Effects of Planting date on yield characteristics of Quinoa (*Chenopodium quinoa* Wild.)

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ABSTRACT

In order to investigate the effect of spring and autumn planting dates on yield and yield components of quinoa, an experiment was conducted in the form of a randomized complete block design with three replications in 2018 and 2019 in Kavar region located in the east of Fars province in Iran. The experimental treatments were included two seasons of planting, spring: (February 19 and 29 and March 10) and autumn: (July 31 and August 10 and 20). In this experiment Q_{29} genotype of quinoa, was used. The results showed that planting date has a significant effect on the, grain yield, 1000 grain weight, number of panicles and biological yield. The results showed that planting in February 19 and August 20 had the highest plant height as compared to other dates. The highest hectoliter weight was obtained on February 19. The relationship between the maximum temperature and yield at first was increasingly significant and then decreasing (Cubic equation). The results showed the highest yields from, February 19 to August 20, which due to the suitable planting conditions in spring and also the higher water use efficiency in this period, so the most suitable planting dates is, 19 and 29 of February.

Key Words: *Quinoa, GDD, Biomass, Plant height.*

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INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd.) is a dicotyledonous plant of the Amaranthaceae family and a subfamily of the Chenopodiaceae family native to the Andean regions of the Americas [1]. This plant is very tolerant of a wide range of non-living stresses such as cold, salinity and drought, and also has good potential in peripheral soils [2]. Quinoa seeds are 5,000 years old and are considered sacred in the Inca rural civilization called the "mother seed" [3]. Quinoa seeds as compared to many cereals and legumes, are more nutritious. Approximately, quinoa seeds contain 10-18% of protein, 4.5-8.5% of crude fat, 54.24% of carbohydrates, 64.2.5% of ash and 2.4-1.9%, f fiber is raw [4]. Young quinoa leaves are used as a fresh or cooked vegetable in a food mix such as soup, but the main product is the seeds. In the United States Quinoa is used to make flour, soups, breakfast cereals, salads and alcohol. Quinoa`s flour is well used as an elastic starch in combination with wheat flour to make bread, biscuits or food products [5]. Meanwhile, the Quinoa`s proteins are suitable for improving the balance of human and animal food amino acids [2]. All eight planted quinoa genotypes were examined in Colorado, USA, with a yield of 1,120,000 kg per hectare, and the Cahuil genotype had the highest yield despite the low plant height (129cm). Genotype C0407 as early plant (100 days after planting) and had the highest protein content with 16.81% and optimal yield [6]. To determine the best planting date for quinoa, two genotypes, KVLQ520Y and Regalona Baer, were studied in dry conditions and in Mediterranean conditions in southern Italy. Regalona Baer genotype produced more on April and also was more tolerant under High temperatures strain and aridity [4]. In India, the highest yields were obtained on 3 November and row spacing was 20cm [7].

Iran's climate change toward a hot, dry climate and the gradual salinization of the country's soils on the one hand, and the high tolerance of quinoa against drought, salinity,

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and frost, on the other hand, indicate a proper rationale for using quinoa as a suitable plant to achieve sustainable agriculture, proper nutrition and industrial production [4]. FAO's recommends for quinoa planting even in poor and barren lands. The researchers reported the potential for quinoa planting and development in areas with an annual rainfall 200-400 mm [8]. Sepahvand and Perkasi (2013) and they have examined the compatibility of quinoa in four different stations in Iran and found a significant difference in its yield [9]. In different parts of Iran, it was reported that the average grain yield in Ahvaz, Karaj and Iranshahr stations was 1162, 1081 and 823 $kg.ha^{-1}$, respectively. Tavousi and Sepahvand (2014) investigated three quinoa genotypes named Sajama, SantaMaria and Sajama Iranshahr in Ahvaz region four planting dates of 10, 25 October, 10 - 25 November, the highest yield (4.2 tons per hectare) In this region belong to 10 October. Due to Iran's climatic diversity, one of the notable cases in the study was planting date which was the most effective and important factor in adapting and increasing plant yield.

