

## Phenological Traits and Yield of Quinoa (*Chenopodium quinoa* Willd.) at Different Plant Densities

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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 phenological traits and yield of quinoa. The experiment was laid out according to randomized complete 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, 30×15 and 30×20). The results of statistical analysis showed significant differences ( $P \leq 0.05$ ) among studied varieties, plant densities (except for vegetative growth and maturity) and interaction between varieties and plant densities for all investigated traits. The days to vegetative growth was significantly higher for variety Red carina at density of 30×20 (69.33 days), and variety Q26 at density of 50×20 (68.67 days). while the days to flowering was significantly higher for variety Red carina at densities of 30×15 and 30×20 (122.67 and 122.0 days respectively), and the days to maturity was significantly higher for variety Q26 at density of 50×10 and Red carina at densities of 50×15, 30×15 and 30×10 (149.67 and 148.67 days respectively). The seed yield was significantly higher for variety Giza-1 at density of 50×15 (2068.7 kg/ha) and variety Q26 at density 50×20 (2058.7 kg/ha). The biological yield was significantly higher for variety Q26 at density of 50×20 (6759.3 kg/ha). The harvest index was significantly higher, for variety Giza-1, at density of 50×15 (31.036 %). The study recommends to grow quinoa at density of 50×20 to get the highest seed yield. In terms of quinoa varieties, Q26 achieved the highest seed yield, Giza-1 and Titicaca exhibit best results for phenological traits.

**Keywords:** Phenological traits, Yield, Quinoa, Plant densities.

### Introduction:

Quinoa (*Chenopodium quinoa* Willd.) is a plant that has been known for a long time cultivated in the Andean region for centuries to consume the seeds and leaves (Jacobsen, 2017). However, the cultivation and consumption of quinoa became popular globally during the last three decades (Wu *et al.*, 2017). Today, it is cultivated in more than 90 countries, 80% of the cultivation is in Bolivia and Peru, while the remaining 20% is distributed among several countries (Bazile *et al.*, 2016). The

popularity of quinoa is due to its high nutritional content, adaptability and ability to grow in harsh climatic conditions, making it an ideal crop for drought-prone and saline agricultural lands (Bazile *et al.*, 2016). In addition to its high protein content, the plant is rich in nutrients including balanced amino acids and high mineral concentrations. Studies demonstrated that only a limited number of grain seeds do not contain gluten and the quality of the mineral, vitamin, antioxidant and protein content is comparable to casein. It was also evidenced to have high levels of essential amino acids such as lysine (Wu *et al.*, 2016). The quinoa life cycle is approximately 6 months, but it varies depending on varieties and region, which determines the sowing and harvest months (Sajjad *et al.*, 2014). Quinoa genotypes perform differently according to their latitude and altitude of origin (Curti *et al.*, 2016), showing important phenological differences in the duration of the phenological stages necessary to complete their life cycle and differing in their morphology at the canopy and inflorescence levels. Planting density is one of the most important agricultural practices affecting crop yield (Leskovar *et al.*, 2000; Cha *et al.*, 2016). For each production system, there is an optimum plant population that maximizes the utilization of available resources (water and nutrients), allowing the expression of maximum attainable potential yield on that environment (Sangoi *et al.*, 2000). However, there is no single recommendation for all conditions because optimum quinoa density for maximum economic grain yield varies depending on various conditions, such as genotype, growth habit, sowing date, climatic conditions and soil fertility as well as agronomical management (Carbone-Risi, 1986; Santos, 1996). Previous studies found differences among investigated quinoa cultivars in agronomical traits such as plant height, panicle length, number of panicles, 1000-seed weight and grain yield (Al-Jbawi *et al.*, 2022; Maliro and Njala, 2019; Präger *et al.*, 2018; Tan and Temel, 2018; Naneli *et al.*, 2017). Oelke *et al.*, (1992) found that the field trial in Great Britain indicated that increasing plant density resulted in a slightly earlier maturity. Rishi and Galwey (1991) reported that days taken to 50 percent flowering was found to be non-significant between wider row spacing of 40 cm (79.3 days) and narrow row spacing of 20 cm (79.0 days) of Baer quinoa variety. They also observed narrow row spacing of 20 cm took the lowest number of days (146 days) compared to wider row spacing of 40 cm (150 days) for maturity of Baer variety of quinoa at University farm, Cambridge, United Kingdom. Olofintoye *et al.*, (2015) studied two varieties of amaranth, TE81/28, CEN18 /97 established at three planting densities (100000, 60000, 40000 plants/ha) and found that planting density did not show significant effect on the biological and seed yield. The seed yield of amaranth crop at planting density of 60000 plants/ha (3330 kg/ha) was significantly higher than the planting density of 100000 plants/ha (2799 kg/ha) and 40000 plants/ha (3211 kg/ha), and the harvest index at planting density of 100000 plants/ha (10.51%) was significantly higher than the planting density of 60000 plants/ha (9.67%), 40000 plants/ha (9.53%) and those two planting densities were on par in sandy loam soil at National Horticultural Research Institute, Nigeria. Pourfarid *et al.*, (2014) tested two genotypes of amaranth, Amar and Anna at four densities (17, 35, 70, 140 plants/m<sup>2</sup>) by hand, and thinning at a row spacing of 30 cm and found optimum yield from plant population of 140 plants/m (1.04 kg/ha) whereas planting density 17 plants/m<sup>2</sup> was (0.18 kg/ha), 35 plants/m<sup>2</sup> was (0.29 kg/ha), 70 plants/m<sup>2</sup> (0.73 kg/ha) at Tehran University. Roberto and Rocha, (2008) tested plant densities varying between 1-6 million plants/ha and reported that grain yield, biomass and harvest index were not affected by varying plant densities and showed strange ability of quinoa to compensate for missing plants by amplified vigor and branching at Brazil. Eisa *et al.*, (2018) found that increasing plant density from 56.000 to 167.000 plants/ha caused some

