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The effect of plant density on growth and seed yield of quinoa (*Chenopodium quinoa* Willd.) in the middle region of Syria

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Abstract

A field experiment was conducted at Homs Agricultural Research Center, General Commission for Scientific Agricultural Research (GCSAR), Syria, during 2021 season, to study the effect of plant density on quinoa growth and seed yield in the middle region of Syria. The experiment was laid out according to randomized completely block design (RCBD) in split plot arrangement with three replicates. Experimental factors included five introduced varieties (Giza, Titicaca, Red Carina, Q26 and NSL) and six plant densities (50 ×10, 50 ×15, 50 ×20, 30 ×10, 15 × 30 and 30×20 cm). The results of statistical analysis showed significant differences ($P \leq 0.05$) among studied varieties, plant densities and interaction between verities and plant densities for all investigated traits. Plant height was significantly higher for variety Red Carina at density of 30 × 10 (214.3 cm), stem diameter was significantly higher for variety Q26 at density of 50 × 20 (11.067 cm), panicle length was significantly higher for variety NSL at density of 50 × 20 (42.6 cm), panicle width was significantly higher, for variety NSL, at density of 50 × 15 (17.0 cm), seed yield was significantly higher for variety Giza-1 at density of 50 × 15 (2068.7 kg/ha) and variety Q26 at density of 50 × 20 (2058.7 kg/ha). Biological yield was significantly higher for variety Q26 at density of 50 × 20 (6759.3 kg/ha). The study recommends to grow quinoa at density of 50 × 20 to get the best morphological and production traits. Also, Q26 variety is recommended to be grown as compared with the other varieties.

Keywords: quinoa, plant densities, growth, seed yield

Introduction

Quinoa is a dicotyledonous plant with the scientific name *Chenopodium quinoa* Willd. from *Amaranthaceae* family and Chenopodiaceae sub-family, (5000) years old and was considered sacred in Inca rural civilization as the "mother seed" (James, 2009) [9]. Compared to many grains, quinoa seeds have a higher nutritional value. Quinoa seeds contain approximately 10-18% protein, 4.5- 8.5% crude fat, 54.1-64.2% carbohydrates, 2.4-3.5% ash, and 2.1-4.9% raw fiber (Jancurová *et al*., 2009) [10]. The plant is highly resistant to a wide range of abiotic stresses like cold, salinity, drought (Al-Jbawi *et al*., 2020) [2] and can grow in marginal soils (Jacobsen *et al*., 2009) [8]. The plant was first commercially cultivated in the state of Colorado, USA, in 1987 and is considered a suitable crop for farmers in most parts of North America (Johnson and Croissant, 1990) [11]. Quinoa is the best plant for cultivation in soils with salinity 19 dS/m (Wilson *et al*., 2002) [26]. Plant density is an important factor to ensure high quinoa seed yield (Aguilar *et al*., 2003) [1], which in turn is influenced by many factors, like crop varieties, climate conditions, and cropping strategies (Henderson *et al*., 2009). Determining the optimal plant density has a significant role in using production resources in agricultural ecosystems (Kafi *et al*., 2011) [12]. The optimal number of plants per unit area is the density, as a result of which all environmental factors are fully utilized by the plant, and at the same time, competition within and outside the plant is minimized. Thus, the maximum yield possible is reached with the desired quality (Khajehpour, 2001) [13]. Previous studies found differences among investigated quinoa cultivars in agronomical traits such as plant height, panicle length, number of panicles, 1000-seeds weight and grain yield (Maliro and Njala, 2019; Präger *et al*., 2018 [20]; Tan and Temel, 2018 [23]; Naneli *et al*., 2017 [17]). In Iran Owji *et al.*, (2011) found that increasing in the seed rate from 6 to 10 kg/ha increased plant height by 2.5% and grain yield increased from 624.41 to 2797.16 kg/ ha. Wang *et al.*, (2020) [25] reported that quinoa height and thousand kernel weight weren't significantly affected by plant density and the seed yield significantly decreased with increasing plant density from 20 to 40 plants m^2, in Brazil, Spehar and Rocha, (2009) [22] found that increasing density from 100000 to 600000 plants. ha^{-1} had a negative effect on plant height, though it didn't affect grain and biomass yield, nor did it affect 1000 grains weight. In Egypt with sparser density, Eisa *et al.*, (2018) [4] found that increasing plant density from 56000 to 167000 plants. ha^{-1} caused some decrements in 1000-seeds weight, also increased seed yield by 34.7%. In Argentina, Erazzú *et al.*, (2016) [5] reported that plant height, stem diameter, and grain yield were higher in sowing density of 70000 plants. ha^{-1} compared to 460000 plants. ha^{-1}. Delatorre *et al.*, (2003) [3] found a little difference in plant height and yield among three densities of 27000,60000, and 83,000. Similarly, Isobe *et al.*, (2015) [7] reported that the differences in seed yield of NL-6 quinoa variety were insignificant among plant densities in both narrow and wider row distances. Sief *et al.,* (2015) [21] reported there were gradual increases in panicle length with increasing row spacing from 20 to 40 cm. and grain yield of quinoa changed in the same trend when increased plant densities at narrow interspacing row treatments (20 cm), but in opposite trend at wider spacing. This may be attributed to the appropriate distribution of plants, which decrease competition among plants and allows it to maximum utilization of the circumstance surrounding it. In the northern part of Vietnam, Nguyen *et al.,* (2018) [18] found that plant density had no effect on the number of panicles, panicle length, or 1000-seeds weight, while yield increased from 7.8 to 36.9% when plant density increased from 130000 to 160000 and 200000 plants. ha^{-1}. Trinh *et al.,* (2001) also reported that plant density didn't affect plant height or panicle length of HV1 var quinoa, whereas individual yield increased when plant density decreased from 166666 to 47620 plants ha^{-1}. At the same time, actual yields were optimal when plant density ranged from 83333 to 111111 plants. ha^{-1}.