Therefore, the present study was conducted to determine the appropriate planting date of quinoa genotype Q_{29} in Mozaffari village located in Kavar (Fars, Iran). In this research, the yield and yield components of this genotype on various planting dates were examined (spring and autumn planting).

MATERIALS AND METHODS

In order to determine by investigating the most suitable planting date of Quinoa (Genotype Q29 experimental), planting, in the form of random block design with three replications in Mozaffari village in the west of Kavar city (29° 19' N, 52° 78′E at 1589m above sea level) with average rainfall of 424mm (during twenty-three years), was conducted in 2018 and 2019. The soil at the site of implementation of the project had a loamy texture, its pH was about 7.84 and its EC was to 5.19 $dS.m^{-1}$.

The experimental treatment consisted of two seasons: spring (February 19 and 29 and March 10) and autumn (July 31 and August 10 and 20). Nitrogen fertilizer was 150 kg nitrogen per hectare was included in the plant nutrition program in three stages: during planting, 4-6 leaf stage and flowering to plant and phosphorus at the rate of 50-70 kg per hectare at planting time. Pests, plants diseases, or environmental stress were monitored and weed control was done manually. Seed sowing was done manually at a distance of 30 cm in rows and 5cm between seeds Irrigation interval was once every 10 days until the leaves changed color.

Using the maximum and maximum thermometers, the GDD from planting to each stage of growth in all treatments were calculated by using the following equation [10].

$$H_i = \sum_{i=1}^{n} \left({(T_{min} + T_{max})}/{2} \right) - T_b \qquad (1)$$

In this formula:

I: Number of days

H_i: Growth Degree day till day i (GDD)

T_{Min}: Minimum air daily temperature with baseline temperature

T_{max}: Maximum air daily temperature with temperature above 30°C

Tb: The basal temperature of quinoa which is 3°C

Table 1. Temperature of growing season during two years of experiment

Year	Month	Max.	Min.	Mean
2018	Jan.	-0.1	15.8	7.9
	Feb.	3.3	17.2	10.3
	Mar.	6.0	19.5	12.7
	Apr.	11.1	28.1	19.6
	May.	15.8	32.3	24.0
	Jun.	19.9	37.7	28.8
	Jul.	21.5	37.7	29.6
	Aug.	19.3	37.6	28.4
	Sep.	16.2	33.4	24.8
	Oct.	11.6	29.2	20.4
	Nov.	4.7	19.3	12.0
	Dec.	2.0	14.1	8.0
2019	Jan.	0.0	14.5	7.3
	Feb.	1.3	17.6	9.4
	Mar.	6.8	20.9	13.9
	Apr.	9.0	25.4	17.2
	May.	16.1	33.4	24.7
	Jun.	19.3	37.2	28.23
	Jul.	22.3	39.7	31.0
	Aug.	19.8	36.6	28.2
	Sep.	15.5	35.0	25.2
	Oct.	9.7	27.5	18.6
	Nov.	2.0	17.7	9.8
	Dec.	0.3	16.9	8.6

In order to determine the height of the plant from each experimental plot, 10 plants were randomly selected and the necessary measurements were performed. To determine the grain yield, two rows of marginal plants along the length and one and a half of a plot from the top and bottom of each plot were removed and the remaining plants were cut at the bottom. After harvesting and separating the seeds, were dried at 75°C for 48 hours in a dry oven after weighing, based on 14% moisture the grain yield per unit area was calculated. To determine the number of panicles per unit area, before the final harvest of the 50 cm in middle of each experimental plot was determined and the number of panicles and the number of panicles were counted by Quadrat. Then 10 whole panicles were randomly harvested and after sowing and counting the seeds with the seed counting machine, the average number of seeds in the panicle was obtained. To calculate the weight of the hectoliter, the net weight of the specific volume of quinoa was measured by a calibrated cylinder (one thousand cc and multiplied by 1000 after weighing). By dividing grain yield to biological yield, the harvest index was obtained. To calculate water use efficiency, grain yield was divided by the volume of water used. The volume of water used was obtained by determining the time required filling the water in the plots and same time required to fill the barrels with the specified volume and the same flow rate as the flow of water entering the plots. The volume of rainfall water was also determined and added to the volume of water used by the plots during the growing season. At the end, by applying SAS. 9.1 statistical software and Excel software for graphs data were obtained. Comparison of the means was performed by Duncan multiple range test at 5% level.

