Wali *et al.*
Bulletin of the National Research Centre (2022) 46:38
https://doi.org/10.1186/s42269-022-00724-0

Bulletin of the National Research Centre

RESEARCH **Open Access**

Productivity of Quinoa (*Chenopodium quinoa* L.) under new reclaimed soil conditions at north-western coast of Egypt

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Abstract

Background: Introducing new crops to reduce the nutritional gap in Egypt is an important target. One of these crops is Quinoa which is characterized by high nutritional value with multiple food uses. However, it will compete with other winter crops, so it is candidate to grow in marginal lands like calcareous soils. Meanwhile, planting density and N requirements are not known under such conditions; therefore, this work was undertaken in calcareous soil $Caco_3 > 50\%$.

Methods: The experiments included three nitrogen fertilization treatments (0, 50 and 100 kg/fed.) and two plant densities (20,000 plants/fed. and 36,000 plants/fed.) on Quinoa (*Chenopodium quinoa* Willd.) cv. Shibaya Field over two consecutive winter seasons of 2018/2019 and 2019/2020 in calcareous soil. Quinoa seed yield, biological yield, straw yield, weight of 1000-seed, harvest index, total nitrogen percentage in seeds, crude protein content in seeds, phosphorus content in seeds and potassium percentage in seeds were determined. The experimental design was a split plot design with three replications.

Results: The results showed that applying nitrogen fertilization at a rate of 100 kg/fed. had significantly greater seed yield, biological yield, seed yield, straw yield and weight of 1000-seed. All seed chemical contents except K percentage were significantly affected due to nitrogen fertilization. Increasing plant density from 20,000 to 36,000 plants per feddan significantly increased the biological yield, seed yield, straw yield, weight of 1000-seed and harvest index. The interaction between the two studied factors was significant on all characters of this investigation except, K percentage in seeds.

Conclusion: It can be concluded from this study that the quinoa crop responds to the increase in nitrogen fertilization and increases productivity and quality when fertilized with a rate of 100 kg nitrogen per fed.

Keywords: Quinoa, Yield, Quality, Nitrogen fertilization, Plant densities

Background

Quinoa (*Chenopodium quinoa*) is a pseudo-grain that produces a grain-like seed that can be used as a whole grain or in bread and soup and as a preparation of various food stuffs for infants and for people suffering from celiac disease or multiple other uses (Schulte et al. 2005a, b; Ascheri et al. 2002). The seeds and leaves are used as human food and can also be grown as a fodder crop for animal feeding or cover crops.

Quinoa has great adaptability to various agro-climatic conditions and can tolerate drought, frost, heat, salinity and poor soil in comparison with other crops (Jacobsen 2003; Jacobsen et al. 2003; Mujica et al. 2004; Geerts et al. 2008; Martinez et al. 2009). Quinoa is one of the promising candidates for sustainable cultivation in salt-affected

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areas. Quinoa is an optional salt plant that can be used as an alternative cash crop for land and water unsuitable for traditional crops in arid and semiarid regions (Eisa et al. 2017). The crop tolerates a wide range of marginal soils with a wide pH range (4.5–9.5) (Hinojosa et al. 2018), saline (Koyro et al. 2008), heat (Rashid et al. 2018) and drought stressful environments (Jacobsen et al. 2003). In addition to its agricultural advantages, quinoa is considered the most important health food in the world. It can meet and exceed a person's daily nutritional requirements recommended by the World Health Organization (Castellión et al. 2010; Hirose et al. 2010) due to its excellent balance of carbohydrates, fats and protein for human nutrition (Maradini-Filho et al. 2017). It is one of the few plant foods that is gluten-free and contains all 9 essential amino acids. The seeds also provide a rich source of a wide range of minerals (Ca, P, Mg, Fe, Zn), vitamins (B1, B2, C and E) and natural antioxidants (Koyro and Eisa 2008; Abugoch et al. 2009; Vega-Galvez et al. 2010). Quinoa has received great attention at the global level recently, and in Egypt now many researches are being conducted on quinoa to try to reduce the food gap and exploit many marginal areas affected by salts and low fertility (Choukr-Allah et al. 2016; Eisa et al. 2017).

Nitrogen is one of the major elements that crops need in large quantities to give ideal growth and a high yield in quantity and quality. Quinoa, like other crops, responds to nitrogen fertilization, but studies are still limited on the best fertilization levels that give a high-quality seed crop due to the diversity of environmental conditions for its growth and different genotypes. Fertilizing with nitrogen increases growth rate, yield and nutrient uptake for its role in improving photosynthesis in leaves, as well as in protein synthesis, cell structure and carbohydrate production (Weisany et al. 2013).