The objective of this study was to study the effect of six plant densities on some quinoa growth and productivity traits in the middle region of Syria.

Materials and Methods

Site of experimentation

The experiment was conducted at Homs Agricultural Research Center, General Commission for Scientific Agriculture Researches (GCSAR), Syria. during growing season 2021. The site has a latitude of 43.77º N, and longitude of 36.71º E with an altitude of 485 meters above sea level. Table (1) shows the meteorological data during the growing season in 2021.

Table 1: Summary of meteorological data during the growing season 2021

Month	Mean of Min. temperature (°C)	Mean of Max. temperature (°C)	Precipitation (mm)
February	4.81	16.08	24.2
March	6.80	16.78	32.9
April	10.35	23.62	53.6
May	16.38	30.10	0
June	18.36	30.24	0
July	23.21	34.52	0

According to Table (1), the mean maximum temperature during the studied period belongs to July with an average of 34.52 °C, and the average minimum temperature belongs to February 4.81 °C. Total precipitation during the experimental period in 2021 was 110.7 mm. The results of physical and chemical analysis of the field soil are shown in Table (2).

Table 2: Physical and chemical analysis of the experiment field soil in 2021

Electrical conductivity	Acidity	Organic matter	Nitrogen	Phosphorous	Potassium	Sand	Silt	Clay
Ec ($ds.cm^{-1}$)	pH	%	ppm			%		
0.12	*8.42*	1.37	30.45	10.00	204.25	26	14	60

According to the results in Table (2), the experiment field soil is clay, alkaline acidity, low organic matter, moderate to good phosphorus, potassium, and nitrogen content. Because of that phosphorus was used in the form of triple superphosphate (46% P_2O_5) and was added at a rate of 108 kg/ha, and potassium was used in the form of potash sulfate (50% K_2O) and was applied at a rate of 100 kg/ha K_2O during soil preparation. Nitrogen fertilizer was used in the form of urea (46% N) and was added at a rate of 261 kg/ha (split into two applications, half was applied with sowing and the remaining half was applied after thinning at 4-6 true leaves stage).

