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National Academy of Agricultural Science (NAAS)
Rating : 3. 03

Control of High Temperature Stress in Maize Crop by Nano-silicon and Nano-zinc Foliar Application

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Abstract: *This research was conducted with the aim to control of high temperature stress in maize crop in south of Iran in 2014. The experiment was conducted as split-plots in randomized complete block design at three replications. The treatments were sowing date on June 22ed and July23th in the main plots, three corn classes, early, middle and late were in sub plots and spraying with nano silicon, zinc and mix of zinc and nano silicon and control were in sub subplots. The results showed that sowing date on July 11 that faced with severe high temperature stress caused the decrease in grain yield to 33.61% than control. Also, high temperature stress for sowing on July 11 caused decrease of 1000-garin weight from 306 g in control to 279 g. The decrease in biological yields from 14.273 t/ha to 3.180 t/ha significantly. Meanwhile, the results showed high temperature stress condition had the least effect on KSC704 hybrid with 31.65% decrease in grain yield and the most effect of heat stress condition was obtained with 35.3% decrease in NS540 hybrid. Moreover, in high temperature stress condition, zinc sulphate foliar application could increase grain yield by 7.7% in comparison to non-stress condition. But, silicon nano particles foliar application could not decline the effect of high temperature stress on grain yield of corn hybrids. Therefore, zinc sulphate foliar application can be more effective in declining the high temperature stress effects on corn plant in tropical regions in Iran.*

Keywords: *High temperature, Silicon, Zinc, nano particles, Maize.*

INTRODUCTION

High temperature or heat stress in plants is the amount of temperature higher than threshold level for plant growth and development. In general, 10-15 C increase higher than the necessary temperature is the main causes for heat stress or high temperature shock in plants (20). In moderate region, high temperature is one of the most important parameters for decreasing the yield and plant biomass production (28). The resistance threshold to high temperature in corn is 38 C during grain filling period (28).

The importance of maize is the power of this plant to flexibility in different climate conditions. For this reason, it is considered as the main products of moderate, hot, semi-tropical and humid regions In high temperature condition and low relative humidity condition, the silks organs in maize were loss in appearance and freshness for acceptance of pollen and pollen germination (5). The previous studies showed that to preventing of corn pollen activity the optimal temperature should not exceed between 25 to 33 C during the day time and 17 to 23 C at night (5). Some studies have shown that for each 1C increase in temperature higher than optimal temperature, the grain yield was showed 3-4% increase (28).In temperature higher than 38 C, plant processes becomes changes and destroyed which results from direct compact of high temperature (3), also the dryness of

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pollen in sever high temperature stress causes the drop in pollination and seed forming (29).

There are different methods that have been suggested for control the heat stress in plants that one of them is the application of some minerals in plants (28). However, one of the main solutions for controlling the high temperature stress is early sowing in summer crops as well as corn in hot weather condition. The other method of reducing harmful effect of high temperature stress that has been one of the objectives of this research was the interaction effect of sowing date and mineral application too. Some investigations showed that silicon is one the mineral that is severely involved in plants under environmental stresses in metabolic and physiological activities (13). Silicon after Oxygen is the most abundant element in the earth's crust (7). In plants the content of 0.2 to 100 mg of silicon in each gram of dry weight has been reported (18). Mechanism of Silicon absorption is different in various plants and also, there is no complete information in this case (19).

In most silicon accumulator plants, the highest silicon concentration was in leaf blade and the lowest in roots. The selectively absorbed silicon by roots and moved towards the young leaves. In conditions that silicon concentration and transpiration of plant are low, more silicon are accumulated in old leaf blade. In addition, silicon in plant is a non-dynamic element (14).

The transmission of silicon in plant is conducted from inside of wooden vessel. Therefore, its distribution in foliages is determined by the severity of transpiration (16). In fact, the highest silicon concentration in plant is observed where there is the highest transpiration (19). Silicon absorption is done both actively and inactively (23). On the other hand, some studies have showed that the significance of silicon in heat stress control emphasizes on new dimensions.

