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PERFORMANCE OF SOME QUINOA (*Chenopodium quinoa* Willd.) GENOTYPES GROWN IN DIFFERENT CLIMATE CONDITIONS

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ABSTRACT

Quinoa (*Chenopodium quinoa* Willd.) is an alternative plant of which cultivation rapidly increases because of its high nutritive value. Background studies should be conducted on the determination of quinoa cultivars appropriate for different ecologies for its cultivation to become widespread in a healthy way. This study was planned to identify suitable quinoa cultivars in Erzurum and Iğdır provinces which demonstrate different ecological characteristics of the Eastern Anatolia Region. The study was conducted in 2015 and 2016 under irrigated conditions. The experiments were conducted with 10 genotypes in each location in a randomized complete blocks design with four replications. The grain yield and some related characteristics were examined in the study. The maturation time, grain yield and related characteristics of quinoa varied significantly depending on genotypes and locations in the study. The earliest and most productive genotype is Q-52 and it produced 979.8 kg ha^{-1} of seeds under Erzurum conditions and 3679.6 kg ha^{-1} of seeds under Iğdır conditions. According to the results of the study, quinoa is a risky product in Erzurum which has a high altitude. However, cultivars such as Q-52, Rainbow, Red Head and Mint Vanilla were found promising for Iğdır location.

Keywords: *Chenopodium quinoa* Willd., genotypes, locations, quinoa, seed yield

INTRODUCTION

In recent years, quinoa (*Chenopodium quinoa* Willd.) which we frequently hear about it is an alternative plant for the agriculture in Turkey. This plant originating from the continent of South America began to become popular in the 2000s and studies on its cultivation and improvement were initiated in many countries in the world. The cultivation area of quinoa in Turkey since 2010 increase rapidly.

The importance of quinoa results from the high nutritive value of its seeds. While it varies by genotypes, they contain approximately 10-18% crude protein, 4.50-8.75% fat, 54.1-64.2% carbohydrate, 2.40-3.65% ash and 2.1-4.9% fiber (Keskin and Kaplan Evlice, 2015). The crude protein rate is prominently higher when compared to crops such as wheat, rice and corn and reaches up to 23% (Abugoch, 2009). Another importance of quinoa in terms of its nutritive value is that it does not contain gluten. Due to this characteristic, it is a significant nutritional source meeting the protein and carbohydrate needs of coeliac patients (gluten allergy) (Jacobsen, 1993). Quinoa seeds are rich in various minerals such as Ca, Mg, K, Fe, Cu and Mn, and vitamins such as A, B, C and E (Repo-Carrasco et al., 2003). It should be better if the researchers mention nutritional balance and digestibility of the plant. Also they should stressed out its low energy thus, it can be used for diet programs.

In Turkey, quinoa, which used to be sold in luxurious markets a few years ago, becomes quickly widespread because of the high demand. Thus, quinoa cultivation and production gain importance. In Turkey, quinoa is not well known, it is a newly discovered plant by researchers and producers, despite its advantages. Although experimental cultivations are conducted in almost all regions, there are a limited number of scientific studies carried out. It was suggested in the studies conducted under the conditions of Izmir that quinoa should be planted in the first half of April (Geren et al., 2014), the row spacing should be set as 35 cm (Geren et al., 2015) and it should be fertilized with 150 kg ha^{-1} nitrogen (Geren, 2015). It was found out in the studies conducted in Cukurova region that saline water and deficit irrigation did not cause a high decrease in yield (Ince Kaya, 2010), and it was stated that seeding should be done as early as possible in the spring (Yazar et al., 2013). There is a need for more scientific studies in various regions for quinoa cultivation to become widespread in a healthy way in Turkey. One of the most important reasons of failure in quinoa cultivation is the lack of appropriate genotypes in production. There are hundreds cultivars or ecotypes of quinoa cultivated in

South America. It is important to identify appropriate introduction materials brought to our country by testing them in various ecologies. Because yield varies greatly depending on genotypes and locations (Miranda et al., 2012).