Experimental design

The experiment was laid out according to randomized complete block design (RCBD) in split plot arrangement with three replicates, and varieties were assigned the main plot, densities in the sub plots. Each plot consisted of four rows with length of 3 m and width ranging from 1.20 to 2 m according to proposed densities. The preceding crop was chickpea in 2019/2020. Quinoa seeds were sown by hand on February 15, 2021 at 2-3 cm of depth underground surface. Quinoa plants grew under rain-fed conditions with water supplements at the sowing date to ensure seed germination, and thinning was carried out two times to retain one plant per hole. There were regular crop management practices to control pests, diseases, and weeds.

Statistical analysis

The data were analyzed using statistical analysis and Gene Stat software to calculate the values of (LSD) at 5% level of significance and (CV%).

Experiment treatments

Proposed treatments were as follow:

1. Varieties

This study used five introduced quinoa varieties i.e., Giza, Titicaca, Red carina, Q26 and NSL. (Table 3).

Table 3: The studied varieties and their sources

No	Variety name	source
1	Giza	Seed and Plant Improvement Institute (Iran)
2	Titicaca	
3	Red Carina	
4	Q26	
5	NSL-106398	International Center for Bio saline Agriculture ICBA

2. Densities

The densities were a combination of tow inter spacing (row spacing) and three intra spacing (plant spacing) as follow: 50×10, 50 ×15, 50 ×20, 30 ×10, 30×15 and 30×20.

Investigated traits

10 guarded plants were chosen randomly from each sub-plot to determine:

- Plant height (PH) in cm measured as the average height from the ground level to the tip of the inflorescence on the main stem at the time of harvesting.
- Stem diameter (SD) in cm.
- Main panicle length of the inflorescence (PL) in cm.
- Main panicle width (PW) which measured as the diameter of the middle inflorescence (maximum diameter).
- Seed and biological yield/plant in g: which measured as weight of seeds or whole air dried plant/ plant on 10 guarded plants/plot, then seed and biological yield ha^{-1} in kg estimated by converting yield per plot to yield per hectare (ha).

Results and Discussion

1. Plant height (cm)

The results of statistical analysis show significant differences ($P \leq 0.05$) among studied varieties, plant densities and interaction between verities and plant densities for the plant height (Table 4). Where it was significantly higher for variety Red Carina (194.9 cm), while it was significantly lower for variety Giza-1 (116.6 cm). Such results agree with Maliro and Njala, (2019); Präger *et al.*, (2018) [20]; Tan and Temel, (2018) [23] and Naneli *et al.*, (2017) [17] who found differences among investigated quinoa cultivars in agronomical traits such as plant height, panicle length and grain yield. The plant height was significantly higher at density of 30 × 10 (176.9 cm), while it was significantly lower at density of 50 × 20 (153.6 cm). It was noticed for the interaction between verities and plant densities the plant height was significantly higher for variety Red Carina at density of 30 × 10 (214.3 cm), while it was significantly lower for variety Giza-1 at density of 50 × 20 (104.4 cm). It was noticed that plant height increased gradually by increasing plant density (Table 1). By increasing density, the competition in sunlight leads to higher plant height among the denser population. Nevertheless, nutrient and water competition may lead to reductions of plant height and other growth parameters in the denser population owing to shortages in nutrient supplement. An optimal density will support the growth balance to achieve the highest grain yield (Minh *et al*., 2020) [16]. These results agree with Owji *et al.*, (2011); and disagree with Trinh *et al.*, (2001); Erazzú *et al.*, (2016) [5] and Wang *et al.*, (2020) [25].