Considering that silicon in plant increases the activity of SOD and CAT enzymes and causes the protection of plant tissues from oxidative damage resulting from stress, thus its consequence can be the increase in chlorophyll and photosynthesis stimulation (7). Zinc is one of the microelements in plant nutrition that have several roles and duties. The importance of zinc is due to its importance in different enzymes activity regulating general metabolism in plants (15). Also, it causes the stability and structural configuration of membrane proteins (2). Zinc plays an important role in constructing Auxin and chloroplast and also in carbohydrates metabolism (15). Regardless of the role of zinc as the structural configuration of membranes, it also plays a key role in controlling production and detoxification of oxygen free radicals that can damage membrane lipids and sulfhydryl group (16). The function of zinc on the deterrence of oxygen free radicals that causes the damage in membrane plays an important role. Also, it protects membrane lipids and proteins from peroxidise by oxygen free radicals in membrane (17). Finding useful effects of silicon and zinc application in reducing damage resulting from high heat stress and also, investigating of their interactions in generating high temperature tolerance in maize is considered as the most important objectives of this research.

METHODS

This research was conducted in the form of split split-plots with Randomized Complete Block Design in three replications in Haji Abad-e-Hormozgan Agriculture Research center, Hormozgan, Iran at 2012-13. Haji Abad has long and dry and hot summers and located in 27′ and 13" latitude, 56′ and 22" longitude with 920 m height than sea level. According to the experiments of agrology, the soil of the place of experiment has 34% sand, 44% silt and 22% clay i.e. loam texture. In this farm study, the high temperature stress treatment was apply by selected two different sowing dates In June 22ed (high temperature stress, SI) and July 23th (control S2) and arranged in main plots.

Three different ripening classes of maize hybrids (V) were planted in sub plots. The earlier was KSC260 (V1), middle NS540 (V2) and delay mature was KSC704 (V3). Mineral treatments were located in sub subplots by foliar application (F) of water (F1) as control, silicon nano-particles (F2), zinc sulfate (F3) and silicon nano-particles plus zinc sulfate (F4). This experiment was cultivated in a farm that was under the wheat plant for last year.

Each plot size was 8.0 m length in 3.0 m width; consist of 4 rows with intervals of 0.75 m. The intervals of bushes on rows were 0.2 m and the plant density was 60.000 bushes per hectare. The intervals of plots were 1.0 m and between blocks were 3 m distance. The seeds were planted at the depth of 2-3 cm manually. To prevent the drought stress, irrigation was complete and soil moisture retained in field capacity all the time in order to inhibited the plants to confront any stress except high temperature stress. Surface irrigation was done with furrow method carefully. Thermal curves (figure 1) and the statistics of the mean of region's temperature were investigated. So that sowing date of June 22 was selected as critical sowing date in terms of high temperature stress (table 1).

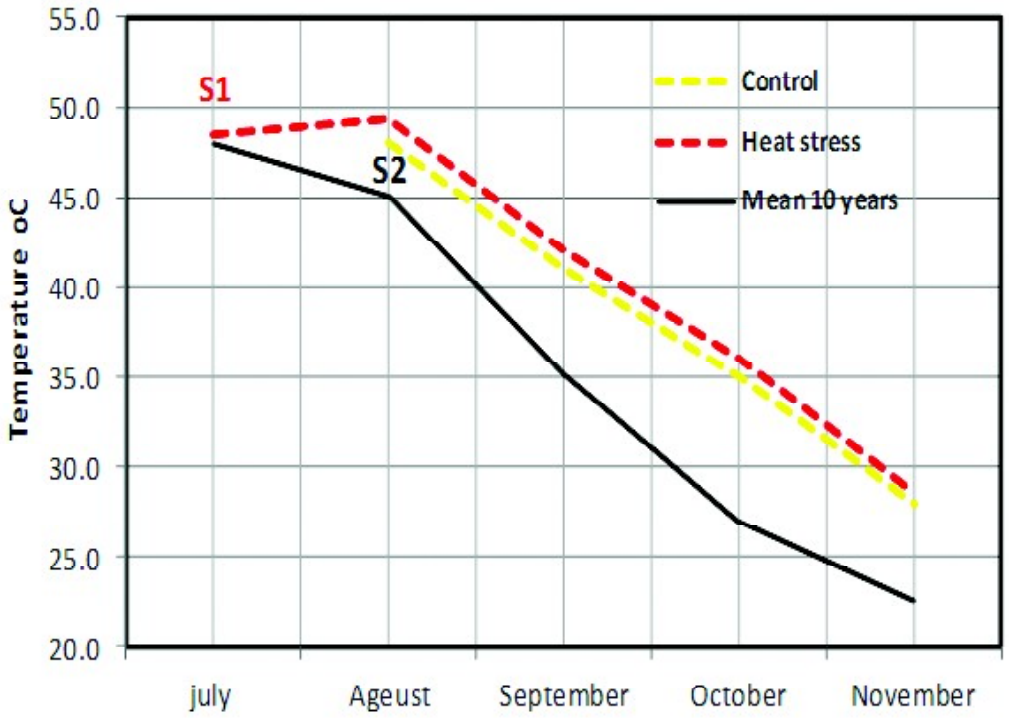

Figure 1: Temperature changes during growth period of maize from sowing date of S1 and S2 until harvest

