Journal of Medicinal Plants and By-products (2016) 2: 145-152

Original Article

Impact of Ssuper Absorbent Polymer and Irrigation Management on Seed and Essential Oil Yields of Cumin

Alireza Samadzadeh[1], Hamid Reza Fallahi[1*], Gholamreza Zamani[1], Shahram Nakhaie[2] and Mahsa Aghhavani-Shajari[3], Amin Amirizadeh[1]

[1]*Department of Agronomy and Plant Breeding, Faculty of Agriculture, University of Birjand, Birjand, Iran*
[2]*Seed Science and Technology Group, Department of Agronomy and Plant Breeding, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran*
[3]*Department of Agronomy, Ferdowsi University of Mashhad, Mashhad, Iran*

Article History: Received: 26 October 2015 /Accepted in revised form: 19 June 2016
© 2013 Iranian Society of Medicinal Plants. All rights reserve

Abstract

Two field and laboratory experiments were conducted to investigate the effects of superabsorbent polymer (SAP) and irrigation management on seed and essential oil yields of Cumin, as well as the impact of water quality on water holding capacity of SAP. Salinity had a negative effect on the amount of water absorbed by SAP (335 and 59 g H_2O per g SAP, for distilled water and solution of 0.5% NaCl, respectively). SAP application (30 $kg.ha^{-1}$) along with three times irrigation at sowing, flowering and seed filling stages increased the amounts of seed and essential oil yields by 2.79 and 3.05 times, compared to control. Positive effects of SAP were related to enhancement of soil water holding capacity (120 gr irrigation water per gr SAP), leaf area duration (one week) and subsequently grain filling period.

Keywords: Deficit irrigation, Leaf area duration, Medicinal plants, Secondary metabolites

Introduction

Cumin (*Cuminum cyminum* L.) as a commercial seed spice crop belongs to the family of Apiaceae. This annual plant is valued for its aroma and medicinal properties. Some therapeutic benefits of different isolated constituents from cumin are including antimicrobial, anti-carcinogenic, anti-diabetic and antioxidant effects. Cumin seed contains around 3-4% volatile oil, 12% protein, 11% starch, 33% carbohydrate and 15% fat. However, it's essential oil composition depends on many factors such as region, climate, plant part, harvest-time, extraction method, cultivar type and storage conditions. The main compounds of cumin seed oil are cuminaldehyde, α-pinene , β-pinene, γ-terpinene, *p*-mentha- 1,3-dien-7-al, *p*-mentha-1,4-dien-7-al and *p*-cymene [1-5].

The main producers of cumin in the world are including Iran, India, Syria, Turkey, Egypt and Morocco [2-6]. This short-lived crop (~3-4 months) is a domestic medicinal plant in Iran, which has been cultivated for centuries within the country especially in Great Khorasan province (Latitude: 30º 31´- 38º 14´N and Longitude: 56º 3´- 61º 16´E). Cumin is resistance to drought stress, so that ~250 mm rainfall is sufficient for its satisfactory production [7-9]. However, it seems that low water availability is affecting growth and metabolic activities of cumin like other plant species. It has been reported that generally water stress has negative effects on growth and development, but positive effect on biosynthesis of secondary metabolites and enzyme activities in many medicinal plants [9,10].
Cumin is cultivated in areas with low rainfall where drought stress is a common problem, thus

*Corresponding author: Department of Agronomy and Plant Breeding, Faculty of Agriculture, University of Birjand, Birjand, Iran
Email Address: Hamidreza.fallahi@birjand.ac.ir

developing suitable irrigation managements is vital for minimizing its yield and quality reduction [10]. So far, some investigations performed on water management of cumin. Mazaheri *et al*., [11] concluded that stopping irrigation at vegetative stage of cumin led to considerable reduction in seed yield. Also, essential oil yield decreased with increasing of drought severity. Bettaibe *et al*., [12] found that moderate water deficit (50% of field capacity) improved the nutritional value and growth of cumin aerial parts. Results of Rebey *et al*., [9] also showed that moderate water deficit improved the number of umbels and umbellets as well as the seed yield, compared with control, but these indices decreased under sever water deficit (25% of field capacity) condition. In another study, Alinia and Razmjoo [10] suggested that cumin is a drought tolerant species, but its water requirement depends on genotypes and purpose of cultivation.

