorophyll content, rising of the energy consumed by the plant to take water and to increase the density of the protoplasm and to change respiratory paths and the activation of pentose phosphate pathway, or the reduction of the root deploy, etc. [20]. The lowest and highest amount of plant height was observed in ecotypes 37496 (23.56 cm) and 31536 (9.67 cm) (Table 4).

A means comparison of the drought stress levels on plant growth parameters is presented in Table 5. Results showed the plant height in the control treatment (D1=16.67 cm) was significantly higher than those in drought stress after the flowering stage with supplemental irrigation in the filling stage (D2=15.54 cm) and post-flowering drought stress (D3=14.04 cm). Reduction of the plant height in response to drought stress can be due to the blockage of xylem and phloem vessels, after which the transfer of materials and assimilate from the plant is reduced [21].

The longest and the shortest spike length observed in ecotypes 38917 (1.94 cm) and 31563 (0.99 cm) (Table 4). Based on the mean comparison, the spike length decreased under drought stress compared to control (1.71 cm) (Table 5). The reduction of spike length under stress conditions can be a result of reduced photosynthesis and subsequently reduced production and transfer of assimilates for plant growth [22]. Bhagat reported a positive correlation between seed number and spike length with grain yield in ispaghula [23]. An increase in the spike length in response to the increase of irrigation frequency and decreasing the irrigation intervals has been reported by Tabrizi in both ispaghula and psilium (*P. psyllium*) [24].

Table 3 Mean squares from analysis of variance for the effects of ispaghula ecotypes (A), drought stress (D), and their interactions on the various parameters measured in the study.

S.OV.	df	Mean Square					
		Plant height	Spike length	Spikes per plant	Seed No. per spike	1000 seeds weight	Grain yield
Replication	2	1.97	0.05	10.09	53.76	0.28	6988.54
Ecotypes (A)	7	244.16**	1.23**	216.57**	500.89**	1.09**	107605.25**
Drought (D)	2	41.63**	1.34**	1000.93**	1650.39**	0.65*	148635.17**
A×D	14	1.53ns	0.06 ns	46.87ns	58.77ns	0.03ns	5200.53ns
Error	46	3.24	0.09	27.58	72.21	0.09	4846.27
CV (%)	-	11.68	19.98	24.07	32.54	25.94	10.42

ns, * and ** are non-significant and significant at 5 and 1 percent probability levels, respectively.

Table 4 Means comparison of the growth parameters of ispaghula ecotypes averaged over drought stress

Ecotype code	Origin	Province	Plant height (cm)	Spike length (cm)	Spikes per plant	Seed No. per spike	1000 seeds weight (g)	Grain yield (kg/ha)
14592	Arak	Markazi	11.39 e	1.57 b	20.22 bcd	39.00 a	1.50 a	772.44 a
21228	Dashtestan	Bushehr	16.22 c	1.67 ab	24.89 ab	31.33 ab	1.11 b	613.11 b
31536	Hormozgan1	Hormozgan	9.67 f	1.09 c	19.67 cd	28.89 b	0.69 c	507.22 c
31563	Hormozgan2	Hormozgan	9.94 ef	0.99 c	16.11 d	27.22 bc	0.61 c	510.33 c
3328	Dehloran	Ilam	13.11d	1.06 c	15.78 d	27.22 bc	1.28 ab	720.00 a
37496	Ghaen	South Khorasan	23.56 a	1.82 ab	26.78 a	20.67 cd	1.38 ab	715.78 a
38917	Sarbisheh	South Khorasan	18.89 b	1.94 a	29.44 a	17.67 d	1.44 a	746.33 a
3968	Karaj	Alborz	20.56 b	1.59 b	21.67 bc	16.89 d	1.43 a	757.11 a
LSD 0.05			1.7091	0.28	4.99	8.06	0.29	66.057

Means with a different letter in each column are not significantly different (LSD=5%).

Table 5 Means comparison of the growth parameters of drought stress levels averaged over ispaghula ecotypes

Drought stress	Plant height (cm)	Spike length (cm)	Spikes per plant	Number of seed per spike	1000 seeds weight (g)	Grain yield (kg ha^{-1})
D1	16.67 a	1.71 a	29.17 a	35.00 a	1.34 a	747.71 a
D2	15.54 b	1.44 b	19.25 b	24.75 b	1.18 ab	665.29 b
D3	14.04 c	1.24 c	17.04 b	18.583 c	1.02 b	590.38 c
LSD 0.05	1.04	0.17	3.05	4.93	0.18	66.06

Means with a different letter in each column are not significantly different (LSD=5%).
D1, control; D2, drought stress after flowering stage with supplemental irrigation in the filling stage; D3, post-flowering drought stress.