The Eastern Anatolia Region appears to be the most disadvantageous region for quinoa cultivation in Turkey, because this region has the high altitude and the plant cultivation season is short. Quinoa is a plant that loves the relatively warm climate, requires a long growth period and needs at least 7-10 °C temperature in the soil to germinate (Tan and Yondem, 2013). But, it has an amazing ability to adapt to adverse conditions of climate and soil where other crops cannot grow, especially at high altitudes. Therefore, quinoa cultivation in high-altitude locations in the Eastern Anatolia Region is a curiosity. The Eastern Anatolia Region has locations which have geographical characteristic different from each other and thus different ecological structures. Bayburt, Erzurum, Ağrı, Kars and Ardahan provinces are located on the high altitude plateau of the region. These provinces have relatively cool climates and a short cultivation season. Moreover, there are provinces of which annual average temperature is higher and cultivation season is long such as Erzincan and Iğdır. Producers are making efforts to grow this plant in many locations of the Eastern Anatolia Region. Therefore, the aim of this study was to evaluate different quinoa genotypes for potential seed yield in two different locations (Erzurum and Iğdır) of Eastern Anatolia Region.

MATERIALS AND METHODS

The study was conducted in irrigated experimental areas of Atatürk University, Faculty of Agriculture (Erzurum), and Iğdır University, Faculty of Agriculture (Iğdır) in 2015 and 2016. 10 quinoa (*Chenopodium quinoa* Willd.) genotypes (1 population and 9 cultivars) were evaluated in two different locations in terms of the grain yield and related characteristics. The materials used in the experiments and their origins are shown in Table 1.

Table 1. Quinoa genotypes used in the research, their origin and phenotypic seed color

Genotypes	Origin	Phenotypic Seed Color
Population	China	Light Brown
Q-52	Denmark	Whitish-Yellow
Rainbow	USA	White
Read Head	USA	White
Sandoval Mix	England	Whitish
Cherry Vanilla	USA	White
French Vanilla	USA	White-Cream
Mint Vanilla	USA	Bright-White
Oro de Valle	USA	Golden-Brown
Moqu-Arrochilla	Peru	Whitish

Field experiments were established on March 29th, 2015 and April 6th, 2016 in Iğdır; May 5th, 2015 and May 10th, 2016 in Erzurum. In the each experiment, 10 quinoa genotypes were sown in a randomized complete blocks design with four replications. During the sowing, 2500-3000 g ha^{-1} seeds were spread with 35 cm row spacing by hand at 1.5-2 cm sowing depth on parcels (Tan and Yondem, 2013; Geren et al. 2015). Plots size was 6 rows of 4 m, with an inter-row spacing of 0.35 m. Nitrogen [$(NH4)_2SO4$] was supplied at sowing (75 kg ha^{-1}) and again during vegetative growth before flowering (50 kg ha^{-1}). Phosphorus was applied in the dose of 80 kg ha^{-1} for once while preparing the seedbed (Jacobsen et al., 1994; Schulte auf'm Erley et al., 2005; Yazar et al., 2013; Tan and Yondem, 2013; Geren et al., 2015). The plants were irrigated in June-August depending on the need and rainfall.

Harvests by hand in end of September were done at physiological maturity, which was defined as the date when seeds from the main panicle become resistant when pressed (Bertero et al., 2004). The time elapsed between seeding and harvest in the genotypes of which seeds matured and reached the harvest season was recorded as maturity period. The plant height was determined by acquiring 10 plants randomly from mid rows of the parcels before the seed harvest. During the harvesting, the rows on the sides and 0.5 m sections from the heads of the plots were taken, and then the remaining area was harvested and filled with bags. The materials were first blended in the open air, then dried in a drying oven set at 40 °C. Biological, seed and straw yields and harvest indexes were calculated from the obtained data. The 1000-grain weights were calculated by weighing 4 x 100 seeds in each plot.

The data obtained from the study were subjected to the variance analysis according to the randomized complete blocks design. Differences between the averages were determined with the LSD multiple comparison test. While the results of the grain yields were presented separately for both years, the results of other parameters were presented as two-year averages in the article.

Both locations are situated in the Eastern Anatolia Region; however, they have characteristics different from each other. Erzurum is the province which has the highest altitude in the Eastern Anatolia Region with its location 1860 m above sea level. Winter period is long, cold and snowy. Summer months are relatively cool and short. Last frosts of spring may extend to May and first frosts of autumn start in September. Therefore, the plant cultivation season is shorter in Erzurum than in other provinces. Iğdır is the province which has the lowest altitude in the region with its 876 m altitude. The plant cultivation season is long in Iğdır which has the characteristics of microclimate in the Eastern Anatolia Region. Summer months are hot and dry, evaporation is high. Thus, agricultural soils usually have salty characteristics.