The root depth of cumin is 12-15 cm, showing that its more water needs is supplied from the upper soil layer [11]. Therefore, programs such as application of super absorbent polymers, is effective way for keeping moisture from rainfall and irrigation in the soil surface layer. So far, positive effects of SAP application has been reported on some crops like peanut and sorghum [13,14]. Super absorbents are hydrophilic cross linked polymers that can absorb lots of water to create a water reservoir, near the root. These polymers grow into several times of their original size, after absorbing water. SAPs delay the time to reach wilting point and prolong plant survival under drought stress by increasing water-holding capacity and nutrient retention of soil. Therefore, they are helpful materials to increase crop production in arid and semiarid areas [15-17].

Given the importance of medicinal plants and the problems caused by drought in a significant parts of the world, the main objectives of this study were to investigate: 1- the effect of water quality on moisture holding capacity of SAP, 2- impacts of SAP application on growth, seed and essential oil yields of cumin and 3- qualitative and quantitative response of cumin to the amount of water availability during its growth period.

Materials and Methods

Study Location

This experiment was conducted during 2013-2014 at the research station of Sarayan College of Agriculture (33°N, 58°E and 1450 masl), University of Birjand, located in the South Khorasan province, Eastern part of Iran. The amounts of long-term rainfall and temperature of sarayan are 150 mm and 17°C, respectively. The main climatic indices of experimental site are given in Table 1.

Experimental Design

In order to investigate the influence of chemical super absorbent polymer (SAP) and irrigation management (IM) on growth, yield and quality of Cumin a factorial experiment based on a randomized complete block design with 3 replications was conducted. Experimental factors were consisted of 2 levels of SAP (0 and 30 $kg.ha^1$) and 4 different IM including irrigation after sowing (SI), SI + irrigation at flowering stage (SI + FI), SI + irrigation at seed filling stage (SI + SFI) and SI+FI+SFI.

Experimental Materials

Cumin seeds were from sarayan landraces. Super absorbent used was a chemical polymer that its main properties are presented in table 2. The consumed SAP was made of potassium polyacrylate and polyacrylamide copolymers. Moisture uptake capacity of SAP is related to water quality. Therefore, this index was measured for distilled water, irrigation water and Solution of 0.5% NaCl, during the first hour of moisture supply (Table 4). The amounts of main criteria for irrigation water are shown in Table 3.

Agronomic Practices

Land preparation was done in early fall and seed planting of Cumin was applied manually in 3 × 3 m plots, with a density of 60 plant per m^2 in 4 December. Before planting amounts of 150 $kg.ha^{-1}$ of diammonium phosphate, 100 $kg.ha^{-1}$ potassium sulfate and 50 $kg.ha^{-1}$ urea were added to the soil. SAP was used properly at a depth of 5 cm below seedbed. All plots were irrigated after seed sowing and then next irrigations were applied according to experimental treatments. Hand weeding of all plots was done 1 time in 10 April. Also, chemical thrips control was done by oxydemeton-methyl (metasystox) (2 liter in 100 liter water) in spring. Leaf area duration in plots treated by SAP lasted about 1 more week compared to non-treated plots. Therefore, seed maturity in SAP application treatment was delayed 1 week and seed harvesting was done in 2 different dates.

Table 1 Some monthly climate features of experimental site during Cumin growth season in 2013 and 2014

Growth months	Temperature (°C)	Rainfall (mm)	Evaporation (mm)	Humidity (%)	Sunshine (hours)
December	9.7	9.7	72.0	49	216.8
January	2.3	9.6	-	58	188.1
February	5.3	4.3	-	53	224.4
March	11.1	20.3	-	43	210.0
April	15.7	13.0	~230	37	288.9
May	22.6	7.2	259.8	29	268.4
June	27.6	0.1	381.4	18	336.5

Table 2 The main features of superabsorbent polymer.

Index	Description	Index	Description
Appearance	White granule	Grain size (mm)	0.5-1
Density (gr. cm^{-3})	1.1-1.5	pH	7.4
Moisture content (%)	11.6	Maximum durability (year)	7

Table 3 Some qualitative indices of irrigation water in research station.

