Effect of planting density on *Chenopodium Quinoa Willd* growth and yield in desert areas

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Abstract

The study was carried out on a private farm in the Algerian desert at El Oued area to examine the cultivation density of two quinoa cultivars, yellow and black, with dimensions (D1, D2, D3, and D4) of 20 cm, 30 cm, 60 cm, and 40 cm, respectively. A split-plot design was given for both cultivars, with three iterations for each dimension. Many criteria were examined, including morphological parameters (panicle length, stem length, stem circumference, and leaf area), biochemical measures (chlorophyll (a) and (b), and sugars), and production properties (panicle weight, panicle seed weight, 1000 seed weight, and seed yield).The findings demonstrated that the quinoa plant responded in morphological and productive criteria to high densities of D1 and medium densities of D2 and D3 when cultivated at various densities. ANOVA analysis indicated significant differences in parameters between the four distances and the two studied cultivars, including stem length (SL), leaf area (LA), aerial dry weight (ADW), total panicle weight TPW, and chlorophyll (b). The yellow cultivar gave better results than the black one, and both cultivars had better results at high densities than other crops (wheat, barley, and maize). However, at densities greater than D4, the results were the opposite.

Keywords: quinoa, yellow, black, cultivation density, morphological, productivity.
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Introduction

The plant quinoa (*Chenopodium quinoa willd*) is indigenous to South America's Andes. Due to its ability to adapt, it can withstand a variety of environmental factors, including cold, acidic soil, salinity, and drought. Mountainous areas with high altitudes can also be used for their cultivation (Mujica et al., 2001).In environments unsuitable for growing significant crops like wheat, barley, and corn, quinoa does well. Therefore, it is one of the non-competitive crops for cultivation areas (Iqbal, 2015). According to Valencia (2003), quinoa is a member of the family *Chenopodiaceae*, a group of plants indigenous to South America's Andes Mountains. (Matiacevich et al., 2006). It is a self-pollinating perennial herbaceous plant (Bhargava and Ohri, 2016). This depends on the cultivar grown, genetic structure, environmental conditions, and soil fertility. The root system of quinoa is pivotal and deep, which helps it resist drought and provides it with the necessary stability.Due to its high nutritional value and reputation as a good source of micronutrients, quinoa—also known as the mother of the Inca civilization's seeds is gaining popularity (Kozio, 1992). Given that quinoa protein contains all nine essential amino acids, making it a complete protein, quinoa is renowned for having a high nutritional value in comparison to other well-known seeds. Ayala et al., 2001. This plant is a good source of minerals, as it contains more calcium, magnesium, iron, and zinc than the main seed crops. Compared to other seeds, a good source of the B2 vitamins riboflavin and folic acid. Gluten-free foods are found mainly in wheat, barley, and oats. It is often recommended as part of the diet for people with Celiac disease (Dini et al., 2005).

The quinoa is affected by environmental, agricultural, and genetic factors. Each of these factors has been the subject of different studies by researchers, depending on the regions and conditions in which the research was carried out. Still, they all lead to increasing this crop by improving or raising the growth efficiency indicators for this plant, using special rates to analyze the growth in the different stages that the plant usually goes through. The future and success of the cultivation of any crop in terms of increasing its spread area and productivity depend mainly on knowing the appropriate date for planting, the optimal agricultural density, and the conditions of the cultivation area. Hence, scientists are interested in studying these matters. The results of Pourfarid et al. (2014) showed that high plant density reduced the thousand-seed weight. Abd El-Hamed and Elwan (2011) attributed the loss of seed vitality and plant competition for the limited water and food resources to the decrease in the weight of 1,000 seeds at high plant density. As for the study carried out by Spehar and Rocha (2009) on the effect of high plant density within the range of 100 to 600.10^3plants/hectare on the productive characteristics of quinoa, they found that there was no effect of the factor of density on seed yield, thousand-seed weight, or biological yield.In a study by Alam et al. (2002) to find out the effect of plant density (100, 200, or 300.10^3 kernels per hectare) and the number of plants per pot (one, two, or three plants per pot) on the seeds of a peanut variety, the results showed that there was no significant effect of the density. The quality of peanut seeds, as represented by their oil and protein content, affected the vegetable density. Still, the low vegetable density gave little preference over the high density for both components.