Table 1
Weather condition in Haji Abad-e- Hormozgan, Iran

Month	*Tmax Long term*	*Tmax 2013-2014*	*Mean of rainfall Long term*	*Mean of rainfall 2013-2014*
April	41.9	35.0	0.3	0.0
May	36.2	26.9	4.4	9.8
June	28.5	22.6	30.5	6.5
July	0.25	15.9	39.2	63.0
August	24.1	18.2	25.0	37.9
September	30.3	23.6	18.9	34.6
October	40.5	28.3	23.3	32.0
November	44.8	35.0	0.6	6.5
December	47.8	41.0	2.9	0.0
January	49.5	42.2	6.5	1.3
February	48.4	42.3	6.7	0.0
Mars	46.1	39.4	6.2	0.0

Corn seeds (*Zea mays* L.) were prepared from Iran seed research institute. The length of growth period for KSC 704 is 130-140, NS 540 is 120-130 and in KSC 280 is 105-115 days respectively.

Foliar application treatment was done after eight leaf stage during two phases to the interval of 15 days at sunset. nano silicon (SiO_2 with 30 nanometre diameter with 2 mill molar concentration) and zinc sulphate (0.4%) and pure water for control treatment were utilized. During the growth season, all agricultural practices such as providing the base fertilizers, thinning, weed control, were managed. To measure the number of pollen, wreath tassel is harvested before pollination, and then blended in one litter of absolute water. The number of pollens was counted from the produced suspension by Lam hemocytometer lamella under optical microscopy in the volume of 0.1 ml3 (12, 25). Harvesting was done when grain moisture reached %14. Harvesting early mature, middle mature and delay mature cultivars was done after 110, 120 and 135 days, respectively. In order to determine grain yield and biological yield, 6 plants were harvested from the middle rows of each plot and traits of pollen number, grain yield, 1000-garin weight, grain number in row, biological yield and harvest index were determined. All statistical calculations were used using SAS .9 Software.

RESULTS AND DISCUSSION

The results from data analysis of variance represented that changing sowing date from June 22ed to July 23th could create significant difference in pollen number, grain yield, 1000-garin weight, grain number in row, biological yield and harvest index significantly. Also, significant differences between cultivars were observed for all presented treats. The interaction of sowing date and hybrids treatments on pollen number, 1000-grain weight, number of grain per row and biological yield was significant but did not affect grain yield and harvest index. On the other hand, spraying treatment and their interactions with other experimental treatments could not cause significant relationship among traits under studied (table 2).

Pollen number

The analysis of variance results showed that the sowing date and hybrids treatments and their interaction effects had significant effect on number of pollens per tassel but the effect of mineral application treatment on pollen number was not significant (table 2).

The mean comparison table shows that the sowing date in June 22th (S1) caused the increase in

Table 2
Analysis of variance results for pollen number, yield and yield components in maize

		MS					
S.O.V	*DF*	*Pollen number*	*Grain yield*	*1000-grain weight*	*No of grain per row*	*Biological yield*	*Harvest index*
Replication (R)	2	137.3^{*}	1.9^{ns}	65.9^{**}	28.5^{ns}	11.5^{ns}	47.2^{ns}
High temperature Stress (S)	1	122.7^{*}	237.9^{**}	500.3^{**}	1970.6^{*}	182.3^{**}	263.3^{**}
Maize cultivars (V)	2	248.7^{*}	33.5^{**}	33.6^{**}	252.9^{**}	47.7^{**}	111.6^{*}
S*V	2	145.7^{*}	0.5^{ns}	145.6^{**}	91.1^{**}	17.8^{*}	22.6^{ns}
Error (E)	10	174.9	28.7	8672.2	172.6	5.9	125.5
Foliar application(F)	3	14.4^{ns}	1.6^{ns}	2.1^{ns}	23.1^{ns}	4.2^{ns}	18.9^{ns}
F*S	3	148.8^{ns}	1.1^{ns}	8.5^{ns}	9.6^{ns}	3.7^{ns}	44.0^{ns}
F*V	6	123.5^{ns}	0.7^{ns}	3.5^{ns}	9.8^{ns}	2.9^{ns}	23.1^{ns}
F*S*V	6	48.1^{ns}	1.2^{ns}	13.5^{ns}	20.9^{ns}	10.2^{ns}	22.6^{ns}
Error (E)	36	1360.2	0.7	11.1	10.8	6.5	26.9
C.V (%)		34.2	9.7	5.7	8.98	20.1	12.5