decrements in 1000-seed weight, also increased seed yield by 34.7%. In Argentina, Erazzú *et al.*, (2016) reported that plant height, stem diameter, and grain yield were higher in sowing density of 70.000 plants/ha compared to 460.000 plants.

The aim of this study was to investigate the effect of six plant densities on the development and yield of some quinoa varieties.

### Materials and methods:

**Site of experiment:** 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 43.77° N, and longitude of 36.71° E with an altitude of 485 meters above sea level. Table (1) shows the summary of the meteorological data during the experimental period in 2021. According to these data, the mean maximum temperature in the studied months 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.

**Table 1. The meteorological data during the experimental period**

| 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                  |

The physical and chemical analysis of the studied experiment soil are shown in Table (2). According to the results, the studied field soil is clay, alkaline acidity, low organic matter, moderate to good phosphorus, potassium, and nitrogen contents. Depending on the results, phosphorus in the form of triple superphosphate (46% P<sub>2</sub>O<sub>5</sub>) was added at a rate of 108 kg/ha, potassium in the form of potash sulfate (50% K<sub>2</sub>O) was applied at a rate of 100 kg/ha K<sub>2</sub>O during soil preparation, and nitrogen fertilizer as urea (46% N) was added at a rate of 261 kg/ha (split into two doses, half was applied with sowing and the remaining half was applied after thinning at 4-6 true leaves stage).

**Table 2. Physical and chemical analysis of the experiment soil.**

| year | Electrical conductivity   | Acidity | Organic matter | Nitrogen | Phosphorus | Potassium | Sand | Silt | Clay |
|------|---------------------------|---------|----------------|----------|------------|-----------|------|------|------|
| 2021 | Ec (ds.cm <sup>-1</sup> ) | pH      | %              | ppm      |            |           | %    |      |      |
|      | 0.12                      | 8.42    | 1.37           | 30.45    | 10.00      | 204.25    | 26   | 14   | 60   |

**Experimental design:** The experiment was laid out according to randomized complete block design (RCBD) in split plot arrangement with three replicates, and the varieties were assigned the main plot, while densities were allocated 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. Quinoa seeds were sown by hand on February 15<sup>th</sup>, 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 GenStat software to calculate the values of (LSD) at the level of significance 5%.

**Experiment treatments:** Proposed treatments were as follow:

**1-Varieties:** This study used five introduced quinoa varieties including Giza, Titicaca, Red carina, Q26 and NSL (Table 3).

**Table 3. Studied quinoa 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<br>ICBA |

**2- 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 cm.

#### Investigated traits

**1- Phenological traits:** were recorded on basis of day to day observation.

- Days to vegetative growth (day).
- Days to flowering (day).
- Days to maturity (day).