Plant density is a significant factor in determining production, according to (Akinotoye et al., 2009), who noticed that production per unit area increased with the increase in plant density until it reached a certain limit and then began to decline. Nasto et al. (2009) assert that plant density increases production. Following a the findings, Aminifard et al. (2012) cultivated sweet peppers in various treatments at different sizes (20 x 50 cm, 20 x 100 cm, 30 x 50 cm, and 30 x 100 cm). The indicators of vegetative growth in plant height, the number of side branches, and the dry matter content of the leaves were low when the plant density was increased, and the treatments (20×50 cm) and (30×100 cm) gave the highest total yield.

The importance of the research and objectives

The agricultural density of the plant in crops plays great importance in influencing the speed of plant growth, its size and the structure of its organs on the one hand, and the speed of its entry into its different phonological stages on the other hand, as each plant occupies a limited size of the nutritional space in the soil and the air space, through which it secures its needs for nutrients and lighting.The purpose of this study on the agricultural density of the quinoa plant is to identify solutions that farmers lack for the issue of agricultural density, whether in small, saline, or degraded lands, and to provide examples and models for farmers so that they can imitate this experience. This experience has been shown to increase yield.
2- Determine the appropriate planting distances (distances between plants, distances between lines). Find the ideal agricultural density for the quinoa crop to produce a high-quality crop with high productivity.

Materials and methods

The field study was conducted on November 30, 2021, on a private farm north of Eloued province. The location is in a desert climate with sandy soil that is hot and dry in the summer and cold in the winter, with a wide range of daily maximum and minimum temperatures. Before using well water with a pH of 6.46 and an electrical conductivity of 11.96 mS/cm, we manually plowed the soil, applied organic fertilizer, and then irrigated it. Two different types of quinoaplants: *Chenopodium quinoa Willd* (black quinoa) and Amarila saccaca (yellow quinoa), both obtained from a lab at Eloued University's Faculty of Natural and Life Sciences.

1. Experiment design

The experiment was conducted on a 40 square meter plot of land with three replications of each distance and cultivar and a 1-meter space between each. The distances in the table () and between the lines were identical.

Symbol	agricultural distance (cm)	Area per plant (cm2)	plant density (plant/ha)
D1	20×20	400	250000
D2	30×30	900	111111.11
D3	40×40	1600	62500
D4	60×60	3600	27777.77

2.Plant materials

2.1. Morphological parameters

2.1.1. Paniclelength (PL)

The length of the panicle was measured after its ripening using a ruler graduated in cm for the four distances and all iterations (D1, D2, D3 and D4).

2.1.2.Stem length (SL):

The stem length was estimated from the end of the root part to the beginning of the panicle after the plant's maturity and before the panicle is drying through a graduated meter in (cm).

2.1.3.Stem circumference (SC)

The stem circumference was counted at its midpoint after the plant matured and before drying with a tape marked in cm.

2.1.4.Leaf area (LA)

Leaf area was calculated according to Hunt (1978).

2.2. Productivity Standards:

2.2.1.Total panicle weight (TPW)

The panicle from each iteration was picked and dried for 5 days in the shade, then weighed using the sensitive electronic scale. The average weight of the three iterations was calculated for each dimension (D1, D2, D3, and D4).

2.2.2. Panicle total seed weight (PTSW)

The seeds for each panicle were purified and filtered from the straw, then weighed using the sensitive electronic scale, and the average weight of the three repetitions was determined for each dimension (D1, D2, D3, and D4).

2.2.3. Thousand seed weight (TSW)

Using a precise electronic scale, 1000 seeds of each panicle were weighted three times for each of the four dimensions (D1, D2, D3, and D4).

2.2.4. Aerobic fresh weight

One stem was taken from each recurrence for the dimensions D1, D2, D3, and D4, and it was then divided into three parts. A sensitive electronic scale was then used to weigh the stem from the root portion of the first phalanx.