RESULTS AND DISCUSSION

Analysis of variance table showed that the effect of planting date on all measured indices include: number of panicles per square meter, hectoliter weight, plant height, aerial biomass, number of seeds per panicle, grain yield, harvest index and water use efficiency, and on all traits was significant in the first year of the experiment (2018), except plant height and number of seeds per panicle **(Table 2)**.

The biomass production of quinoa on February 29, 2018 and 2019 was 6200 and 8680 kg.m^{-2}, respectively, which was in the highest statistical group. On July 31, aerial biomass group with 18.7% and 15.6% decrease, respectively was in the last statistical. The effect of planting date in 2019 on plant height was not significant, and in 2018 the highest plant height belonged to February 19 and August 20. The lowest altitude in 2018 was on February 29. The highest weight of hectoliters of seeds in 2018 and 2019 was obtained with 35.04 and 44.76 kg, on August 20, respectively. The number of seeds in panicle in 2019 was not affected by the planting date. In 2018, the highest number of seeds in the panicle was on August 20. The highest harvest index in both years of study was due to the planting date of August 20 (63.6% and 54.2%, respectively).

Table 2. Summary of variance analysis for panicles Number (P.N.), Hectoliter weight (H.W), plant height (P.H.), Biomass (B.), Grain yield(G.Y.), panicle seed number (P.S.N.), Harvest index (H.I.). and Water Use Efficiency (W.U.E.) in different sowing dates.

Year	S.O.V	D.f.	Mean squares							
			P.N.	H.W.	P.H.	B.	G. Y.	P.S.N	H.I	W.U.E.
2018	Rep.	2	1800^{ns}	37.79 ^{ns}	22.2 ^{ns}	107860.16 ^{ns}	51377.13*	237119.0*	2.6*	0.003 ^{ns}
	Sowing date	5	15840**	39.58**	47.6**	556683.69**	141781.77	134688.5*	53.3**	0.090**
	Error	10	1080	9.52	2.4	21610.06	10423.07	204.0	0.5	0.0007
	C.V.%		13.7	11.12	11.7	12.6	13.2	14.4	12.2	12.7
2019	Rep.	2	200 ns	88.50 ^{ns}	179.8 ^{ns}	81261.35 ^{ns}	31437.40 ^{ns}	34333.2*	13.7*	0.0028 ^{ns}
	Sowing date	5	17600*	65.87**	78.4*	1076672.15*	202306.19*	240524.2*	38.1**	0.0403**
	Error	10	4040	26.74	116.5	575169.05	27629.41	427472.0	24.7	0.0021
	C.V.%		7.01	14.6	9.3	9.7	14.4	16.5	10.2	14.5

**significant at level 1%, *significant at level 5%, ns not significant

Table 3. Average traits examined by quinoa in spring and autumn planting dates in 2018 and 2019.

Measured attributes	Sowing date											
	Feb. 9		Feb. 19		Marr. 1		Jul. 31		Aug. 10		Aug. 20	
2018												
P.N.	960	a	900	ac	960	ab	800	d	800	d	860	cd
H.W.(kg)	26.31	b	25.36	b	25.98	b	26.5	b	27.19	b	35.04	a
P.H.(cm)	94.67	a	87.67	bc	84.67	c	88.67	b	89.67	a	94.67	b
B.(kg ha^{-1})	5500	c	5900	b	6200	a	5039.4	d	5229.6	cd	5419.8	c

P.S.N	3012.3	b	2729.9	d	2729.9	d	2918.1	c	3012.3	b	3294.7	a
H.I.(%)	59.1	b	54.6	d	51.3	e	57.4	c	55.3	d	63.6	a
						2019						
P.N.	1000	a	920	ab	980	a	820	b	820	b	900	ab
H.W.(kg)	33.48	b	32.27	b	33.08	b	33.75	b	34.59	b	44.76	a
P.H.(cm)	121.35	a	112.36	a	108.51	a	113.65	a	114.93	a	121.35	a
B.(kg ha^{-1})	7700	ab	8260	ab	8680	a	7064	b	7330.6	ab	7597.1	ab
P.S.N	4025.4	a	3648	a	3648	a	3899.6	a	4025.4	a	4402.8	a
H.I.(%)	50.5	ab	46.5	ab	43.9	b	48.9	ab	47.2	ab	54.2	a