**2- Yield- related traits:** The samples were taken twice by using quadrat of 1m<sup>2</sup> per treatment and their means was taken to calculate yield (seed and biological yield) (kg/m<sup>2</sup>). The yield was then converted to kilogram per hectare by multiplying the yield with 10.000.

- Seed yield (kg/ha).
- Biological yield (kg/ha).
- Harvest index (%).

#### Results and discussion:

**1-Days to vegetative growth (DAS):** The results of statistical analysis show significant differences ( $P \leq 0.05$ ) among studied varieties, and interaction between varieties and plant densities, but differences weren't significant in densities for the days to vegetative growth (Table 4). Where it was significantly higher for varieties Red Carina and Q26 (67.33 and 66.94 days respectively), while it was significantly lower for varieties Giza-1 and Titicaca (50.06 and 50.61 days respectively). In terms of the interaction between varieties and plant densities, the days to vegetative growth was significantly higher for variety Red Carina at density of 30 × 20 (69.33 days), and variety Q26 at density of 50×20 (68.67 day), while it was significantly lower for variety Giza-1 at density 50×10 (49.00 days) and variety Giza-1 at density of 30×10 (49.67 days).

**Table 4. Effect of plant densities of five quinoa varieties on vegetative growth (day).**

| Densities (D)  | Varieties (V)      |                    |                    |                    |                    | Mean               |
|--|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
|  | Giza-1             | Red Carina         | Q26                | Titicaca           | NSL                |                    |
| 50 × 20  | 51.00              | 66.00              | 68.67              | 51.67              | 51.67              | 57.80 <sup>a</sup> |
| 50 × 15  | 50.33              | 66.67              | 67.67              | 50.00              | 52.67              | 57.47 <sup>a</sup> |
| 50 × 10  | 49.00              | 67.00              | 66.33              | 50.67              | 52.67              | 57.13 <sup>a</sup> |
| 30 × 20  | 50.00              | 69.33              | 66.00              | 50.67              | 54.67              | 58.13 <sup>a</sup> |
| 30 × 15  | 50.33              | 68.33              | 66.00              | 50.67              | 55.33              | 58.13 <sup>a</sup> |
| 30 × 10  | 49.67              | 66.67              | 67.00              | 50.00              | 53.00              | 57.27 <sup>a</sup> |
| Mean   | 50.06 <sup>c</sup> | 67.33 <sup>a</sup> | 66.94 <sup>a</sup> | 50.61 <sup>c</sup> | 53.33 <sup>b</sup> | 57.66              |
| LSD <sub>0.05</sub> (V)=1.355, LSD <sub>0.05</sub> (D)= 1.484, LSD <sub>0.05</sub> (V*D) =3.319, CV= 3.5 % |                    |                    |                    |                    |                    |                    |

The means with at least one common letter do not differ significantly.

**2-Days to flowering (day):** The results of statistical analysis show significant differences ( $P \leq 0.05$ ) among studied varieties, plant densities and interaction between varieties × plant densities for the days to flowering (Table 5). Where it was significantly higher for varieties Red Carina and Q26 (120.9 and 120.1 days respectively), while it was significantly lower for variety Giza-1 (96.2 days), and it was significantly higher at densities of 30×20 and 30×15 (108.53 and 108.07 days respectively), while it was significantly lower at density of 30×10 (106.47 days). It was noticed for the interaction between varieties and plant density that the days to flowering was significantly higher for variety Red carina at densities 30×15 and 30×20 (122.67 and 122.0 day respectively), while it was significantly lower for variety Giza-1 at density of 30×10 (95.0 days). These results disagree with Rishi and Galwey, (1991) who reported that days taken to 50 percent flowering was found to be non-significant between wider row spacing of 40 cm (79.3 days) and narrow row spacing of 20 cm (79.0 days) of Baer variety of quinoa, and disagree in some studies on other plants.