The number of spikes in the plant is one of the yield components that determine the yield potential because the spikes contain the grain numbers and on the other hand, provide the photosynthetic material needed by the seeds [8]. The highest Spikes per plant was recorded for the ecotype 38917 (29.44). Most spikes per plant were observed in the control irrigation (29.17). Drought stress reduced the number of spikes to 19.25 and 17.04 for D2 and D3, respectively (Table 5). Drought stress may reduce the flowering intensity or delay the flowering stage or shorten the flowering period [25]. Similar to the result reported by Mousavinick that showed by decreasing the irrigation frequency in ispaghula, the number of spikes was decreased [26].
The number of seeds per spike determines sink capacity. The higher number of seeds represents the larger sink for receiving photosynthetic material and increasing this trait led to the higher yield [8]. The number of seeds per spike in ecotype 14592 with an average value of 39 was significantly higher than other ecotypes. The highest number of seeds per spike with an average value of 35 was observed in the control irrigation (Table 4), indicating drought stress decreased the number of seeds per spike in comparison with control irrigation. Ramroudi *et al*. reported that the number of spikes per plant and the number of seeds per spike on ispaghula decreased in the delayed irrigation at the flowering stage [27]. In many crops, the occurrence of water stress at the flowering stage reduces the number of fertile flowers and consequently reduces the number of seeds and thus greatly reduces yield [8]. Since the potential number of seeds is determined at the time of pollination and before, the main reason for decreasing number of seeds under severe water stress at the flowering stage can be mainly decreasing the allocation of nutrients to each grain and then increasing the number of empty seeds in the spike [28]. 1000-seed weight differed among ecotypes and the highest was in ecotype "14592" (1.5 g) (Table 4).
Also, the lowest and highest amount of 1000 seeds weight was obtained in the control (D1=1.34 g) and post-flowering drought stress (D3=1.02 g), respectively (Table 5). There was no significant difference between drought stress after the flowering stage with supplemental irrigation in the filling stage (D2) and post-flowering drought stress (D3). Water stress was effective on sink size, reduced the source capacity, and caused a reduction of seed weight consequently. In many crops, water stress impresses on grains during the grain filling period and causes seed wrinkling, which can be due to the closure of the stomata, reduced leaf area, and reduced photosynthetic activity in the reaction to water shortage as well as shortening of the grain filling period in water stress treatments [29]. According to Najafi, the maximum 1000 seeds weight (1.8 g) for ispaghula was obtained in the 7 days irrigation interval, although there was no significant difference between 12, 14, and 28 days irrigation interval [16]. Tabrizi found the highest 1000 seeds weight in the 10 days irrigation interval [24], also

was reported that there was a significant difference in the irrigation interval between 10 and 20 days irrigation treatments in ispaghula [24].

Regardless of drought stress, the ecotype ‘3328’ produced the highest grain yield (720 kg/ha) (Table 4). A significant difference in grain yield was observed among different levels of drought stress. Control treatments had the highest grain yield with an average of 747.71 kg/ha. Ispaghula grain yield decreased by an average of 11.02% with drought stress after the flowering stage with supplemental irrigation in the filling stage (D2) and 23.65% with post-flowering drought stress (D3) in comparison with control (D1). Also, there was a significant difference between drought stress after the flowering stage with supplemental irrigation in the filling stage (D2) post-flowering drought stress, and grain yield decreased by 11.26% (Table 5).

Reducing the amount of irrigation had negative effects on grain yield components. The reason for this decrease can be attributed to less vegetative growth and consequently, more limited photosynthetic level and less dry matter production in the plant under drought conditions. On the other hand, shortening the grain filling period and earlier ripening due to drought stress can be effective in reducing grain yield [28]. It seems that the reduction of grain yield under irrigation cutoff in the flowering stage compared to stopping irrigation at filling stage is due to the reduction of photosynthesis period and transferring of current photosynthesis material to seed and also reducing remobilization of stored material in the stem to seed. As a result, grain yield has been reduced. Afsharmanesh *et al*. reported that the grain yield of ispaghula under severe stress conditions (irrigation after 25% of field capacity) was 88 kg/ha, which compared to mild stress (irrigation after 75% of field capacity), it decreased by 43% [30]. Tabrizi by studying the effect of irrigation intervals of 10, 20, and 30 days on ispaghula yield and its components, observed the highest yield at irrigation intervals of 10 days [24]. Also, with reducing irrigation intervals, plant height, the number of spikes per plant, straw yield, and grain yield increased.

Conclusion

In this study, our results demonstrated that grain yield and yield components were significantly reduced by drought stress after the flowering stage with supplemental irrigation in the filling stage and post-flowering drought stress of ispaghula ecotypes. The differential response of ecotypes to imposed water stress conditions indicates the drought tolerance ability of ecotypes. Ecotype "3328" showed a higher ability to capture soil moisture under severe competition and had the least reduction in seed yield compared to the other ecotypes. Ecotype "37496" had the lowest percentage of yield reduction and it was the best yielding in water stress conditions.

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