Averages with at least one common letter in each row has not significant differ (Duncan 5%)

The highest yield in 2018 with an average of 346.16 kg. ha^{-1} belonged to 20th August In 2019. The highest yield was obtained from the same planting date (4029 kg.ha^{-1}). There was not significant different between Yields in this treatment in 2019 and spring planting treatments.

The highest water use efficiency of spring planting treatments was obtained in both experimental years, which were in the same statistical group without significant differences. The highest water use efficiency in autumn planting belonged to August 20, which showed a decrease of 20.4% and 7.4%, respectively, compared to February 19, 2018 and 2019 **(Table 2)**.

Quinoa is one of the few plants that tolerate the cold weather, and the amount of its tolerance to cold largely depends on the period of cold, growth stage, variety, relative humidity and microclimate conditions [11]. In this study, due to the lack of temperature below 2.5°C below zero, no signs of cold damage were observed on the growth process of the crop.

Quinoa tolerates a temperature of -8°C for 2-4h in the two-leaf stage, and that the most sensitive stage of quinoa growth in the cold weather, is the flowering and budding stages. Frost stress at -6°C during flowering causes complete destruction of plant [12].

Different growth stages investigation showed that quinoa seeds are not sensitive for emergencing to high temperatures. The mean minimum temperature during the emergencing period was 5.2 and 5.11 and in the spring planting dates was 3.21 and 2.20°C, in the autumn planting dates respectively. During emergencing period until budding, the highest temperature of 29.6 and 30.1°C for August 20 and the lowest temperature were in February 19 with 6.5 and 9°C per year, for the first and second experimented years respectively.

Minimum, optimal, and maximum temperatures for quinoa germination, is 30 to 35, and 50°C [13]. The temperatures between 2 and 20°C for emergencing of 10 quinoa genotypes and it is showed that increasing the temperature can case increasing the germination rate of quinoa seeds [12]. Jacobsen and Bach (1998) also reported the best time to plant is when the temperature reaches 8-10°C.

The amount of GDD obtained in the fall planting dates was higher than in the spring planting dates, although this amount of GDD was obtained during the shorter growth period. The maximum GDD received during the first and second year of the experiment was 1792 and 1882 on July 31. The yield on this planting date was 1590 and 1892 kg.ha^{-1}, respectively.

On planting dates of 19 February, receiving GDD 1296 and 1325 in 2018, 2019 and 20 August, respectively, receiving GDD 1536, 1837, it produced higher grain yield **(Figure 1; Table 2)**. In 2018, it ranged from 14 to 142 GDD in the 2019 crop year and 46 to 153 GDD in the following year. The GDD absorbed during the spring planting period was much lower than in the fall, but the total temperature received in the fall did not differ much between the ages studied. Minimum required GDD of quinoa at 30. The maximum GDD required for budding in the first and second years of the experiment was 1062 and 1083 for July 31, respectively [13]. The GDD difference between emergencing and budding on this planting date was 929 and 906 degrees, respectively.