**Table 5. Effect of plant densities of five quinoa varieties on days to flowering (day).**

| Densities (D)  | Varieties (V)      |                     |                     |                    |                     | Mean                 |
|--|--------------------|---------------------|---------------------|--------------------|---------------------|----------------------|
|  | Giza-1             | Red Carina          | Q26                 | Titicaca           | NSL                 |                      |
| 50 × 20  | 96.33              | 119.33              | 119.33              | 99.00              | 102.00              | 107.20 <sup>ab</sup> |
| 50 × 15  | 96.33              | 120.67              | 120.00              | 98.67              | 101.67              | 107.47 <sup>ab</sup> |
| 50 × 10  | 96.33              | 121.00              | 120.33              | 98.00              | 101.33              | 107.40 <sup>ab</sup> |
| 30 × 20  | 97.00              | 122.00              | 121.67              | 98.67              | 103.33              | 108.53 <sup>a</sup>  |
| 30 × 15  | 96.00              | 122.67              | 120.33              | 97.67              | 103.67              | 108.07 <sup>a</sup>  |
| 30 × 10  | 95.00              | 120.00              | 119.00              | 97.00              | 101.33              | 106.47 <sup>b</sup>  |
| Mean   | 96.17 <sup>d</sup> | 120.94 <sup>a</sup> | 120.11 <sup>a</sup> | 98.17 <sup>c</sup> | 102.22 <sup>b</sup> | 107.52               |
| LSD <sub>0.05</sub> (V)= 1.261, LSD <sub>0.05</sub> (D)=1.381, LSD <sub>0.05</sub> (V*D) =3.088, CV=1.8% |                    |                     |                     |                    |                     |                      |

The means with at least one common letter do not differ significantly.

**3- Days to maturity (day):** The results of statistical analysis show significant differences ( $P \leq 0.05$ ) among studied varieties, interaction between varieties and plant densities, but no significant differences were appeared among densities (Table 6). Days to maturity was significantly higher for varieties Red

carina and Q26 (148.44 and 148.33 days respectively), while it was significantly lower for variety Giza-1 (119.06 days). It was noticed for the interaction between varieties and plant densities days to maturity was significantly higher for variety Q26 at density of 50×10 and Red Carina at densities of 50×15, 30×15 and 30×10 (149.67 and 148.67 days respectively), while it was significantly lower for variety Giza-1 at density of 30×10 (118.0 days). These results disagree with Oelke *et al.*, (1992) who indicated that increasing plant density resulted in a slightly earlier maturity, and disagree with Rishi and Galwey, (1991). Perhaps the reason to that is due to the variation in varieties performance, growth habits and growing seasons length.

**Table 6. Effect of plant densities of five quinoa varieties on days to maturity (day).**

| Densities (D)  | Varieties (V)       |                     |                     |                     |                     | Mean                |
|--|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
|  | Giza-1              | Red Carina          | Q26                 | Titicaca            | NSL                 |                     |
| 50 × 20  | 118.67              | 148.00              | 147.33              | 123.67              | 127.33              | 133.00 <sup>a</sup> |
| 50 × 15  | 120.00              | 148.67              | 148.33              | 122.67              | 128.00              | 133.53 <sup>a</sup> |
| 50 × 10  | 119.00              | 148.33              | 149.67              | 122.00              | 126.67              | 133.13 <sup>a</sup> |
| 30 × 20  | 119.33              | 148.33              | 148.00              | 122.00              | 127.67              | 133.07 <sup>a</sup> |
| 30 × 15  | 119.33              | 148.67              | 148.33              | 122.33              | 127.33              | 133.20 <sup>a</sup> |
| 30 × 10  | 118.00              | 148.67              | 148.33              | 121.00              | 127.00              | 132.60 <sup>a</sup> |
| Mean   | 119.06 <sup>d</sup> | 148.44 <sup>a</sup> | 148.33 <sup>a</sup> | 122.28 <sup>c</sup> | 127.33 <sup>b</sup> | 133.09              |
| LSD <sub>0.05</sub> (V)= 0.897, LSD <sub>0.05</sub> (D)=0.983, LSD <sub>0.05</sub> (V*D)=2.198, CV=1.0 % |                     |                     |                     |                     |                     |                     |

The means with at least one common letter do not differ significantly.

**4- Seed yield (kg/ha):** The results of statistical analysis show significant differences ( $P \leq 0.05$ ) among studied varieties, plant densities and interaction between varieties and plant densities for the seed yield (Table 7). Where it was significantly higher for variety Q26 (1884.8 kg/ha), while it was significantly lower for variety Titicaca (1427.3 kg/ha). Such results agree with Maliro and Njala, (2019); Präger *et al.*, (2018); Tan and Temel, (2018); and Naneli *et al.*, (2017) 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 and 1877.3 kg/ha respectively), while it was significantly lower at density of 30×10 (1475.7 kg/ha). The interaction between varieties and plant densities 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), while it was significantly lower for variety Titicaca at density 30 × 10 (1212.0 kg/ha). It was noticed that seed yield increased with decreasing plant densities this can be attributed to the fierce competition for light and nutrients among plants (Khan *et al.*, 2017). Such results agree with Erazzú *et al.*, (2016), and disagree with Eisa *et al.*, (2018); Olofintoye *et al.*, (2015); Pourfarid *et al.*, (2014) and Roberto and Rocha, (2008).