Table 4: Effect of plant densities of five quinoa varieties on plant height (cm)

Densities (D)	Varieties (V)					Mean
	Giza-1	Red Carina	Q26	Titicaca	NSL	
50 × 20	104.0	181.0	168.3	158.3	156.3	153.6^{f}
15 × 50	113.0	185.0	171.0	163.7	159.0	158.3^{e}
10 × 50	118.3	191.3	176.0	168.0	173.0	165.3^{c}
20 × 30	116.7	193.0	172.0	162.7	168.7	162.6^{d}
15 × 30	120.0	204.7	181.7	170.3	176.3	170.6^{b}
10 × 30	127.3	214.3	185.7	176.7	180.3	176.9^{a}
Mean	116.6^{e}	194.9^{a}	175.8^{b}	166.6^{d}	168.9^{c}	164.56
LSD0.05 (V) = 2.072, LSD0.05 (D) = 2.270, LSD0.05 (V*D) = 5.075, CV=1.9 %						

Means with common letter do not have statistically a significant difference

2. Stem diameter (cm)

The results of statistical analysis shows significant differences ($P \leq 0.05$) among studied varieties, plant densities and interaction between verities and plant densities for the stem diameter (Table 5). Where it was significantly higher for variety Q26 (10.494 cm), followed by variety Red Carina (10.433 cm), while it was significantly lower for variety NSL (10.050 cm), and it was significantly higher at densities of 50 × 20 and 50 × 15 (10.853, 10.773 cm respectively), while it was significantly lower at density of 30 × 10 (9.140 cm). It was noticed for the interaction between verities and plant densities the stem diameter was significantly higher for variety Q26 at density of 50 × 20 (11.067 cm), while it was significantly lower for variety NSL at density of 30 × 10 (8.700 cm). Such results disagree with Erazzú *et al.*, (2016) [5] who found that stem diameter was higher at lower planting density.

Table 5: Effect of plant densities of five quinoa varieties on stem diameter (cm)

Densities (D)	Varieties (V)					Mean
	Giza-1	Red Carina	Q26	Titicaca	NSL	
50 × 20	10.867	10.833	11.067	10.667	10.833	10.853a
15 50 ×	10.733	10.800	11.000	10.633	10.700	10.773a
10 × 50	10.500	10.567	10.867	10.167	10.500	10.520b
20 × 30	10.667	10.767	10.767	10.633	10.233	10.613b
15 × 30	10.067	10.133	10.633	9.967	9.333	9.927c
10 × 30	9.400	9.500	10.233	9.333	8.700	9.140d
Mean	10.372b	10.433ab	10.494a	10.172c	10.050d	10.304
LSD0.05 (V) = 0.1137, LSD0.05 (D) = 0.1245, LSD0.05 (V*D) = 0.2785, CV= 1.7 %						

Means with common letter do not have statistically a significant difference

3. Panicle Length (cm)

The results of statistical analysis showed significant differences ($P \leq 0.05$) among studied varieties, plant densities and interaction between verities and plant densities for the panicle length (Table 6). Where it was significantly higher for varieties Q26, Giza-1, NSL and Red Carina (37.7, 37.3, 37.2, 37.1 cm respectively), while it was significantly lower for variety Titicaca (30.6 cm). Such results agree with Maliro and Njala, (2019), Präger *et al.*, (2018) [20]; Tan and Temel, (2018) [23]; and Naneli *et al.*, (2017) [17] who found differences among investigated quinoa cultivars in agronomical traits such as plant height, panicle length and grain yield. The panicle length was significantly higher at density of 50 × 20 (42.6 cm), while it was significantly lower at density of 30 × 10 (27.0 cm). It was noticed for the interaction between verities and plant densities the panicle length was significantly higher for variety NSL at density of 50 × 20 (42.6 cm), while it was significantly lower for variety Titicaca at density of 30 × 10 (23.2 cm). These results agree with Sief *et al.*, (2015) [21] who reported there were gradual increases in the panicle length with increasing row spacing from 20 to 40 cm, and disagree with Nguyen *et al.*, (2018) [18] and Trinh *et al.*, (2001) who found that plant density had no effect on the panicle length.