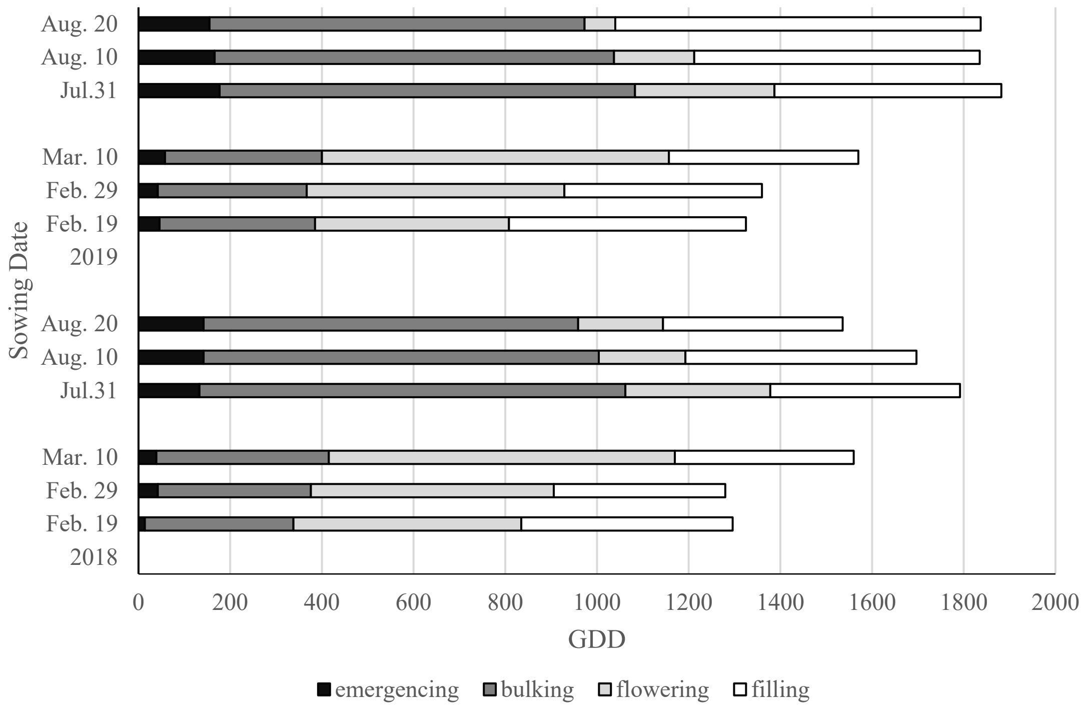

Figure 1. The amount of GDD (The degree of growth days) until the harvest of different dates of quinoa planting

The maximum GDD was for fall planting treatments, which occurred (in both years) on July 31st, and the minimum GDD was on March 10th for the entire growing season (1560 and 1570 degrees, respectively, for the first and the second experiment. the difference between the maximum GDD obtained was 232 and 312 degrees, respectively **(Figure 1)**.

In the first and second years of experiment on March 10 the highest temperature at the time of stem elongation (from budding to flowering), were 23.8 and 25.9, respectively, **(Table 2)**. Plant heights on this planting date was 84 and 107 cm in two years, respectively, which was the lowest as compared with the other dates **(Table 3)**. Hirich *et al*. (2014) in a study of 5 quinoa genotypes in greenhouse conditions stated that increasing the temperature causes a decrease in altitude, number of lateral branches and the size of the panicle [14]. Although in preset study, the difference between plant heights in the studied planting dates was not significant, but the trend of changes in plant height in both years showed this **(Table 3)**.

The maximum temperature was between flowering and the time of loading product on 10 March. During these planting dates, the lowest yield was obtained in both years **(Table 1; 3)**. It seems that the higher temperature at the time of ripening seed has reduced yield. In general, quinoa was sensitive during the period of ripening seed to high temperatures (above 20°C) or low. At high temperatures, pollen and the number of flowers decreased [15], and most Quinoa`s genotypes do not produce seeds at temperatures above 35°C.

Due to the shortening of the developmental stages due to the faster receipt of GDD, yield components that are stabilized in these stages were affected by the daytime degree of collective growth [16] reported. Cumulative growth per day rate as an indicator of the relationship between yield and temperature may be misleading and other indices appear should be used [17]. The time of the onset of growth for reproductive organs and their number depends on the temperature and length of the day, but the survival and size of these organs depend on the availability of nutrients [18].

Temperature is one of the most important factors affecting on growing of any crop [19]. Relationship between yield and maximum temperature in the flowering (2018) and filling stages and in the budding and filling stages based on the third degree of significant relationships was defined (2019). Based on these, the yield, in the flowering stage in 32°C and filling stage increased in 33°C and Then it starts to decrease, (2018), **(Figure 2)**.