EC (µm.cm)	pH	TDS (ppm)	Ca^{2+} (ppm as $CaCo_3$)	Mg^{2+} (ppm as $Caco_3$)	Na^+ (ppm)	K^+ (ppm)	Cl^- (ppm)
1300	7.81	8510	48	51.5	156.4	0.45	170.4

Table 4 The actual capacity of moisture absorbing by super absorbent polymer in response to water quality during the first hour of water availibility.

Treatment	Solution of 0.5% NaCl	Irrigation water*	Distilled water
Water holding capacity (gr.gr^{-1})	59	120	335

*EC= 1300 µm/cm

Sampling and Measured Criteria

In each plot, 8 plants were randomly sampled 1 day before seed harvesting and then growth indices and yield components were measured. These indices were including of plant height, plant dry weight, number of lateral branches, number of umbel per plant, number of umbellets per umbel, number of seed per umbel, number of seeds per plant, seed yield per plant and thousand seed weight. For determining the final seed yield of each treatment, the remaining plants in each plot were harvested separately. Essential oil extraction was made by hydro-distillation method. For this purpose, 3 samples of air-dried Cumin seeds of each treatment were finely ground in an electric grinder. Then, 25 grams of each ground fruits were used for 3.5 hours hydro-distillation by Clevenger-type apparatus. Finally, the volume of the collected oil was measured [2].

Data Analysis

Data analysis was done by SAS 9.1 software. Moreover, means comparisons was done by Duncan's multiple range test at the 5% level of probability.

Results

Water Quality and SAP Efficiency

Moisture absorbent capacity of superabsorbent polymer (SAP) was affected considerably by the amount of water salts. The value of this index in distilled water treatment was ~10-fold higher than control (solution of 0.5% NaCl). In addition, the capacity of SAP for absorbing of irrigation water of research station (EC=1300 µm/cm) was 2.5 times higher than control treatment (Table 4). Therefore, the use of SAP is most effective for increasing soil water holding capacity, if irrigation water is not salty.

Seed Yield and Yield Components

Interaction effects of SAP and irrigation management (IM) were significant on almost all growth indices and yield components of Cumin (Table 5).

SAP application had a positive effect on plant dry weight and increased it 2.1-fold compared to control. Consumption of SAP along with 3 times irrigation at sowing (SI), flowering (FI) and seed filling (SFI) stages was the best treatment in terms of numbers of lateral branches and umbels per plant (Table 6). The highest number of umbellets obtained when SAP was used in all irrigation treatments. SI+FI+SFI plus SAP usage was the best treatment in terms of number of seeds per umbel and per plant as well as seed yield per plant. The amount of thousand seed weight in all irrigation treatments was higher than control (SI). Moreover, this index in SAP application treatment was 15% more than non-SAP treatment (Table 6, 7).

Seed yield of Cumin was significantly affected by SAP application and IM (Table 5). SAP application produced 24% more seed compared to non-SAP treatment. In addition, seed yield in SI+FI+SFI was 37, 26 and 11% higher than SI, SI+FI and SI+SFI treatments, respectively. Overall, the maximum value of seed yield obtained at SI+FI+SFI plus SAP usage, so that this index in mentioned treatment was 2.8 times more than control (SI + non-SAP) (Table 7).

Essential oil yield

Effect of IM and IM×SAP was not significant on essential oil percentage of Cumin, while SAP was significantly affected this index (Table 5). Application of SAP increased the amount of essential oil percentage by 8%. Three irrigation times at sowing, flowering and seed filling stages in combination with 30 kg.ha^{-1} SAP application was the best treatment in terms of essential oil yield. This treatment increased the amount of Cumin essence yield by more than 3-fold compared to control (SI + non-SAP) treatment (Table 7).