2.2.5. Aerialdry weight

The stem pieces for replication and each dimension (D1, D2, D3, and D4) were dried and kept in an incubator at 105 °C for 4 hours. During that time, the weight was monitored using a sensitive electronic balance.

2.2.6. Root dry weight

After ceasing irrigation and waiting until the soil was completely dry, the root portion from each recurrence for each distance (D1, D2, D3, and D4) was cut. This allowed us to remove the root completely. The soil and organic matter that had been attached to it were cleaned off, and after that, it was dried in the incubator. Using a delicate electronic balance, we measured its weight over four hours at 105 °C.

2.2.7. Seed yield per hectare (SYH)

The seeds for each panicle were rubbed and filtered from the straw, then weighed using the sensitive scale. The average weight of the three iterations was calculated for each dimension and converted from g to kg. Then it estimated the seed yield (seed) for each dimension (D1, D2, D3, and D4) in the triangular mathematical relationship.

2.3. Chemical properties

2.3.1. Determination of chlorophyll (a) and (b) in leaves:

The chlorophyll contents in the leaves of the both quinoa cultivars were determined using Vernon and Seenly (1965) method and modified by Hegazi et al. (1998). 100 mg of green leaves were cut into small pieces, ground, immersed in 10 ml of acetone (100%), and then kept in a warm and dark place for 48 hours. After a spectrophotometer measured the optical density of various sample extracts at 663 nm and 645 nm wavelengths, the chlorophyll concentration was determined using the formula:

$$\boldsymbol{Chlorophyll(a)\ (mg/100\ mg\ FM) = 12.9 \times A_{663} - 2.67 \times A_{645}}.$$
$$\boldsymbol{Chlorophyll(b)\ (mg/100\ mg\ FM) = 22.5 \times A_{645} - 4.68 \times A_{663}}.$$

2.3.2. Determination of total sugars in leaves:

According to (Dubois et al., 1956), the phenol method was used to determine the sugars by soaking 100 mg of plant leaves for various samples in 3 ml of 80% ethanol for 48 hours in a dark location. The alcohol evaporates by placing the samples in an incubator at 85 °C and then adding 20 ml of distilled water to each sample. In glass tubes, 1 ml of each extract, 1 ml of phenol (5%), and 5 ml of concentrated sulfuric acid (H2SO4) were taken. After homogenizing the color of the samples with a vortex device for 10 minutes, the samples were carried out and placed in a water bath at 30 °C for 15 minutes. At a wavelength of 490 nm, the sugar contents were determined using a spectrophotometer. The following equation was employed to form the curve:

$$\boldsymbol{Sugar\ contents\ (\mu g/100mg\ FM) = 1.24 + 97.44 \times A_{490}}.$$

Result and discussion

The results showed that the quinoa plant responded to agricultural density through the characteristic of the panicle weight, particularly in the yellow quinoacultivar, where the weight was in agricultural density D1 (20 cm), which is higher density than D3 and D4, which explains why the quinoa plant in high agricultural densities is preferred (Tab. 1). It grew in the best possible way, starting from low agricultural densities. This growth is due to the plant receiving enough light rays to reach every vegetative group, even though there were few of them, as well as the absence of ground root competition for the plant's absorption of the required nutrients, even though there were insufficient amounts. Although (Abd El-Hamed and Alwan, 2011) found different results in their study on the impact of agricultural density on the quinoa plant, they discovered that agricultural density impacted the growth of panicle in terms of the number and weight of seeds. This was attributed to the various cultivars investigated, the climate, and the overall experimental circumstances.