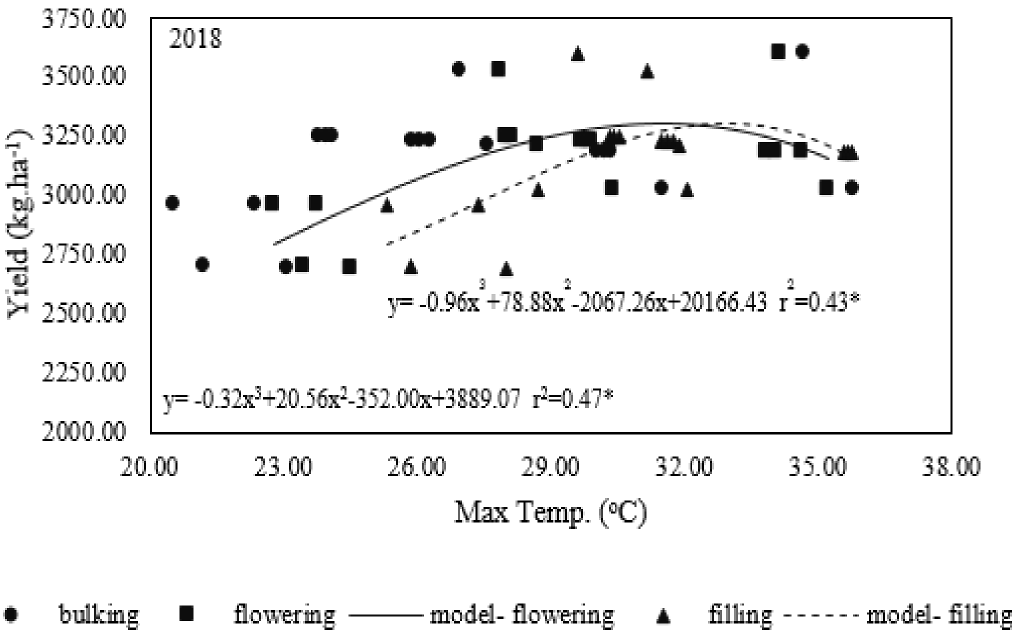

Figure 2. The effect of maximum temperature on grain yield, on different stages of budding, flowering and grain filling (2018)

In 2019, the yield increased to 26°C during the budding stage and then to 32°C, after which the yield increased again. During the filling phase, up to 30°C had an increasing trend, and then an increase in temperature reduced the yield **(Figure 3)**.

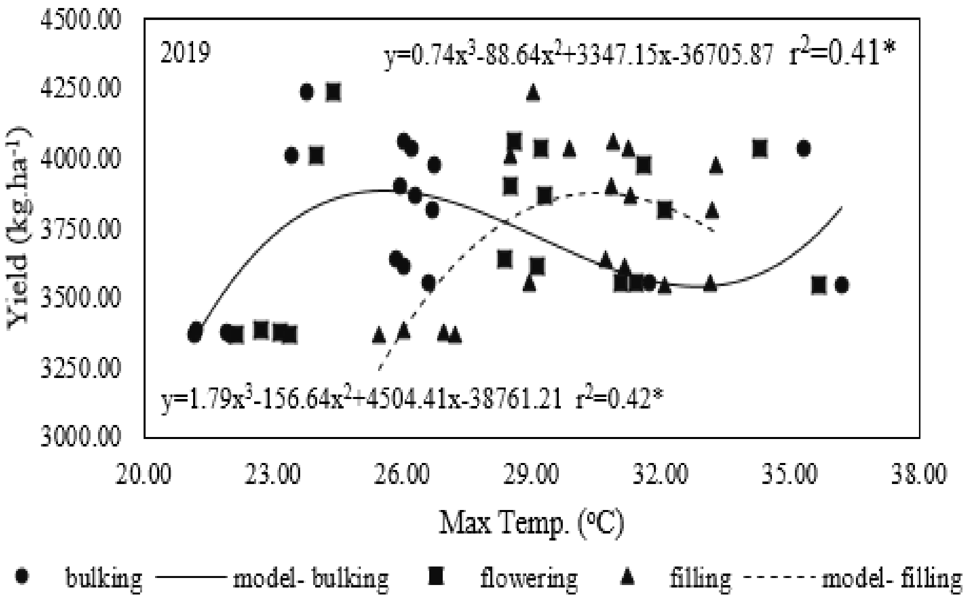

Figure 3. The effect of maximum temperature on grain yield, on different stages of budding, flowering and grain filling (2019)