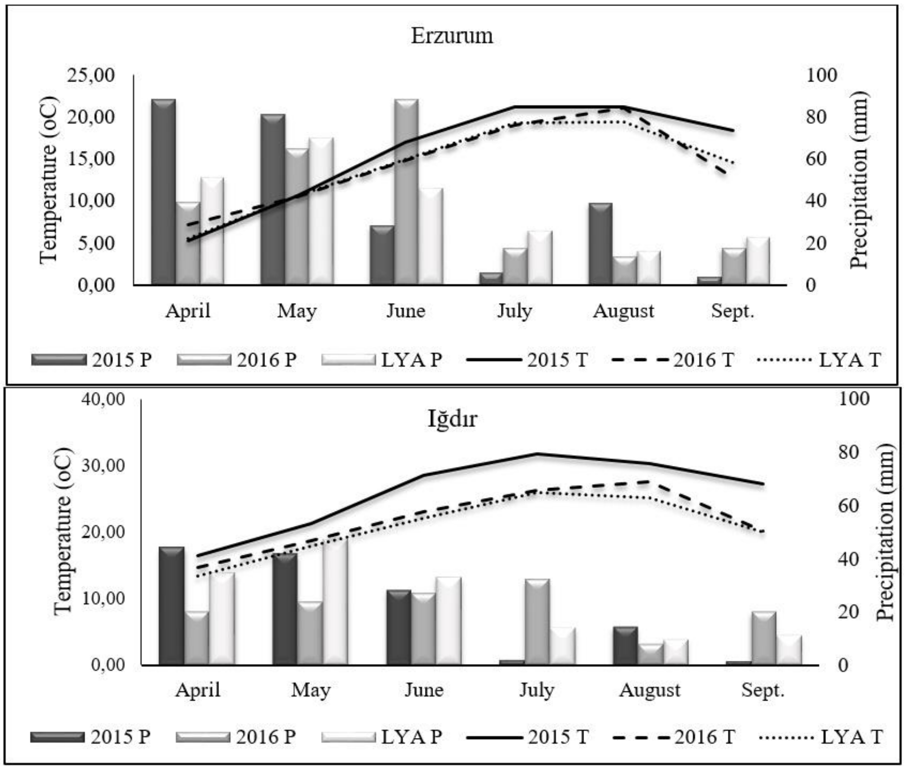

Figure 1. Monthly temperature (lines) and precipitation (bars) of study months in Erzurum and Iğdır locations, 2015, 2016 and long year average (LYA)

The temperature and precipitation characteristics of Erzurum and Iğdır locations are shown in Figure 1. During the period (April-September) in which both Erzurum and Iğdır were experimentally conducted, the temperature in 2015 and 2016 was higher than the average for many years. The monthly average temperature in 2015 and 2016 in the research period (April-September) which both Erzurum and Iğdır was higher than the long-term average. The total precipitation in experimental years was found to be higher than the long-term average in Erzurum location and was found to be lower in Iğdır location. The temperature and precipitation differences between the locations are quite apparent. According to Erzurum location, Iğdır has got warmer and drier conditions in every two years.

Some characteristics of the soil in which the experiments were conducted are shown in Table 2. While locations are similar in terms of the soil texture class, they are different with regard to electrical conductivity (EC), pH, $CaCO_3$ and available phosphorus and potassium for plants. The soils in Iğdır location have the characteristics of being slightly salty, slightly alkaline and mid-calcareous, differently from Erzurum location.

Table 2. Some physical and chemical properties of soils in research areas

Soil Properties	**Erzurum**	**Iğdır**
Texture class	Clay-loamy	Clay-loamy
EC (ms cm^{-1})	0.48	2.00
pH	7.1	7. 9
CaCO3 (%)	2.5	6.5
K (kg K_2O ha^{-1})	1380	3430
P (kg P_2O_5 ha^{-1})	74	80
Organic matter (%)	1.4	1.6

RESULTS AND DISCUSSION

Days to Harvest (Maturity) and Plant Height

Quinoa genotypes examined in the study grew to maturity of the seed harvest in 119 days under the conditions of Erzurum and in 141 days under the conditions of Iğdır (Table 3). The reason why quinoa grows mature in a longer time under the conditions of Iğdır is that it is planted earlier. All genotypes were also matured under the conditions of Erzurum, but they have achieved less growth and development. Quinoa is a short-day plant; it comes into flower and matures with the shortening of days in summer months. While the Q-52 cultivar reached harvest earlier in the both locations (107 and 125 days), the latest genotypes were population and Mint Valle in Erzurum location (125 days) and Oro de Valle in Iğdır location (158 days). Early maturity is important because of the increased risk of frost toward the end of the season. Since the genotypes needed different day lengths and temperatures, their maturations were also different. Similar results have been reported by Szilagyi and Jornsgard (2014), the days to harvest of quinoa varied greatly between varieties in Romania. Jacobsen (2003) stated that quinoa genotypes grew to harvest maturity between 108 and 181 days in Denmark.