**Table 7. Effect of plant densities of five quinoa varieties on seed yield (kg/ha).**

| Densities (D)   | Varieties (V)       |                      |                     |                     |                     | Mean                |
|---|---------------------|----------------------|---------------------|---------------------|---------------------|---------------------|
|   | Giza-1              | Red Carina           | Q26                 | Titicaca            | NSL                 |                     |
| 50 × 20   | 2026.3              | 1866.7               | 2058.7              | 1568.3              | 1866.3              | 1877.3 <sup>a</sup> |
| 50 × 15   | 2068.7              | 1875.0               | 2052.7              | 1546.3              | 1862.7              | 1881.1 <sup>a</sup> |
| 50 × 10   | 1887.0              | 1785.3               | 1898.3              | 1415.0              | 1754.3              | 1748.0 <sup>c</sup> |
| 30 × 20   | 1989.3              | 1822.3               | 1966.3              | 1531.0              | 1850.0              | 1831.8 <sup>b</sup> |
| 30 × 15   | 1675.3              | 1707.7               | 1760.7              | 1291.0              | 1657.0              | 1618.3 <sup>d</sup> |
| 30 × 10   | 1561.0              | 1531.3               | 1572.0              | 1212.0              | 1502.0              | 1475.7 <sup>e</sup> |
| Mean  | 1867.9 <sup>b</sup> | 1764.7 <sup>ab</sup> | 1884.8 <sup>a</sup> | 1427.3 <sup>c</sup> | 1748.7 <sup>b</sup> | 1738.7              |
| LSD <sub>0.05</sub> (V)=40.16, LSD <sub>0.05</sub> (D)= 43.99, LSD <sub>0.05</sub> (V*D)= 98.37, CV=3.5 % |                     |                      |                     |                     |                     |                     |

The means with at least one common letter do not differ significantly.

**5- Biological yield (kg/ha):** The results of statistical analysis showed significant differences ( $P \leq 0.05$ ) among studied varieties, plant densities and interaction between varieties and plant densities for the biological yield (Table 8), where it was significantly higher for the variety Q26 (6548.4 kg/ha), while it was significantly lower for the variety Titicaca (5538.2 kg/ha). It was significantly higher at densities of 50×15 and 50×20 (6347.2 and 6341.3 kg/ha respectively), while it was significantly lower at density of 30×15 (6006.3 kg/ha). It was noticed for the interaction between varieties and plant densities that the biological yield was significantly higher for the variety Q26 at density of 50×20 (6759.3 kg/ha), while it was significantly lower for the variety Titicaca at density of 30×15 (5255.7 kg/ha). These results disagree with Olofintoye *et al.*, (2015) and Roberto and Rocha, (2008).

**Table 8. 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              | 6341.3 <sup>a</sup>   |
| 50 × 15  | 6672.0              | 6366.3               | 6756.0              | 5638.7              | 6303.0              | 6347.2 <sup>a</sup>   |
| 50 × 10  | 6395.3              | 6258.3               | 6447.3              | 5588.0              | 6118.0              | 6161.4 <sup>abc</sup> |
| 30 × 20  | 6564.3              | 6124.0               | 6648.7              | 5748.7              | 6236.3              | 6264.4 <sup>ab</sup>  |
| 30 × 15  | 5737.0              | 6492.3               | 6282.0              | 5255.7              | 6264.3              | 6006.3 <sup>c</sup>   |
| 30 × 10  | 5804.3              | 6511.3               | 6397.0              | 5453.7              | 6183.0              | 6069.9 <sup>bc</sup>  |
| Mean   | 6314.8 <sup>b</sup> | 6361.3 <sup>ab</sup> | 6548.4 <sup>a</sup> | 5538.2 <sup>c</sup> | 6229.4 <sup>b</sup> | 6198                  |
| LSD <sub>0.05</sub> (V)= 200.3, LSD <sub>0.05</sub> (D)= 219.5, LSD <sub>0.05</sub> (V*D)= 490.7, CV= 4.8% |                     |                      |                     |                     |                     |                       |

The means with at least one common letter do not differ significantly.