Table 6: Effect of plant densities of five quinoa varieties on panicle length (cm)

Densities (D)	Varieties (V)					Mean
	Giza-1	Red Carina	Q26	Titicaca	NSL	
50 × 20	43.2	43.0	43.7	37.4	45.5	42.6a
15 50 ×	41.2	42.4	42.3	35.7	42.5	40.8b
10 × 50	37.3	37.6	38.5	31.9	37.4	36.5c
20 × 30	38.8	39.9	39.5	29.5	38.8	37.3c
15 × 30	34.0	32.9	33.6	25.7	31.9	31.6d
10 × 30	29.5	26.7	28.8	23.2	27.0	27.0e
Mean	37.3a	37.1a	37.7a	30.6b	37.2a	35.98
LSD0.05 (V) = 1.021, LSD0.05 (D) = 1.119, LSD0.05 (V*D) = 2.502, CV= 4.3 %						

Means with common letter do not have statistically a significant difference

4. Panicle Width (cm)

The results of statistical analysis shows significant differences (P≤0.05) among studied varieties, plant densities and interaction between verities and plant densities for the panicle width (Table 7). Where it was significantly higher for varieties NSL and Q26 (14.6 and 14.5 cm respectively), while it was significantly lower for variety Titicaca (13.7 cm), while it was significantly higher at density of 50 × 20 and 50 × 15 (15.8 and 15.7 cm respectively), while it was significantly lower at density 30 × 10 (11.4 cm). It was noticed for the interaction between verities and plant densities the panicle width was significantly higher, for variety NSL, at density of 50 × 15 (17.0 cm), while it was significantly lower for varieties Titicaca and Q26 at density of 30 × 10 (11.3 cm).

Table 7: Effect of plant densities of five quinoa varieties on f panicle width (cm)

Densities (D)	Varieties (V)					Mean
	Giza-1	Red Carina	Q26	Titicaca	NSL	
50 × 20	15.7	16.0	15.7	14.9	16.9	15.8a
15 50 ×	15.5	15.6	15.7	14.9	17.0	15.7a
10 × 50	15.0	15.2	15.7	14.3	15.0	15.0b
20 × 30	14.5	15.5	15.9	14.2	14.5	14.9b
15 × 30	12.2	11.8	12.9	12.8	12.8	12.5c
10 × 30	11.5	11.5	11.3	11.3	11.5	11.4d
Mean	14.1b	14.3b	14.5a	13.7c	14.6a	14.247
LSD0.05 (V) = 0.2223, LSD0.05 (D) = 0.2435, LSD0.05 (V*D) = 0.5445, CV= 2.3%						

Means with common letter do not have statistically a significant difference

5. Seed yield (kg ha^{-1})

The results of statistical analysis shows significant differences (P≤0.05) among studied varieties, plant densities and interaction between verities and plant densities for the seed yield (Table 8). Where it was significantly higher for variety Q26 (1884.8 kg.ha^{-1}), while it was significantly lower for variety Titicaca (1427.3 kg.ha^{-1}). Such results agree with Maliro and Njala, (2019); Präger *et al.*, (2018) [20]; Tan and Temel, (2018) [23] and Naneli *et al.*, (2017) [17] who found differences among investigated quinoa cultivars in agronomical traits such as plant height, panicle length and grain yield. The seed yield was significantly higher at densities of 50 × 15 and 50 × 20 (1881.1, 1877.3 kg.ha^{-1} respectively), while it was significantly lower at density 30 × 10 (1475.7 kg.ha^{-1}). The interaction between verities and plant densities was significantly higher for variety Giza-1 at density of 50 × 15 (2068.7 kg.ha^{-1}) and variety Q26 at density (50 × 20) (2058.7 kg/ha), while it was significantly lower for variety Titicaca at density of 30 × 10 (1212.0 kg.ha^{-1}). It was noticed that seed yield and its component increased with decreasing plant densities this can be attributed to the fierce competition for light and nutrients among individuals (Khan *et al.*, 2017*)* [14]. Such results agree with Wang *et al.*, (2020) [25], Erazzú *et al.*, (2016) [5], Trinh *et al.*, (2001) and disagree with Spehar and Rocha, (2009) [22]; Owji *et al.*, (2011), Eisa *et al.*, (2018) [4], Isobe *et al.*, (2015) [7], Nguyen *et al.*, (2018) [18].