Table 1. Morphologicalproperties in the quinoa cultivarsyellow (Va) and black (Vn) cultivated lands

Morphological Parameter		Yellow quinoa	Black quinoa
SL	D20	61.83 ± 5.78	57.5 ± 0.67
	D30	69.5 ± 1.67	63 ± 0.67
	D40	66.83 ± 5.78	66.33 ± 1.89
	D60	66.5 ± 0.00	67.17 ± 2.44
SC	D20	2.93 ± 0.33	4.05 ± 0.35

	D30	3.15 ± 0.30	4.27 ± 0.50
	D40	2.94 ± 0.14	4.4 ± 0.30
	D60	2.97 ± 0.27	4.38 ± 0.23
LA	D20	22.69 ± 5.77	19.54 ± 1.26
	D30	33.46 ± 7.08	18.31 ± 3.09
	D40	35.31 ± 8.84	20.42 ± 3.38
	D60	30.71 ± 4.45	26.65 ± 1.32
BL	D20	19.67 ± 1.44	25.5 ± 0.67
	D30	23.17 ± 1.22	26.83 ± 0.89
	D40	22.33 ± 1.11	22.83 ± 0.56
	D60	21.5 ± 1.00	24.17 ± 2.11

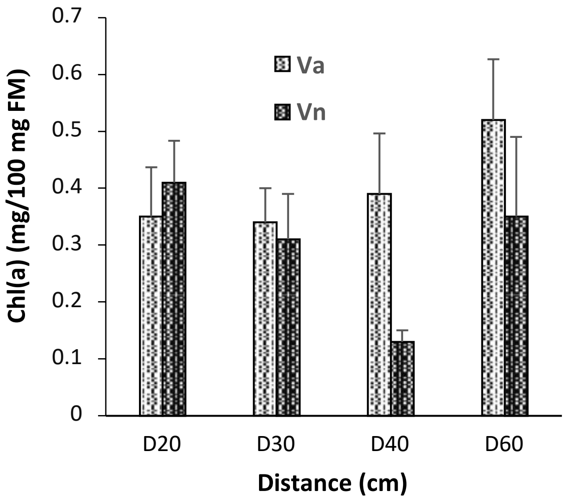
Moreover, Alak (2001), in his study on the effect of planting density on the yellow corn, interpreted by not providing the needs of plants equally when planting at high density. The difference in agricultural density was also observed to have a negligible impact on the characteristic of cultivars' 1000-seed weight (TSW). According to Al-Sahoki (2002), the dry matter in seeds does not vary significantly depending on their density, which results in a relatively constant seed weight. Genetic variation in seed yield and physiological performance, which includes root system expansion and an increase in root hairs to absorb more nutrients, as well as the development of the shoot system to reserve more light for photosynthesis, resulted in different findings between the two cultivars under study (Inamullah et al., 2011).This effect is similar to the work reported by Knoush (2011), who found significant differences in the plant's seed yield characteristics among several yellow corn genotypes. Since the weight of 1000 seeds did not show significant differences in comparison between the four dimensions (D1, D2, D3, and D4), the difference in the average weight of panicle compared between the four dimensions is due to the number of seeds and not to the size of the seed itself.

There is no proof that the characteristics of the stem, such as its length and circumference, significantly influenced the change in density, according to our analysis of these factors. The quinoa plant continues to grow at the same rate despite increasing density. Low densities permit more light to pass through the vegetative cover, which causes auxin to oxidize and cause the internodes to lengthen, shortening the plant's length.However, it was observed in D3 (40 cm) a decrease in the stem circumference, and this is due to the lack of density, and this is another evidence that the quinoa plant is affected by the high intensity of light and the lack of agricultural density, as they negatively affect growth in general and the stem circumference in particular, and this is considered a rare positive feature in crops, for which farmers want every yield.Boroomand (2011) was found that plants ultimately depend on the green leaf area to accumulate dry matter, as the leaves intercept solar radiation and accumulate photosynthesis products; the green leaf area is a vital headquarters for crop production rate.By reducing plant density at all distances except for dimension D4 (60 cm), the results also indicated an increase in leaf area. The reason is that there were more leaves due to the abundance of nutrients, lack of shading, lack of competition, and the arrival of light to the bottom leaves at low plant densities, which positively impacted the increase in the leafy area. These results differ from those of Al-Amiri (2001), who found that the leafy area of one plant decreased with increasing plant density when studying the yellow corn plant.Additionally, it supports Hala, (2015) earlier findings in her investigation into the impact of agricultural density on the coriander plant, where it was found that low agricultural density significantly increased leaf area compared to high agricultural density. Given that some cultivars of this plant prefer medium and high agricultural densities, it was observed a decrease in the leaf area at dimension D4 for the yellow cultivar.