Table 5 Analysis of variance (sum of squares) for effect of SAP and IM on quantitative and qualitative indices of Cumin

Source of variation	df	Plant height	Plant dry weight	Number of lateral branches	Number of umbels per plant	Number of umbellets per umbel	Number of seeds per umbel
Replication	2	10.5^{ns}	0.37^{ns}	201.6*	201.6*	0.001^{ns}	0.18^{ns}
IM	3	22.5^{ns}	3.55**	211.2^{ns}	211.2^{ns}	0.040*	43.5**
SAP	1	81.6**	17.52**	3682.5**	3682**	0.448**	38.7**
IM*SAP	3	13.7^{ns}	2.93*	446.9**	446.9**	0.062**	27.6**
Error	14	71.9	3.29	392.4	392.4	0.041	21.3
Total	23	200.4	27.69	4934.8	4934.8	0.594	131.4
CV		13.5	20.4	17.1	17.2	1.3	7.3

Source of variation	df	Number of seeds per plant	Seed yield per plant	Thousand seed weight	Seed yield per hectare	Essential oil percentage	Essential oil yield per hectare
Replication	2	13483.8^{ns}	0.13^{ns}	0.02^{ns}	47367^{ns}	0.63^{ns}	331.4^{ns}
IM	3	432921.7**	2.34**	0.80**	842736**	0.40^{ns}	1183.4**
SAP	1	1344205.1**	1.45**	1.68**	522150**	0.46*	981.1**
IM*SAP	3	382066.6**	2.67**	0.33**	961506**	0.17^{ns}	1072.9**
Error	14	185059.7	0.67	0.30	242577	1.65	743.1
Total	23	2357737.0	7.26	3.14	2616336	3.33	4312.2
CV		22.5	12.0	4.19	12.0	10.1	19.6

IM= Irrigation management and SAP= Superabsorbent polymer

Table 6 Results of means comparison for effect of SAP and IM on growth and yield components of Cumin.

Superabsorbent polymer ($kg.ha^{-1}$)	Irrigation management	Plant height (cm)	Plant dry weight ($gr.m^{-2}$)	Number of lateral branches	Number of umbels per plant	Number of umbellets per umbel	Number of seeds per umbel
0	SI	14.0c	49.2e	21.7c	21.7c	3.94c	14.6c
	SI+FI	14.7bc	70.2e	18.3c	18.3c	3.97c	15.0c
	SI+SFI	14.8bc	146.4cd	16.1c	16.1c	3.95c	16.3bc
	SI+FI+SFI	16.0bc	97.2de	17.4c	17.4c	3.98c	16.1bc
30	SI	17.0abc	161.4bc	34.4b	34.4b	4.31a	18.3b
	SI+FI	17.6abc	207.6ab	41.0b	41.0b	4.08b	15.3c
	SI+SFI	21.1a	178.2abc	43.0b	43.0b	4.30a	17.0bc
	SI+FI+SFI	18.5ab	225.6a	54.2a	54.2a	4.23a	21.6a

SI= Sowing irrigation, FI= Flowering irrigation, SFI= Seed filling irrigation

Table 7 Results of means comparison for effect of SAP and IM on quantitative and qualitative indices of Cumin.

Superabsorbent polymer ($kg.ha^{-1}$)	Irrigation management	Number of seeds per plant	Seed yield (g.plant)	Thousand seed weight (g)	Seed yield ($kg.ha^{-1}$)	Essential oil percentage	Essential oil yield ($kg.ha^{-1}$)
0	SI	275d	0.95e	2.89e	572e	3.16a	18.08d
	SI+FI	264d	1.22e	3.57bc	736e	3.20a	23.55cd
	SI+SFI	261d	2.31ab	3.32cd	1390ab	3.35a	47.37ab
	SI+FI+SFI	287d	1.78cd	3.11de	1068cd	3.21a	34.05bc
30	SI	633bc	1.85cd	3.64b	1114cd	3.19a	35.52bc
	SI+FI	467cd	2.07bc	3.74b	1242bc	3.70a	45.98ab
	SI+SFI	711b	1.65d	4.04a	992d	3.69a	37.22bc
	SI+FI+SFI	1169a	2.66a	3.58bc	1598a	3.46a	55.48a