**,* and ns: significant in probability level of %1, significant in probability level of %5 and non-significant, respectively.

pollen numbers compared to next sowing date. It might be regard to the plant has been influenced by high temperature stress until pollen production; it has been so stimulated to produce more pollens. Thus, proving this issue needs more investigation. In this research, NS540 hybrid produced more pollen to the amount of 60 million in unite compared with other existing cultivars. Puteh and colleges (2009) in a study on rice reported that moisture stress caused about 13-34% decrease in the number of pollens. Shahriari (2001) in another research on sweet corn, under draught stress condition propounded that; the content of producing pollens dependent on the type of hybrid can be different. It is obvious that maize hybrids with higher pollen under irrigation stress condition can do more effective and better pollination by producing higher pollen. The results of this study are in agreement with the results of Hall and colleges (1982) based on the difference between pollen in male inflorescence and different maize hybrids. It is obvious the higher pollen in the increase in percentage of pollination in maize has a significant effect Shahriari (2001).

Grain yield

The comparison of the average grain yield showed that the different sowing date for maize hybrids was significantly important. In July sowing date (S1) weather condition might cause the decrease rate in grain yield by 3.636 t/ha compare to average. Also in this study, the highest grain yield was obtained in KSC704 (V3) cultivar to the amount of 8.4 t/ha and the least grain yield in KSC260 (V1) to the amount of 6.4 t/ha. In general, in the region under study the KSC704 and NS540 were highly influenced by high temperature stress that this decrease in NS540 hybrid by 35.3% and for KSC704 31.65% (table 4).

The interactions between hybrids and mineral application showed that zinc sulphate application in NS540 had the highest increase in grain yield than other hybrids that can be due to the genetic of this hybrid that was in agreement with the results Najafi Zadeh (1998) had obtained in Arzueeyeh in Kerman, Iran (50 kilometre far from the place of doing experiment). Dehghan (1994) has reported that in Ahvaz, Iran hot weather conditions, earlier sowing date due to the synchronization of flowering time with sever high temperature and non complete pollination of maize the yield of product became less and Herberk and colleges (1989) announced that grain yield of each hybrid can be due to the yield potential of that hybrid too.

Table 3
Mean comparison for pollen number, yield and yield components in maize

Treatments	*Mean traits*					
	Pollen number (no.10⁶/cm³)	*Grain yield t/ha*	*1000-grain weight g*	*No of grain per row*	*Biological yield t/ha*	*Harvest index %*
S1	57.9a	7.2b	279.6 b	31.3 b	11.1 b	39.6 b
S2	49.9b	10.8a	306.0 a	41.8 a	14.3 a	43.4 a
V1	52.3a	8.1b	284.0 b	34.3b	10.7 b	42.9 a
V2	61.4a	8.6b	280.15 b	35.1 b	13.5 a	39.1 a
V3	47.8b	10.3a	314.2 a	40.3 a	13.9 a	42.6 a
F1	55.7a	8.8a	291.9 a	36.2ab	12.2 a	41.9 a
F2	54.0a	9.2a	295.3 a	36.2ab	13.3 a	40.6 a
F3	53.7a	9.4a	292.2 a	38.2 a	12.9 a	42.8 a
F4	51.9a	8.7a	291.7 a	35.6 b	12.5 a	40.9 a

Data in each column with at least one common letter lack the significant difference based on Duncan's multiple range test 5%. In the above table, the sowing date is on first July (S1) and first August (S2), maize (KSC260 (V1), (NS540 (V2) and KSC 704 (V3) and foliar application with water or control (F1), with silicon nanoparticles (F2), with zinc sulphate (F3) and with silicon nano particles and zinc sulphate together (F4).