**6- Harvest index (%):** The results of statistical analysis show significant differences ( $P \leq 0.05$ ) among studied varieties, plant densities and interaction between varieties and plant densities for the harvest index (Table 9). This trait was significantly higher for the variety Giza-1 (29.535%), while it was significantly lower for the variety Titicaca (25.771%), and it was significantly higher at density of 50×15, 50×20 and 30×20 (29.578, 29.570 and 29.187 % respectively), while it was significantly lower at density of 30×10 (24.320 %). It was noticed for the interaction between varieties and plant densities of the harvest index was significantly higher, for the variety Giza-1, at density of 50×15 (31.036 %),

while it was significantly lower for the variety Titicaca at density of 30×10 (22.249%). These results disagree with Olofintoye *et al.* (2015) and disagree with Roberto and Rocha, (2008).

**Table 9. Effect of plant densities of five quinoa varieties on harvest index (%).**

| Densities (D)  | Varieties (V)       |                     |                     |                     |                     | Mean                |
|--|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
|  | Giza-1              | Red Carina          | Q26                 | Titicaca            | NSL                 |                     |
| 50 × 20  | 30.222              | 29.105              | 30.442              | 28.294              | 29.787              | 29.570 <sup>a</sup> |
| 50 × 15  | 31.036              | 29.462              | 30.379              | 27.461              | 29.552              | 29.578 <sup>a</sup> |
| 50 × 10  | 29.530              | 28.547              | 29.459              | 25.407              | 28.691              | 28.327 <sup>b</sup> |
| 30 × 20  | 30.306              | 29.760              | 29.574              | 26.633              | 29.664              | 29.187 <sup>a</sup> |
| 30 × 15  | 29.194              | 26.402              | 28.070              | 24.582              | 26.489              | 26.947 <sup>c</sup> |
| 30 × 10  | 26.924              | 23.522              | 24.568              | 22.249              | 24.335              | 24.320 <sup>d</sup> |
| Mean   | 29.535 <sup>a</sup> | 27.800 <sup>c</sup> | 28.749 <sup>b</sup> | 25.771 <sup>d</sup> | 28.086 <sup>c</sup> | 27.988              |
| LSD <sub>0.05</sub> (V)= 0.5719, LSD <sub>0.05</sub> (D)= 0.6265, LSD <sub>0.05</sub> (V*D)=1.4009, CV= 3.1% |                     |                     |                     |                     |                     |                     |

The means with at least one common letter do not differ significantly.

### Conclusion:

There were significant differences among studied varieties, plant densities (except for vegetative growth and maturity) and interaction between varieties and plant densities for all studied traits. With increasing planting density, seed yield, biological yield and harvest index decreased. Density at 50×20 achieved the most suitable planting density for the highest seed yield. Among quinoa varieties Q26 achieved the highest seed yield, Giza-1 and Titicaca exhibited best results for phenological traits.

### References:

- Al Jbawi, E.; M. Othman; T. Al Hunnish; and F. Abbas (2022). The effect of plant density on growth and seed yield of quinoa (*Chenopodium quinoa* Willd.) in the middle region of Syria. International Journal of Phytology Research. 2(1):19-24
- Bazile, D.; S.E. Jacobsen; and A. Verniau (2016). The global expansion of quinoa: Trends and limits. Frontiers in Plant Science. 7: 622.
- Carbone-Risi, J.J.M. (1986). Adaptation of the Andean grain crop quinoa for cultivation in Britain. Ph.D. Thesis, University of Cambridge, Cambridge, UK.
- Roberto, C.S.; and J.E.S. Rocha (2008). Effect of sowing density on plant growth and development of quinoa (*Chenopodium quinoa* willd.) genotype 4.5 in the Brazilian savannah highlands. Biosci Uberlandia. 25(4):53 58.
- Cha, M.K.; Y.A. Jeon; J.E. Son; and Y.Y. Cho (2016). Development of planting-density growth harvest (PGH) charts for quinoa (*Chenopodium quinoa* Willd.) and sow thistle (*Ixeris dentata* Nakai) grown hydroponically in closed-type plant production systems. Hort. Environ. Biotechnol., 57(3): 213-218.
- Curti R.N.; A.J. De la Vega; A.J. Andrade; S.J. Bramadi; and H.D. Bertero (2016). Adaptive responses of quinoa to diverse agro ecological environments along an altitudinal gradient in North West Argentina. Field Crops Research. 186: 10–18.
- Eisa, S.S.; E.H. Abd El-Samd; S.A. Hussin; E.A. Ali; M. Ebrahim; J.A. González; M. Ordano; L.E. Erazzú; N.E. El-Bordeny; and A.A. Abdel-Ati (2018). Quinoa in Egypt – Plant density effects on seed yield and nutritional quality in Marginal regions. Middle East J. Appl. Sci., 8(2):515-522.