Table 2. Productionproperties in the quinoa cultivarsyellow (Va) and black (Vn).

Production Parameter		**Yellow quinoa**	**Black quinoa**
ADW	D20	16.76 ± 8.65	42.58 ± 34.37
	D30	20.96 ± 17.49	31.4 ± 4.66
	D40	22.25 ± 6.15	26.91 ± 7.66
	D60	25.85 ± 7.54	36.55 ± 7.44
RDW	D20	5.56 ± 0.40	6.98 ± 0.37
	D30	5.31 ± 1.89	6.21 ± 0.69
	D40	4.28 ± 0.94	5.55 ± 0.47
	D60	4.48 ± 0.39	9.02 ± 1.56
TPW	D20	86.58 ± 22.51	45.69 ± 15.41
	D30	85.24 ± 25.05	46.94 ± 3.58
	D40	67.00 ± 17.73	52.47 ± 14.21
	D60	31.91 ± 18.39	58.77 ± 8.04
SYH	D20	42.97 ± 9.68	14.24 ± 3.10
	D30	29.77 ± 5.46	12.82 ± 3.82
	D40	35.41 ± 12.45	24.77 ± 5.08
	D60	14.17 ± 5.88	16.59 ± 1.41
TSW	D20	3.97 ± 0.41	4.05 ± 0.36
	D30	3.15 ± 0.30	4.27 ± 0.51
	D40	2.94 ± 0.14	4.40 ± 0.30
	D60	2.97 ± 027	4.18 ± 0.16

Furthermore, concerning the root dry weight, it was noted that the density affected the root system insignificantly with respect to the dimensions D1, D2, D3, and D4 at the yellow cultivar (Va), where the higher the density, the greater the root dry weight, and this is due to the fact that the quinoa plant can control its roots. Nevertheless, Ahmed, (2020), in his research on the carrot plant, discovered results that were different from what we discovered in our study. As a result of less competition between plants, which encourages vegetative growth (stem length), it explains why carrot plants grown at low density had an increase in average root weight compared to plants grown at high density.In terms of the (Black quinoa) root dry weight, the results were in agreement with those of yellow quinoa, except for the increase in root weight in dimension D4. On the other hand, Hala, (2015) indicated that chlorophyll is characterized by its active role in photosynthesis, especially chlorophyll (a), which is responsible for receiving light rays in green plants.The findings of our study demonstrate that plant density affects the amount of chlorophyll (a) and (b) in fresh leaves of the quinoa plant at various densities (Fig. 1). The highest concentration of these pigments was found in theyellow cultivar in dimension D1, which is the highest studied density because the quinoa plant receives enough light at high densities. Regarding the black quinoa (Vn)cultivar, it was found that, insignificantly, the lower the agricultural density, the higher the chlorophyll content, as a result of the plants' increased branching, exposure to light, and lack of mutual shading.



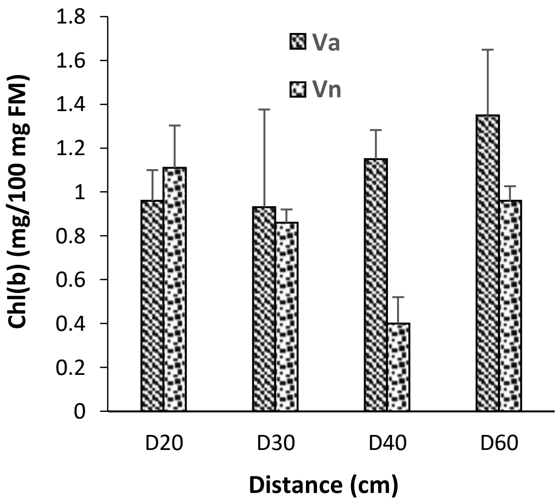


Figure 1. Chlorophyll (a) and (b) contentsin quinoa cultivars yellow (Va) and black (Vn).