Zinc sulphate application in the form of spraying can be due to the role of deterrence and oxygen free radicals and relative prevention from cell membrane in plant (16). To gain the maximum grain yield it is necessary to consider the specific condition for each hybrid.

1000-grain weight

Maize hybrids in sowing date of July (S1) confronted 1000-grain weight decline. Among the cultivars under experiment, KSC 704 showed the highest 1000-grain weight to 314.2 g. Considering that in this sowing date, natal growth and development is complete and some of the grain filling period is faced with the severe high temperature of higher than 35 C and because the temperature is during the night, plant respiration and consumption of carbohydrate reserves are increased and the content of assimilates transmission to the grain is decreased. This issue compared to the second sowing date causes the decrease in 1000-grain weight (29). The highest 1000-grain weight was observed by zinc sulphate foliar application and KSC 704 to the amount of 316.25 g. The reason can be due to the more duration of growth and grain being filled in this cultivar (28).

Table 4
Mean comparison for pollen number, yield and yield components in maize

Treatments	*Mean traits*											
	Pollen number (no.10⁶/ cm³)		*Grain yield (t/ ha)*		*1000-grain weight (g)*		*No. grain per row*		*Biological yield (t/ha)*		*Harvest index (%)*	
	S1	*S2*	*S1*	*S2*	*S1*	*S2*	*S1*	*S2*	*S1*	*S2*	*S1*	*S2*
V1	57.4 b	47.3b	6.4 e	9.7bc	258 c	310ab	31.0 dc	37.5b	9.4d	11.9bc	40.7ab	45.2a
V2	69.8 a	52.9 b	6.7de	10.4b	277bc	282bc	27.9d	42.3a	10.9c	16.1a	38.2b	39.9ab
V3	46.1 b	49.7 b	8.4cd	12.3a	302ab	326a	35.0bc	45.5a	12.9b	14.8a	39.9ab	45.3a
F1	64.1 a	47.3 a	7.1bc	10.5a	356b	361a	31.0b	29.9a	10.4b	13.9a	40.8abc	43.1ab
F2	62.0 a	45.9a	7.1bc	11.3a	356b	362a	29.9b	42.5a	12.4ab	14.2a	36.9 c	44.2a
F3	53.2a	54.3a	7.8b	10.9a	355b	362a	33.7b	42.7a	10.8b	14.7a	42.6ab	42.9ab
F4	51.7 a	52.1a	6.8c	10.6a	356b	360a	30.6b	40.5a	10.7b	14.2a	38.2bc	43.5ab
V1F1	60.9abc	43.9bc	6.5gh	8.9def	2525i	310a-f	30.1f-h	36.6def	9.5de	12.1a-e	40.5a-d	43.0a-d
V1F2	57.0abc	36.5bc	6.1gh	10.1cd	2646hi	318a-d	30.2fgh	38.6cde	9.5de	12.5a-e	39.5a-d	44.6a-c
V1F3	55.5abc	60.5abc	6.6gh	10.13cd	265 hi	303b-f	29.8gh	39.0b-e	8.7e	11.9a-e	43.2a-d	46.1ab
V1F4	55.9abc	48.0abc	6.5gh	9.9cde	250i	310a-f	32.9efg	36.1d-g	9.9de	11.2cde	39.5a-d	46.9a
V2F1	81.0 a	54.9abc	7.3fg	10.0cd	282f-i	279ghi	30.0gh	40.7a-d	12.1a-d	14.3a-d	37.9a-d	41.5a-d
V2F2	70.9ab	49.9abc	6.7gh	10.8bc	285eh	278fgh	26.4hi	43.7abc	11.8b-e	16.0abc	36.2bcd	40.4a-d
V2F3	60.0abc	52.5abc	7.6fg	10.8bc	265hi	288d-h	31.5fgh	43.8abc	9.6de	16.9ab	45.3abc	39.1a-d
V2F4	67.3abc	54.0abc	5.5h	10.1cd	282fi	279ghi	23.8fgh	40.8a-d	10.2de	17.1a	33.4d	38.4a-d
V3F1	50.5abc	42.9bc	7.6fg	12.5a	308ag	321abc	31.9fgh	46.9a	9.7de	15.5abc	43.9abc	44.7abc
V3F2	58.2abc	51.5abc	8.3ef	13.0a	295ch	328ab	33.4efg	45.1ab	15.8abc	14.2a-d	34.9cd	47.7a
V3F3	43.9bc	49.9abc	9.2cde	11.8ab	294cg	339a	39.7bcd	43.3ab	14.3a-d	15.4abc	39.4a-d	43.7a-d
V3F4	31.9c	54.5abc	8.5def	11.86ab	312a-f	327a-e	35.0defg	44.8abc	11.9b-e	14.3a-d	41.6a-d	45.2abc