- Erazzú, L.E.; J.A. González; S.E. Buedo; and F.E. Prado (2016). Effects of sowing density on *Chenopodium quinoa* (quinoa), Incidence on morphological aspects and grain yield in Var. CICA growing in Amaicha del Valle, Tucumán, Argentina. *Lilloa*. 53 (1): 12-22.
- Jacobsen, S.E. (2017). The scope for adaptation of quinoa in Northern Latitudes of Europe. *Journal of Agronomy and Crop Science*. 203(6): 603-613.
- Khan, S.; S. Anwar; J. Kuai; S. Ullah; S. Fahad; and G.S. Zhou (2017). Optimization of nitrogen rate and planting density for improving yield, nitrogen use efficiency, and lodging resistance in oilseed rape. *Front. Plant Sci.*, 8:532.
- Leskovar, D.I.; L.A. Stein; and F.J. Dainello (2000). Planting systems influence growth dynamics and quality of fresh market spinach. *Hort. Sci.*, 35: 1238-1240.
- Maliro, M.F.A.; and A.L. Njala (2019). Agronomic performance and strategies of promoting quinoa (*Chenopodium quinoa* Willd) in Malawi. *Cien. Inv. Agr.*, 46(2):82-99.
- Naneli, I.; A. Tanrikulu; and T. Dokuyucu (2017). Response of the quinoa genotypes to different locations by grain yield and yield components. *Int. J. Agri. Innov. Res.*, 6(3):447-451.
- Oelke, E.A.; D.H. Putnam; T.M. Teynor; and E.S. Oplinger (1992). *Alternative field crops manual*. University of Minnesota extension service university of Minnesota Extension Service, Centre for Alternarnative plant and animal products.
- Olofintoye, J.A.T.; Y.A. Abayomi; and O. Olugbemi (2015). Yield response plant development and grain yield in a temperate environment. *Agri. Sci.*, 117: 325-332.
- Pourfarid, A.; B. Kamkar; and A.G. Akbari (2014). The effect of density on yield and some agronomical and physiological traits of amaranth (*Amaranthus* spp.). *International and Allied Sci.*, 3(12):1256-1259
- Präger, A.; S. Munz; P.M. Kebiwe; B. Mast; and S. Graeff (2018). Yield and quality characteristics of different quinoa (*Chenopodium quinoa* Willd.) cultivars grown under field conditions in Southwestern Germany. *Agronomy*. 8:197.
- Rishi, J.; and N.W. Galwey (1991). Effect of sowing date and sowing rate on plant development and grain yield in a temperate environment. *Agri. Sci.*, 117: 325-332.
- Sajjad, A.; H. Munir; A.A.S. Ehsanullah; M. Tanveer; and A. Rehman (2014). Growth and development of *Chenopodium quinoa* genotypes and different sowing dates. *Journal of Agricultural Research*. 52: 535–546.
- Sangoi, L.; M. Ender; and A.F. Guidolin (2000). Evolution of disease resistance of maize hybrids from different seasons in three plant populations. *Revista Ciência Rural*, Santa Maria. 30(1): 17-21.
- Santos, R.L.B. (1996). Estudos iniciais para o cultivo de quinoa *Chenopodium quinoa* Willd.) no Cerrado. Dissertation (Masters degree). Universidade de Brasília, Faculdade de Agronomia e Medicina Veterinária, Brasília, DF, 129p.
- Tan, M.; and S. Temel (2018). Performance of some quinoa (*Chenopodium quinoa* Willd.) genotypes grown in different climate conditions. *Turk J. Field Crops*. 23(2):180-186.
- Wu, G.; C.F. Ross; C.F. Morris; and K.M. Murphy (2017). Lexicon development, consumer acceptance, and drivers of liking of quinoa varieties. *Journal of Food Science*. 82: 993-1005.