It was also consistent with the study of Ali, (2019), on the effect of agricultural density on the yellow corn plant, as his results indicated that the low plant density exceeded the high densities, justifying this by the availability of the essential elements for growth such as water, light, and nutrients and the lack of competition for them by plants.Hala, (2015**)** noted that there was a significant effect of plant density on the content of chlorophyll (a) in fresh leaves when planting at different densities; the lowest plant density achieved the highest value, significantly superior to high densities, and attributed this to increasing the distance between plants, which prevented plants from shading each other and increased their branching and exposure to light rays significantly due to an increase in the content of chlorophyll (a) in fresh leaves. Kumaret al,(2010) found that chlorophyll (a) is more sensitive to heat than chlorophyll (b) and its photosynthesis efficiency, which we also observed (Fig. 1).

The high concentration of chlorophyll (a) and (b) at high densities of the yellow cultivar(Va) is explained by the fact that it is more responsive to high densities than black quinoa, and both cultivars responded to densities more than other crops. The fullness of seeds at highdensities explains the higher concentration of sugars (D1) compared to low densities (D4) (Fig. 2). The increase in seed yield is attributed to a significant increase in high densities, as the plant increases more in the higher agricultural densities D1 and D2, which are not found in other types of crops, which is also a very positive indicator for farmers in increasing production and yield.As the density D1 achieved the highest average, significantly superior to the other densities, this effect is attributed to increasing the number of plants per unit area and thus increasing fruit productivity. Varieties of quinoa found contrary results: high plant density leads to low seed yield. The decrease in yield was explained by the high contribution of secondary branches to productivity at low densities.

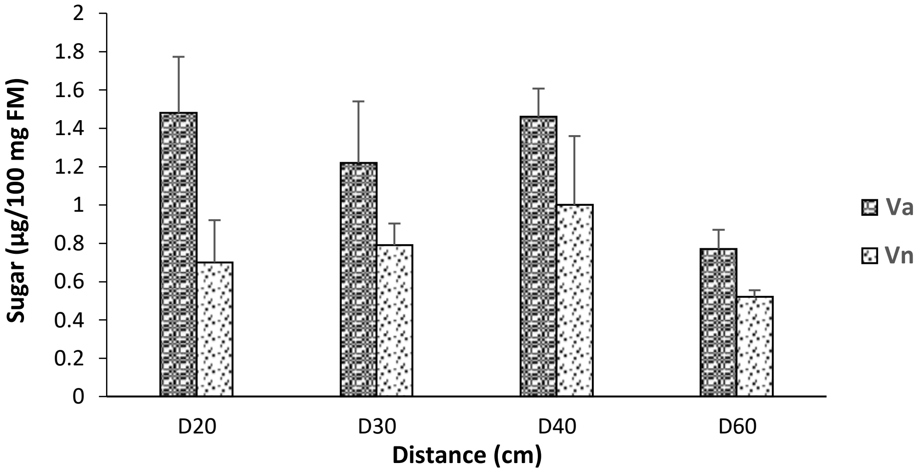


Figure 2. Sugar contents in quinoa cultivars yellow (Va) and black (Vn).

Many reviews also displayed that increasing plant density increased seed yield, including a study (Nimr and Al-Hosary, 2015), on yellow corn that found that a significant increase in seed yield occurred with a decrease in the agricultural distance between plants, and this was attributed to the corn plant's inability to benefit from the wide agricultural distance in increasing the other yield components (panicle length, seedsnumber).

Conclusion

The quinoa prefers high planting densities determined by analyzing the results obtained from panicle length and weight, stem circumference and length, leaf area, and seed weight. The results were favorable compared to other crops that did not respond well to high densities. This feature specific to the quinoa plant is considered a positive material indicator for the farmer with small areas. However, yellow cultivar showed a better response at higher densities than black cultivar due to the genetic characteristics of each cultivar.The quinoa plant can control its characteristics to adapt to high and medium densities by extending its roots to get enough water and organic matter, and by increasing the stem's height and the leaf's area. These approving findingsin the sufficiency of the quinoa plant from the light necessary for the process of photosynthesis, nutrients, and water, but it was noticed that in the case of high lighting at low densities, the plant is negatively affected.

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