Oelke et al. (1992) recommended that the rate of nitrogen fertilization of quinoa not exceed 170–200 kg of nitrogen per hectare and clarified that more than this rate would lead to plant dormancy and delay in maturity. Shams (2012) found significant effect of nitrogen fertilization at different rates on plant height characteristics, seed yield and biological yield, reaching 360 kg/ha. Gomaa (2013) studied both nitrogen and phosphorous fertilizers, and it was found that the protein and nutrient content of quinoa seeds increased. Geren (2015) found that the content of crude protein in seeds increased by 16% when fertilized at a rate of 150 kg of nitrogen per hectare and the seed yield increased to 2.95 tons per hectare. There are many other researches on the impact of nitrogen fertilization on the nutritional content of the seeds of quinoa. It is well known that quinoa grain has higher contents of P and K mineral. Also, quinoa is a good source of protein and can be used as a nutritional ingredient in food products] (González et al. 2012). Mujica et al. (2004), reported that while quinoa's need for nitrogen (N) and calcium (Ca) is high, its need for phosphorous (P) and potassium (K) is moderate and minimal, respectively.

Planting density is one of the most important agricultural practices affecting crop yields (Lescovar et al. 2000; Cha et al. 2016). Quinoa is sensitive to different planting densities, fertilizer types and application rates (Siavoshi et al. 2010). Currently, there are no specific densities recommended for growing quinoa. The differences in planting densities are due to differences in soil fertility and general soil characteristics in an area (Maliro et al. 2017); hence, it is difficult to recommend an ideal planting density for an area if the crop is newly introduced. Seif et al. (2015) found an ideal spacing rate of 40–80 cm with nitrogen application rates of 120 kg of urea ha-1 in non-leaky soils.

The key to successful crop production is the ability to produce sufficient yields from the lowest possible area, volume and energy inputs (Beaman et al. 2009). The amount of light that reaches the plant canopy and is absorbed by photosynthesis changes mainly with the intensity of the plant through planting density factor (Francescangeli et al. 2006).

For each production system, there is an ideal vegetation group that maximizes the utilization of available resources (water and nutrients), allowing the expression of the maximum potential return attainable in that environment (Sangoi et al. 2000). However, there is no single recommendation for all conditions because the optimum quinoa density for maximum economical yield of the grain varies with different conditions, such as genotype, growth habits, sowing history, climatic conditions, soil fertility as well as agricultural management (Carboni-Risi 1986; Santos 1996). The objectives of this study were to examine the effects of nitrogen application rate and plant densities on quinoa seed yield, yield attributes and quality.

Methods

Experimental site and soil characteristics

Field experiments were conducted over two consecutive winter seasons of 2018/2019 and 2019/2020 to determine the effects of nitrogen fertilization and plant densities on yield, yield components and quality of quinoa (*Chenopodium quinoa* Willd.) at the experimental Station, Borg E-l Arab, Alexandria Governorate, Egypt. The experiments' field soil parameters are listed in Table 1.

Experimental design and treatments

Each experiment included six treatments, which were the combination of three nitrogen fertilization treatments 50

Table 1 Physical and chemical characteristics of the experimental soil (0–30 cm depth)

Characteristics	Values of physical and chemical characteristics
Sand (%)	83.67
Silt (%)	5.94
Clay (%)	10.39
Texture	Sandy loam
Electric conductivity (μs cm^{-1})	3.18
pH	8.09
$CaCO_3$ (%)	54.86
Organic matter (%)	0.84
N (%)	0.05
P(ppm)	0.88
K(ppm)	267.15

and 100 kg/fed. as ammonium nitrate 33.5% addition to non-nitrogen (Zero N) and two plant densities (20,000 plants/fed. and 36,000 plants/fed.). The experimental design was a split plot design with three replications. Each plot consisted of 5 ridges, each of 70 cm apart (15 and 30 cm between plants) and 3 m long, comprising an area of 10.5 m^2 (1/400 fed.).

Agronomic practices

Experimental soil was prepared by land plough and ridges construction. Organic matter as compost at rate of 10 m^3/fed. and phosphorus at rate of 31 kg/fed. as calcium super phosphate (15.5% P_2O_5) were added during the final preparation of land and thoroughly mixed with the soil. Potassium was added once at rate of 24 kg/fed. as potassium sulphate (48% K_2O) pre-flowering stage. Seeds of quinoa cv. Shibaya which obtained from ARC were sown on 11th November 2018 in the first season and 10th November 2019 in the second one and harvested on7th March 2019 and 11th March 2020 in both seasons of study. After one Month from sowing date, seedlings were thinned to one seedling per hill and crop practice managements of including fertilization, pest, disease and weed control were regularly carried out according to Ministry of Agriculture and Land Reclamation recommendations.

Data collected

At harvesting stage, quinoa plants in each experimental plot were cut at 5 cm above the soil surface, and then plants were left to air-dried for 7 days. The dried panicles for each experimental plot were threshed by hand. After that, biological, seed and straw yield (kg/fed.) were determined on the basis of per sub plot as well as the weight of 1000-seeds (g) was estimated. Also, harvest index (%) was calculated from dividing seed yield (kg/fed.) at biological yield (kg/fed.).