Data in each column with at least one common letter lack the significant difference based on Duncan's multiple range test 5%. In the above table, the sowing date is on first July (S1) and first August (S2), maize (KSC260 (V1), (NS540 (V2) and KSC 704 (V3) and foliar application with water or control (F1), with silicon nanoparticles (F2), with zinc sulphate (F3) and with silicon nano particles and zinc sulphate together (F4).

Number of grain in row

Maize sowing date of July (S1) caused the decrease in the number of grain per row, but this decrease was less in KSC 704. In high temperature stress condition resulting from early mature sowing of maize, KSC 704 could show the highest resistance to high temperature by producing the highest grain number per row. Also the investigation of the results of average number of grain in row showed that high temperature stress in maize caused the decrease in the number 10 grains in row than control treatment that the reason can be due to the synchronization of severe high temperature period and wasting pollen and making disorder in pollination stage. This result was announced in the reports of other researches (28).

Biological yield

Maize sowing date in July (S1) caused the decrease in the biological yield to the amount of 3.180 t/ha than sowing date of June. In high temperature stress condition, the highest biological yield related to KSC 704 cultivar was 12.94 t/ha and the least amount related to KSC 260 9.4 t/ha.

The results of mean comparison table for biological yield showed that silicon application caused the relative improvement of this index to the amount of 0.9 t/ha but in sowing date in June. In July sowing date, biomass production in KSC 704 with silicon application was observed to its highest amount i.e. 13 t/ha than other maize hybrids. Obviously, in high temperature stress condition the highest amount of biomass yield was obtained with zinc sulphate application to the amount of 9.23 t/ha in cultivar KSC 704. It seems that in high temperature stress condition the effect of zinc sulphate foliar application is more effective than silicon. The investigation showed that the role of silicon in the increase in chlorophyll and photosynthesis stimulation in natural growth condition for plants was completely obvious (7), but in environmental stress conditions and also high temperature stress, zinc sulphate application has improved biomass yield more than silicon that maybe be due to the role of deterrence and oxygen free radicals and relative prevention from cell membrane in plant (17). Considering that maize is more sensitive to the lack of zinc and zinc is the main component of enzymes involved in photosynthesis including RUBPc can be a reason of zinc being more effective than silicon (15).

Harvest index

On the basis of the obtained results the least amount of harvest index in high temperature stress condition was resulting from July sowing date related to NS540 and to the amount of 38.24%; i.e. high temperature stress caused the percentage decrease in harvest index to the amount of 8.7% than control treatment. The highest harvest index was obtained in KSC704 and KSC260 cultivars to the amount of 45% on June and the highest harvest index in heat stress condition resulting from sowing on July in KSC704 cultivar was obtained to the amount of 40.66%.

CONCLUSIONS

In case of pollen number it might be regard to the plant has been influenced by high temperature stress until pollen production; it has been so stimulated to produce more pollens. Thus, proving this issue needs more investigation. In this research, NS540 hybrid produced more pollen to the amount of 60 million in unite compared with other existing cultivars. The results have shown that when maize is subject to temperatures higher than 35æ% C during the endosperm cell division even for 4 days, it decreases grain weight about 30 to 40% and just grain size increases (4). This phenomenon can be the resultant of the decrease in grain capacity as reservoir in acceptance and reserving assimilates (4). Grain capacity as a reservoir is a function of endosperm cells and starch granules constituted in grains during 10-14 days after pollination (14,17, 29). Therefore, in this study, the rate of 1000-grain weight decrease in NS540 was slower than other hybrids. Herberk et al. (1989) announced that the grain yield of each hybrid can be due to the potential of that hybrid. Furthermore, the harvesting index results showed the increase in the growth period in delay mature cultivars and higher yield of this cultivar can be an effective reason for these results. KSC 260 cultivar had higher harvest index due to the relative early mature and less biological yield.

ACKNOWLEDGEMENTS

Authors appreciate to Islamic Azad University for supplying the required instruments and facilities, and also Hormozgan agricultural research center for provide laboratory of plant analysis of this experiment.

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