Table 8: Effect of plant densities of five quinoa varieties on seed yield (kg ha^{-1})

Densities (D)	Varieties (V)					Mean
	Giza-1	Red Carina	Q26	Titicaca	NSL	
50 × 20	2026.3	1866.7	2058.7	1568.3	1866.3	1877.3a
15 50 ×	2068.7	1875.0	2052.7	1546.3	1862.7	1881.1a
10 × 50	1887.0	1785.3	1898.3	1415.0	1754.3	1748.0c
20 × 30	1989.3	1822.3	1966.3	1531.0	1850.0	1831.8b
15 × 30	1675.3	1707.7	1760.7	1291.0	1657.0	1618.3d
10 × 30	1561.0	1531.3	1572.0	1212.0	1502.0	1475.7e
Mean	1867.9b	1764.7ab	1884.8a	1427.3c	1748.7b	1738.7
LSD0.05 (V) = 40.16, LSD0.05 (D) = 43.99, LSD0.05 (V*D) = 98.3, CV= 3.5 %						

Means with common letter do not have statistically a significant difference.

6. Biological yield (kg.ha^{-1})

The results of statistical analysis shows significant differences (P≤0.05) among studied varieties, plant densities and interaction between verities and plant densities for the biological yield (Table 9). Where it was significantly higher for the variety Q26 (6548.4 kg.ha^{-1}), while it was significantly lower for the variety Titicaca (5538.2 kg.ha^{-1}), while it was significantly higher at densities of 50 × 15 and 50 × 20 (6347.2, 6341.3 kg.ha^{-1} respectively), while it was significantly lower at density of 30 × 15 (6006.3 kg.ha^{-1}). It was noticed for the interaction between verities and plant densities the biological yield was significantly higher for variety Q26 at density of 50 × 20 (6759.3 kg.ha^{-1}), while it was significantly lower for variety Titicaca at density of 30 × 15 (5255.7 kg/ha). These results disagree with Spehar and Rocha, (2009) [22] who found that increasing density did not affect grain and biomass yield this may due to the variation in quinoa varieties behavior among varied environment.

Table 9: Effect of plant densities of five quinoa varieties on biological yield (kg/ha)

Densities (D)	Varieties (V)					Mean
	Giza-1	Red Carina	Q26	Titicaca	NSL	
50 × 20	6716.0	6415.3	6759.3	5544.3	6271.7	6341.3a
15 50 ×	6672.0	6366.3	6756.0	5638.7	6303.0	6347.2a
10 × 50	6395.3	6258.3	6447.3	5588.0	6118.0	6161.4abc
20 × 30	6564.3	6124.0	6648.7	5748.7	6236.3	6264.4ab
15 × 30	5737.0	6492.3	6282.0	5255.7	6264.3	6006.3c
10 × 30	5804.3	6511.3	6397.0	5453.7	6183.0	6069.9bc
Mean	6314.8b	6361.3ab	6548.4a	5538.2c	6229.4b	6198
LSD0.05 (V)= 200.3, LSD0.05 (D)= 219.5, LSD0.05 (V*D) = 490.7, CV= 4.8%						

Means with common letter do not have statistically a significant difference

Conclusions

There were significant differences among studied varieties, plant densities and interaction between verities and plant densities for all studied traits. With increasing planting density, plant height increased but stem diameter, panicle length, panicle width, seed yield and biological yield decreased. Plant spacing of 50 × 20 cm achieved the most suitable planting density for the highest seed yield. Among quinoa varieties, Q26 performed best in the studied conditions.

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