SI= Sowing irrigation, FI= Flowering irrigation, SFI= Seed filling irrigation

Discussion

Sustainable use of water is a vital subject because of reduction in water resources that is predicted to be increasingly severe due to climate change [15]. Therefore, development of strategies such as water deficit irrigation, super absorbent polymer (SAP) application and use of plants adapted to drought, like Cumin is essential for sustainable development in arid and semi-arid regions. Results of current experiment revealed that SAP application affected positively the growth and yields of Cumin (Table 6, 7). These findings is near to results of Ziaeidoustan *et al*., [14] on peanut and Fazeli Rostampour [13] on sorghum which concluded that SAP application is a suitable strategy for improving plant growth and yield especially in water deficit situation. SAPs are hydrophilic materials that can absorb and retain water or aqueous solutions, dozens time of their original size. Hence, application of SAPs is a suitable way for reduction of water losses, increasing soil water-holding capacity and nutrients use efficiency [15]. Nevertheless, water quality is an important factor for water absorbing capacity of SAPs, as in the present study water absorption rate by irrigation water (EC=1300 µm/cm) was 2.8-fold lower than distilled water and 2.5-fold higher than solution of 0.5% NaCl (Table 4). It has been reported that acrylic acid and acryl-amide super absorbents are very sensitive to ions and are not suitable for use in saline agriculture. Therefore, research on producing salt resistant and cost effective SAPs has wide interest [16].

SAP application prolonged the active growth period and consequently leaf area duration of Cumin by around one week. It seems that this phenomenon is caused by increasing of moisture availability and retention of nutrients for plant in response to SAP application. Finally, increase in photosynthetic period caused an enhancement in plant height and biomass, number of lateral branches per plant, number of umbels and umbellets per plant, mean seed weight and so seed and essence yields (Table 6, 7). Delaying of permanent wilting point in response to SAP application is a driving factor for enhancement of plant survival under water shortage [17]. In similar study on Cumin, growth period duration reduced in response to low water availability and concluded that induced maturity stage is a drought avoidance approach in plants are under drought stress [10]. Bannayan *et al*., [18] also concluded that water deficit induced earlier maturity in black Cumin (*Nigella sativa*) and isabgol (*Plantago ovata*).

SAP application resulted in significant increase in vegetative growth indices such as number of lateral branches compared with reproductive growth criteria (Table 6, 7). Accordingly, the values of plant dry weight and seed yield of Cumin in SAP application treatment were 2.13 and 1.32 times more than no-SAP treatment. Therefore, harvest index of Cumin in SAP application treatment was 14% lower than no-SAP treatment. However, water use efficiency increased significantly by SAP application, so that, the amounts of this index in SAP and no-SAP treatments were 1.03 and 0.78 kg seed per m^{-3} H_2O, respectively. Overall, SAP application increased Cumin seed and essential oil yields by increasing plant photosynthetic capacity through enhancement of green area index (GAI) and leaf area duration (LAD). Results of a similar study on Cumin showed that consumption of SAP at irrigation after 50 mm pan evaporation (non-stress condition) was not effective for essential oil production compared with the no-SAP application, but with increasing drought severity (100-200 mm pan evaporation) was need to different levels of SAP (60-300 $kg.ha^{-1}$) to mitigate the effects of drought stress [19].

Increased irrigation frequencies of Cumin from 1 (sowing stage) to 2 and especially 3 times (sowing, flowering and seed-filling stages) enhanced the plant growth, seed and essential oil yields (Table 6, 7). Our finding is in line with results of Kafi and Keshmiri [20] which stated that 2 and 3 times of irrigation in Cumin produced higher biological and seed yields compared with 1 and 4 irrigation treatments. In another study in Khorramabad (west of Iran) concluded that two irrigations (at sowing and seed formation phases) increased seed and essential oil yields of Cumin, while, one irrigation at sowing stage didn't show any significant difference with no irrigation treatment [21]. Rebey *et al*., [18] also concluded that Cumin is adapted to a moderate dryness, because moderate water deficit (50% FC) treatment produced higher seed yield than control, whereas sever water deficit (25% FC) reduced its growth and yield. In another study Alizadeh *et al*., [22] reported that Cumin doesn't need to be irrigated in years with around 185 mm rainfall during plant growth. Morphological properties of Cumin such as low plant height, leaf shape, plant colour and special coating on the outer layer of plant tissues all shows the Cumin adaptability to drought condition [23]. Therefore, Cumin has a potential to be a rainfed crop, but supplemental irrigation is needed to produce more productivity [21]. As in a study at Herat condition it was shown that rainfed cultivation of Cumin is possible, but one irrigation especially in the beginning of flowering stage can increase it seed and essential oil production [24].