Table 3. Days to harvest and plant height of some quinoa genotypes in Erzurum and Iğdır conditions

	Maturity (days)			Plant Height (cm)		
Genotypes	**Erzurum**	**Iğdır**	**Mean**	**Erzurum**	**Iğdır**	**Mean**
Population	125	145	135 AB	95.8	103.3	99.5 ABC
Q-52	107	125	116 D	66.5	89.4	78.0 D
Rainbow	121	142	132 ABC	106.6	112.5	109.6 A
Red Head	122	138	130 BC	91.1	116.4	103.8 AB
Sandoval Mix	120	144	132 ABC	85.6	111.6	98.6 ABC
Cherry Vanilla	122	142	132 ABC	78.5	111.0	94.8 BC
French Vanilla	114	144	129 BC	95.0	114.8	104.9 AB
Mint Vanilla	125	143	134 AB	105.0	109.3	107.1 A
Oro de Valle	122	158	140 A	89.4	113.1	101.3 AB
Moqu Arrochilla	115	133	124 CD	94.8	83.8	89.3 CD
Mean	119 B	141 B	130	90.8 B	106.6 A	98.7
Probability and LSD Value						
Genotype (G)		8.4**			11.6**	
Location (L)		3.8**			5.2**	
G x L		9.0*			16.4**	

*: 0.05, **: 0.01, Capital letters within the same column and row are significantly different at 1%.

The plant height of quinoa varied significantly depending on the genotype and location (Table 3). While the longest genotype was Rainbow in Erzurum location (106.6 cm), it was Red Head cultivar in Iğdır location (116.4 cm). Q-52 which originated from Denmark was the genotype with the shortest height in both locations. The plant height was related to the duration of maturity and generally shorter varieties showed earlier characteristics. On the other hand, late maturity varieties, like Oro de Valle and Mint Vanilla grew taller than that matured early as Q-52 and Moqu Arrochilla (Table 3). The differences in the plant heights of genotypes may have resulted from genetic structures and different reactions to the environment. Thus, similar results were obtained from the studies conducted in different geographical regions and it was indicated that the heights were different in quinoa varieties and populations (Pulvento et al., 2010; Bhargava et al., 2007; Spehar and Da Silva Rocha, 2009).

Grain Yield

Grain yields of quinoa genotypes varied significantly with regard to genotypes, locations and years and the genotype x location interaction was found to be statistically significant (Table 4). While the average grain yield was found to be 630.9 kg ha^{-1} in Erzurum location, it was identified to be 2857.7 kg ha^{-1} in Iğdır location. Iğdır location has a warmer climate when compared to Erzurum (Figure 1). Sowings were done earlier in this region and plants had a longer growth time. Additionally, the fact that the soils in the region have slightly salty characteristics may be effective on the high yield. Because quinoa is resistant to soil salinity, its performance is higher in slightly salty soils (Jacobsen, 2003; Wilson et al., 2002). Grain yields were found to be considerably lower in Erzurum, because of the fact that the plants came into flower before they found time to grow enough and the growing season ended. Although the plants grew to harvest maturity technically, the vast majority of the panicles did not set the seed. This plant is able to grow in higher altitudes in South America than Erzurum, but the climatic conditions there are more suitable for quinoa cultivation.

Seed performance of quinoa varied greatly between genotypes in both locations. The highest grain yield was obtained from Q-52 cultivar in both regions (Table 4). Q-52 cultivar provided 979.8 kg ha^{-1} yield in Erzurum which was followed by Rainbow cultivar (931.6 kg ha^{-1}). In Iğdır, Q-52 again while taking the first order (3679.6 kg ha^{-1}), it was followed by Red Head (3208.1 kg ha^{-1}), Rainbow (3062.5 kg ha^{-1}) and Mint Vanilla (3019.1 kg ha^{-1}). The studies conducted with different genotypes in different locations in the world revealed that quinoa grain yield varies between 250-5000 kg ha^{-1} (Gesisnski, 2008; Risi and Galwey, 1991). This difference results from the fact that the genotypes exhibit different performances under different ecological conditions (Miranda et al., 2012). Bertero et al. (2004) identified that the grain yield in 24 quinoa genotypes provided from different locations in the world varies between 1111 kg ha^{-1} and 2574 kg ha^{-1}. The researchers stated that the grain yield varied significantly between 17 locations having different altitudes (from 5 to 3841 m a.s.l.) and temperatures (average daily temperatures during crop cycle varied from 9 to 22.1 °C).