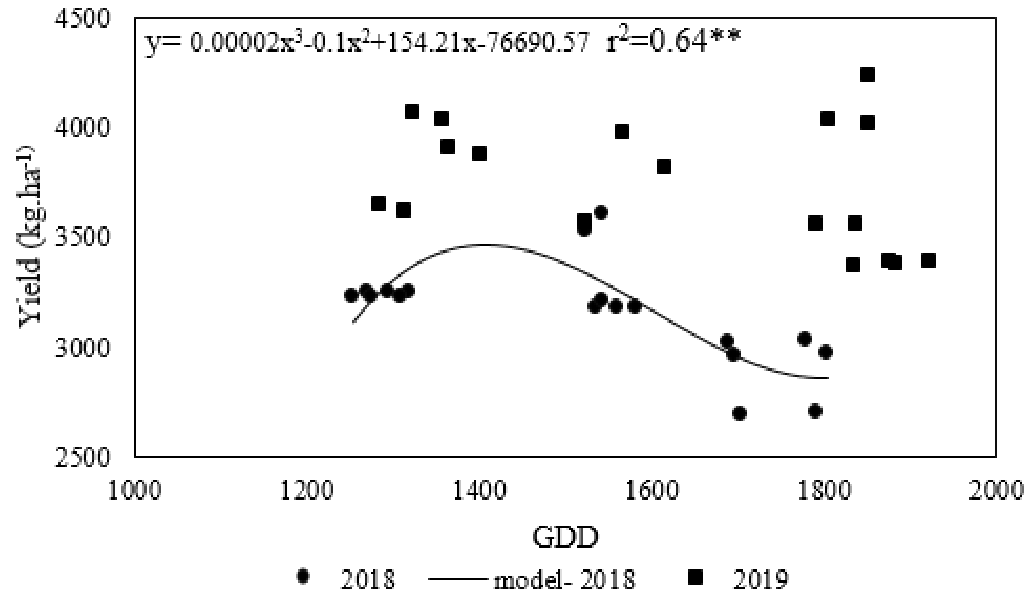

Figure 4. The relationship between grain yield and the degree of growth days to maturity