In similar study on Cumin observed that water stress reduced seed yield but has an increasing effect on essential oil percentage and yield [25]. Lower yields of Cumin under sever water deficit condition are related to insufficient photosynthesis due to reduction in stomatal conductivity that which limits CO_2 uptake. Moreover, lesser nutrients availability along with lower translocation of photo-assimilates are two other reasons for yields reduction under severe drought stress condition [9-10]. In a study on two ecotypes of Cumin concluded that drought stress decreased relative water content and relative leaf water loss rate, while electrolyte leakage was significantly increased [26]. It has been reported that reduction in number and mean weight of Cumin seeds under sever water stress is because of pollination disruption, flower abscission, abortion of newly formed seeds and reduction in leaf area and duration [25]. However, it should be noted that the tolerance to drought stress is different among different ecotypes of Cumin, where in a study concluded that Ravar ecotype (belonging to dry region) demonstrated higher tolerance to drought stress, as compared to Gonbad ecotype which was belonged to sub-humid areas [26].

Despite of decline in Cumin yields by reducing the irrigation frequencies, water use efficiency increased through deficit irrigation regimes. So that, water use efficiencies for SI, SI+FI, SI+SFI and SI+FI+SFI treatments were ~1.40, 0.82, 0.99 and 0.74 kg seed per m^3 H_2O, respectively. In addition, it must be taken into account that high water availability reduced the essential oil percentage in both levels of SAP application (Table 7). Similar results were obtained by Ahmadian *et al*., [23] where more essential oil percentage was obtained under moderate stress condition and increase in secondary metabolites content under drought stress was expressed as an adaptability approach against drought stress. Therefore, water deficit strategy can be led to water saving with little or no reduction in crop yield and is a suitable approach for drought tolerant and short-lived plants like Cumin [18-20].

Conclusions

Overall, a good strategy for adaptation to drought stress is the use of locally resistant crops which have high adaptability to local ecological conditions. Cumin is one of the drought adapted crops in low rainfall countries, which has high water use efficiency and produces satisfactory yields with low amount of water consumption. Based on current experimental results this plant produces 570 kg seed per hectare only with 1 irrigation at sowing stage. However, application of 30 $kg.ha^{-1}$ super absorbent increased the seed yield of mentioned treatment to 1114 $kg.ha^{-1}$. Therefore, the use of super absorbents as water retentive materials is a suitable way for sustainable crop production in arid regions of the world. In addition, the effectiveness of SAP_s is heavily dependent on water quality, where we concluded that saline water has a reducing effect on water holding capacity of SAP.