Table 4. Grain yields of some quinoa genotypes grown in Erzurum and Iğdır conditions in 2015 and 2016 (kg ha^{-1}).

Genotypes	Erzurum			Iğdır			General Mean
	2015	2016	Mean	2015	2016	Mean	
Population	600.3	736.8	668.5	2659.5	2557.8	2608.6	1638.6 BC
Q-52	703.8	1255.8	979.8	4004.3	3355.0	3679.6	2329.7 A
Rainbow	638.3	1225.0	931.6	3152.5	2972.5	3062.5	1997.1 AB
Red Head	351.8	871.0	611.4	3126.3	3290.0	3208.1	1909.8 AB
Sandoval Mix	413.0	1050.5	731.8	2426.3	2451.5	2438.9	1585.3 BC
Cherry Vanilla	103.5	793.3	448.4	2510.8	3400.0	2955.4	1701.9 BC
French Vanilla	82.5	585.0	333.8	1767.3	2449.5	2108.4	1221.1 C
Mint Vanilla	616.0	794.0	705.0	3611.0	2427.3	3019.1	1862.1 AB
Oro de Valle	586.8	541.3	564.0	2557.0	2487.5	2522.3	1543.1 BC
Moqu Arrochilla	243.0	426.8	334.9	2841.8	3105.5	2973.6	1654.3 BC
Mean	433.9	827.9	630.9 B	2865.7	2849.7	2857.7 A	1744.3
LSD Value	G: 628**	L: 281**	Y: 212*	GxL: 671*	GxY: ns	LxY: ns	GxLxY: ns

*: 0.05, **: 0.01, ns: non-significant, Capital letters within the same column and row are significantly different at 1%.

Biological Yield and Straw Yield

Significant differences were observed in the biological and straw yield of quinoa genotypes with different origins (P<0.01) (Table 5). The interaction of genotype x location was found highly significant effects on straw and biological yields in the present study. The highest biological yield (7843.3 and 13486.9 kg ha^{-1}) and straw yield (7108.8 and 11048.0 kg ha^{-1}) were identified in Sandoval Mix cultivar both in Erzurum and Iğdır. However, some genotypes exhibited different performances in different locations. This situation caused the genotype x location interaction to be significant in biological and straw yield. For instance, while French Vanilla had the lowest biological yield (4354.6 kg ha^{-1}) in Erzurum location, it was one of the genotypes which had the high yield under the conditions of Iğdır. This cultivar exhibited a similar performance in straw yield. It is an expected result that biological yield and straw yield vary between quinoa genotype and locations with different characteristics and similar results were obtained from other studies (Bertero and Ruiz, 2008; Gesinski, 2008; Bhargava et al., 2007).

Table 5. Biological and straw yields of some quinoa genotypes in Erzurum and Iğdır conditions

Genotypes	Biological Yield (kg ha^{-1})			Straw Yield (kg ha^{-1})		
	Erzurum	Iğdır	Mean	Erzurum	Iğdır	Mean
Population	6772.3	10518.8	8645.5 B	6102.6	7910.1	7006.4 B
Q-52	6139.9	9668.1	7904.0 B	5182.0	5988.5	5585.3 C
Rainbow	7298.3	10400.1	8849.2 B	6646.0	7338.8	6991.4 B
Red Head	5399.9	9706.8	7503.3 B	4696.3	6498.9	5597.6 C
Sandoval Mix	7843.3	13486.9	10665.1 A	7108.8	11048.0	9074.9 A
Cherry Vanilla	4971.8	9960.6	7466.2 B	4525.1	7005.3	5765.2 BC
French Vanilla	4354.6	10477.1	7415.9 B	3835.3	8368.8	6102.0 BC
Mint Vanilla	6935.8	10801.1	8868.4 B	6366.3	7782.0	7074.1 B
Oro de Valle	5875.1	9608.3	7741.7 B	5310.6	7086.0	6198.3 BC
Moqu Arrochilla	5808.9	9392.3	7600.6 B	5470.5	6418.6	5944.6 BC
Mean	6130.0 B	10402.0 A	8266.0	5523.4 B	7544.5 A	6534.0
Probability and LSD Value						
Genotypes (G)		145.7**			131.8**	
Location (L)		65.1**			59.0**	
G x L		155.8*			186.4**	

*: 0.05, **: 0.01, Capital letters within the same column and row are significantly different at 1%.