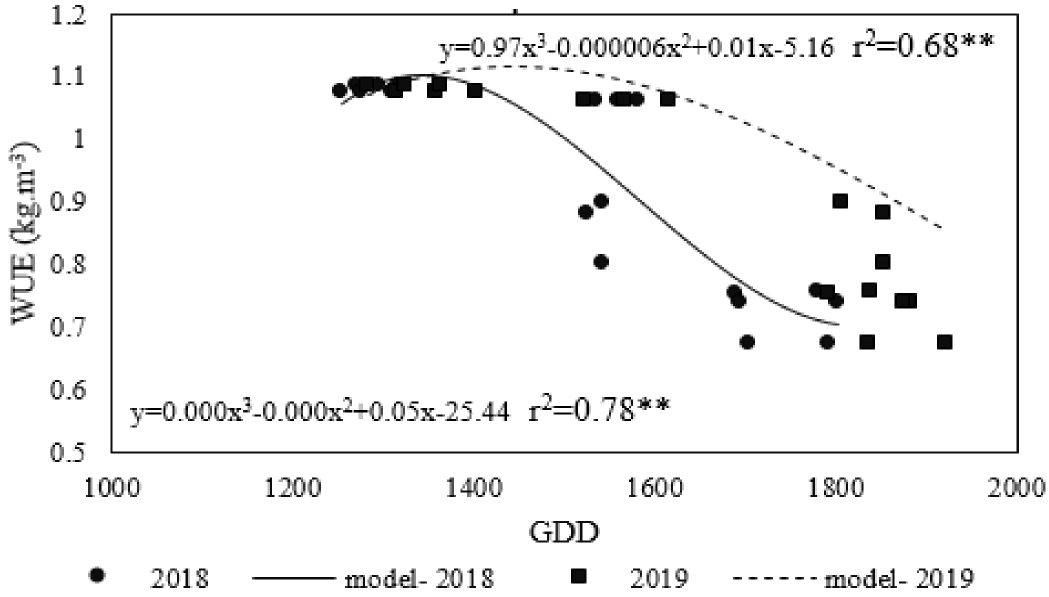

Figure 5. The relationship between water use efficiency and GDD until processing

High temperatures in most crops during the reproductive stage, especially during pregnancy and panicking, ultimately reduce yield by increasing the length of flowering period, sterility of flowers, reduce fertility, imperfect seed growth, loss of 1000 grain weight [20-22]. Occurrence of high temperatures in the reproductive stage reduces merely the period of grain filling and ultimately affects the yield [23]

The relationship between yield and GDD till maturity was achieved as a significant cubic equation with a regression coefficient of 0.64 (2018). With increasing GDD till 1406, grain yield was increased and then start decreasing, **(Figure 4)**. The water use efficiency has had a similar relationship with GDD. This relationship was also of the cubic equation type for both experimental years with a regression coefficient of 0.78 and 0.68, respectively. GDD was increased till amount of 1352 with a light slope of the upward trend and then with a steep slope of the trend has decreased in year 2018. GDD, was increased till1, 489 and then it has a sharp decline in year 2019 **(Figure 5)**.

Table 4. Correlation of studied traits

	P.N.	H.W.	P.H.	B.	G. Y.	P.S.N	H.I	W.U.E.
P.N.	1.00							
H.W.	0.65**	1.00						
P.H.	0.02^{ns}	0.56*	1.00					
B.	0.76**	0.04^{ns}	0.51*	1.00				
G. Y.	0.64**	0.34^{ns}	0.44^{ns}	0.46^{ns}	1.00			
P.S.N	-0.28^{ns}	0.80**	0.86**	-0.59*	0.33^{ns}	1.00		
H.I	-0.17^{ns}	0.27^{ns}	0.91**	-0.57*	0.46^{ns}	0.91**	1.00	
W.U.E.	0.918**	0.09^{ns}	0.27^{ns}	0.55*	0.61*	0.14^{ns}	-0.33^{ns}	1.00

The yield is a complex quantitative trait, which is controlled by a large number of genes and is strongly influenced by the environment. This attribute is the result of many characteristics that affect it alone or together. The selection of optimal genotypes based yield is not beneficial (effective) and is much more useful if it is based on traits that directly or indirectly contribute to yield [24]. The highest significant correlations the studied traits between function and the number of panicles per unit area were observed. Grain yield was also not significantly correlated with other traits studied in this study. The number of panicles per unit area is an attribute that plays a key role in determining yield [25, 26]. The number of cereals fertile spike per unit area was reported to be the most important determinant of grain yield. It is considered that the highest observed correlation was related to plant height and harvest index and then grain harvest index in panicle **(Table 4)**.

CONCLUSION

Temperature is one of the most important non-living factors affecting growth and production in quinoa [27-29]. Therefore, in order to describe growth and yield, it is necessary to Investigate the relationships between these components. Date of August 20th had the highest rate among the date of planting, on this date, the plant produced the largest number of seeds in the panicle and harvest index in a shorter time and finally produced the highest yield. According to the results of the yield in the treatments of the planting dates of February 19 and 29, after the best treatment, they had the highest amount of yield and were placed in a statistical group without any significant statistical difference with the planting date of August 20. Accordingly, due to the favorable water and soil conditions in these two dates and also due to the higher efficiency of water consumption and the lack of growth restrictive cold in these planting dates, planting dates of 19 and 29 February are recommended for planting this quinoa genotype in Kavar region.

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Conflict of interest: None

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Ethics statement: 1) This material is the authors' own original work, which has not been previously published elsewhere. 2) The paper reflects the authors' own research and analysis in a truthful and complete manner.

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