References

1. Ghannadnia A, Haddad R, Zarinkamar F, Sharifi M. Manganese treatment effects on terpene compounds of *Cuminum cyminum* flowers. Ind Crops Prod. 2014;53:65-70.
2. Hashemi P, Yarahmadi A, Azizi K, Sabouri B. Study of the effects of N fertilization and plant density on the essential oil composition and yield of *Cuminum cyminum* L. seeds by HS–SME. Chromatographia. 2008;67:253-257.
3. Siow HL, Gan CY. Functional protein from cumin seed (*Cuminum cyminum*): Optimization and characterization studies. Food Hydrocol. 2014;41: 178-187.
4. Sowbhagya HB, Srinivas P, T Purnima K, Krishnamurthy N. Enzyme-assisted extraction of volatiles from cumin (*Cuminum cyminum* L.) seeds. Food Chem. 2011;127:1856-1861.
5. Sowbhagya HB. Chemistry, technology, and nutraceutical functions of Cumin (*cuminum cyminum* L): An overview. Crit Rev Food Sci Nut. 2013;53:1-10.
6. Rezvani Moghaddam P, Moradi R, Mansoori H. Influence of planting date, intercropping and plant growth promoting rhizobacteria on cumin (*Cuminum cyminum* L.) with particular respect to disease infestation in Iran. J Appl Res Med Arom Plants. 2014;1:134-143.
7. Kafi M. Cumin; Technology, Production and Process, Ferdowsi University of Mashhad, 2002.
8. Nezami A, Eyshi-Rezaei E, Khorasani Z, Khorramdel S, Bannayan M. Evaluation of the impacts of fall sowing dates on different ecotypes of Cumin (*Cuminum cyminum*-Apiaceae L.) productivity in northeast of Iran. Not Sci Biol. 2011; 3:123-128.
9. Rebey IB, Jabri-Karoui I, Hamrouni-Sellami I, Bourgou S, Limam F, Marzouk B. Effect of drought on the biochemical composition and antioxidant activities of cumin (*Cuminum cyminum* L.) seeds. Ind Crops Prod. 2012; 36:238-245.
10. Alinian S, Razmjoo J. Phenological, yield, essential oil yield and oil content of cumin accessions as affected by irrigation regimes. Ind Crops Prod. 2014;54:167-174.
11. Mazaheri M, Fakheri B, Piri I, Tavassoli A. The effect of drought stress and micronutrient of Zn and Mn on yield and essential oil of *Cuminum cyminum*. J Novel Appl Sci. 2013;2:350-356.
12. Bettaieb I, Knioua S, Hamrouni I, Liman F, Marzouk B. Water-deficit impact on fatty acid and essential oil composition and antioxidant activities of Cumin (*Cuminum cyminum* L.) aerial parts. J Agri and Food Chem. 2011;59:328-334.
13. Fazeli Rostampour M. The effect of irrigation regimes and polymer on several physiological traits of forage sorghum. Asian J Agri and Food Sci. 2013;1:274-280.
14. Ziaeidoustan H, Azarpour E, Safiyar S. Study the effects of different levels of irrigation interval, nitrogen and superabsorbent on yield and yield component of peanut. Inter J Agri Crop Sci. 2013; 5:2071-2078.
15. Li X, He JZ, M Hughes J, Liu YR, Zheng YM. Effects of super-absorbent polymers on a soil–wheat (*Triticum aestivum* L.) system in the field. Appl Soil Ecol. 2014; 73: 58-63.
16. Mo C, Zhanbin H, Bang X, Tao F, Hui D. Preparation, characterization and salt-resistance of a coal based super absorbent composite. Mining Sci Tech. 2010;20:864-871.
17. Yang L, Yang Y, Chen Z, Guo C, Li S. Influence of super absorbent polymer on soil water retention, seed germination and plant survivals for rocky slopes eco-engineering. Ecol Eng. 2014;62:27-32.
18. Bannayan M, Nadjafi F, Azizi M, Tabrizi L, Rastgoo M. Yield and seed quality of *Plantago ovata* and *Nigella sativa* under different irrigation treatments. Ind Crops Prod . 2008;27:11-16.
19. Pirzad A, Darvishzadeh R, Hassani A. Seed yield and essential oil responses of cumin to different irrigation

regimes and super absorbent levels in Urmia climatic conditions. Agron Res Dry Reg. 2014;1:151-164.
20. Kafi M, Keshmiri E. Study of yield and yield components of Iranian land race and Indian RZ19 cumin (*Cuminum cyminum*) under drought and salinity stress. J Hort Sci. 2011;25:327-334.
21. Rezaei Nejad A. Productivity of cumin (*Cuminum cyminum* L.) as affected by irrigation levels and row spacing. Australian J Basic Appl Sci. 2011;5:151-157.
22. Alizadeh A, Tavoosi M, Imanlo M, Nassiri M. Effect of irrigation regimes on yield and yield components of cumin. Iranian J Field Crop Res. 2005; 2:35-42.
23. Ahmadian A, Ghanbari A, Gholavi M, Siahsar B, Arazmjo E. The effect different irrigation regimes and animal manure on nutrient, essential oil and chemical composition on cumin (*Cuminum cyminum* L.). J Crop Ecophysiol. 2011;16:83-94.
24. Jami MY. Effect of irrigation time on yield and yield component of cumin (*Cuminum cyminum* L.) landraces in Herat province-Afghanistan. 2011; MSc thesis. Shahed University of Iran.
25. Yazdani Chamheidary Y, Ramroudi M, Asgharipour MR. Evaluation the effects of drought stress on yield, yield components and quality of (*Cuminum cyminum* L.) under Fe and Zn foliar spraying conditions. J Appl Res Plant Ecophysiol. 2014;1:81-96.
26. Karimi-Afshar A, Baghizadeh A, Mohammadinejad G. Physiological assessment of drought tolerance of two ecotypes of cumin (*Cuminum cyminum* L.) under greenhouse conditions. J Sci Tech Greenhouse Cul. 2015;23:175-185.

.