Harvest Index and 1000-Seed Weight (TGW)

Harvest index ranged from 13.6% to 27.0% between genotypes and Q-52 cultivar showed the highest value (27.0%) (Table 6). Since the grain yields of the plants were higher under the conditions of Iğdır, harvest index values were found to be considerably higher. The Q-52 cultivar, which is high yielding and early maturing, has a higher harvest index than late maturing genotypes in both locations. The harvest indexes of late maturing genotypes were found to be lower especially in Erzurum location. Earliness is significant for grain yield and harvest index in high altitude regions (Bhargava et al., 2007). Low harvest index values for late and high values for early maturing genotypes supported similar findings by Szilagyi and Jornsgard (2014).

Table 6. Harvest index and 1000-grain weight of some quinoa genotypes in Erzurum and Iğdır conditions

Genotypes	Harvest Index (%)			1000-Grain Weight (g)		
	Erzurum	Iğdır	Mean	Erzurum	Iğdır	Mean
Population	9.5	26.2	17.9 BC	2.27	2.51	2.39 BC
Q-52	16.1	38.0	27.0 A	2.36	2.87	2.61 A
Rainbow	12.5	30.6	21.6 AB	2.36	2.62	2.49 AB
Red Head	9.9	34.5	22.2 AB	2.09	2.52	2.31 C
Sandoval Mix	9.6	19.9	14.8 C	2.12	2.12	2.12 D
Cherry Vanilla	8.5	31.0	19.8 BC	2.10	2.36	2.23 CD
French Vanilla	6.2	21.0	13.6 C	1.98	2.52	2.25 CD
Mint Vanilla	9.9	28.5	19.2 BC	2.19	2.33	2.26 CD
Oro de Valle	10.6	26.7	18.7 BC	2.49	2.74	2.61 A
Moqu Arrochilla	5.6	32.2	18.9 BC	2.30	2.83	2.56 A
Mean	9.9 B	28.9 A	19.4	2.23 B	2.54 A	23.9
Probability and LSD Value						
Genotype (G)		6.3**			0.18**	
Location (L)		2.8**			0.08**	
G x L		8.9*			0.25**	

*: 0.05, **: 0.01, Capital letters within the same column and row are significantly different at 1%.

The effects associated with genotypes, locations and interactions were significant with respect to TGW (Table 6). Results show that TGW ranged from 2.12 g to 2.61 g between genotypes. Q-52, Oro de Valle, Moqu Arrochilla and Rainbow had higher TGW values than the others. TGW was higher in Iğdır location than Erzurum location. It may be due to long growth period in Iğdır which was conducive for better grain filling and grain weight. Q-52 which is the earliest genotypes had a higher TGW value in both locations (2.36 g and 2.87 g). Researchers such as Bertero et al. (2004), Bertero and Ruiz (2008) and Sajjad et al. (2014) determined that TGWs were different in quinoa depending on genotypes and locations.

CONCLUSION

Quinoa could be an alternative crop with favourable features for cropping systems in the low lands of Eastern Anatolia Region. Quinoa plant has a high yield potential in locations such as Iğdır which have low altitude and long cultivation season. 3500-4000 kg ha^{-1} grain yield seems to be quite good when compared to the studies conducted in other regions of Turkey. The chance of growing many other products in regions with salty soils such as Iğdır is low. Thus, quinoa cultivation gains importance in such locations. Cultivars such as Q-52, Rainbow, Red Head and Mint Vanilla can be suggested for Iğdır and similar locations. However, quinoa cultivation seems to be risky in high altitude locations such as Erzurum. Even though earlier cultivars such as Q-52 can grow to maturity, their yield is low. Since soil temperature must reach 8-10 ºC for quinoa seeds to germinate, there is no chance of planting them earlier. Therefore, it will be useful to identify earlier genotypes with a high yield potential in high altitude locations of the Eastern Anatolia Region such as Erzurum.

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