Chemical analyses

Total nitrogen percentage (N %) in seeds was determined according to the modified micro Kjeldahl method (A.O.A.C. 1990). Crude protein content in seeds was estimated by multiplying total N value by conversion factor of 6.25. Phosphorus content (P %) in seeds was determined as reported by Fric et al. (1964) using calorimetric determination with ascorbic acid. Potassium percentage in seeds was determined by using flame photometer method (JENWAY, PFP-7, ELE Instrument Co. Ltd., UK) as described by Chapman and Pratt (1961).

Statistical analyses

All treatments were arranged and analysed as a split plot design according to Snedecor and Cochran (1969) with three replicates, after testing the homogeneity of the error according to Bartlett's test, combined analysis for both seasons were done. Means of the different treatments were compared using the least significant difference (LSD) test at $P < 0.05$.

Results

Biological yield/fed. (kg)

Significant effects were detected due to nitrogen rates on biological yield (Table 2), whereas there were successive gradual significant increases from zero nitrogen

Table 2 Means of yield and yield components of quinoa as affected by N fertilization rate (combined means of 2018 and 2019 seasons)

Nitrogen fertilization	Biological yield (kg/fed.)	Seed yield (kg/fed.)	Straw yield (kg/fed.)	1000-seed weight (g)	Harvest index (%)
Zero N	485.13	220.58	264.55	2.97	44.98
50 kg N/fed	744.50	351.54	392.96	3.19	47.03
100 kg N/fed	947.28	445.54	501.74	3.32	46.75
L.S.D. ($_{0.05}$)	40.6	57.2	95.8	0.25	N.S

to 100 kg N/fed.; the highest value (947.28 kg/fed.) was obtained from 100 kg N/fed. with a percentage increase 95.26% compared with control. These results behaved the trend of the results of straw yield Table 2.

Data in Table 3 revealed that biological yield increased significantly with increasing plant density, whereas it reached its maximum value (885.78 kg/fed.) under the density of 36,000 plant per fed.; on the other side, minimum mean value of biological yield (565.48 kg/fed.) was recorded at 20,000 plant per fed. The increase in this trait was due to increasing the plant density. The interaction between nitrogen fertilizers and plant densities had significant effect on biological yield, whereas the highest mean value (1141.8 kg/fed.) was recorded at 100 kg nitrogen with 36,000 plants per fed (Table 4).

Seed yield/feddan (kg)

Similarly to biological yield/fed, seed yield/fed was significantly affected by nitrogen applications, whereas the maximum dose of nitrogen recorded the highest values of seed yield (445.54 kg/fed.). Nitrogen fertilization at rates of 50 and 100 kg/fed. increased the yield by about 59.37 and 101.98% more than the control as shown in Table 2. The obtained results in Table 3 clearly showed that the high density (36,000 plant per fed.) significantly increased by 66.98% as compared with the low planting density (20,000 plant per fed.). Data recorded in Table 4 cleared the effect of the interaction between nitrogen fertilizers and plant densities on seed yield which was significant, whereas the highest mean value (550.1 kg/fed.) was observed by applying 100 kg N/fed. with plant density of 36,000 plant per fed.

Straw yield/feddan (kg)

The trend of straw yield behaved similarly to biological yield as affected by nitrogen application. It is clear from Table 2 that the highest value (501.74 kg/fed.) was obtained from 100 kg N/fed. and the lowest value (264.55 kg/fed.) was accorded from zero nitrogen with high significance differences between the three treatments of nitrogen, whereas the treatment of 36,000 plant per fed. obtained 461.47 kg/fed. of straw, but the 20,000 plant per fed. recorded 311.37 kg/fed. as shown in Table 3. Straw yield was significantly affected by the interaction between nitrogen fertilizers and plant densities (Table 4), whereas the highest straw yield (591.7 kg/fed.) was obtained under the interaction effect 100 kg N and 36,000 plant per fed.

Weight of 1000-seed (g)

Data in Table 2 indicated that subjecting plants to nitrogen rates caused significant effects on 1000-grain weight

Table 3 Means of yield and yield components of quinoa as affected by plant densities (combined means of 2018 and 2019 seasons)

Plant densities	Biological yield (kg/fed.)	Seed yield (kg/fed.)	Straw yield (kg/fed.)	1000-seed weight (g)	Harvest index (%)
20,000 plants/fed	565.48	254.12	311.37	3.19	44.67
36,000 plants/fed	885.78	424.32	461.47	3.12	47.84
L.S.D. ($_{0.05}$)	26.3	7.9	19.5	N.S	1.6

Table 4 Means of yield and yield components of quinoa as affected by the interaction between N fertilization and plant densities (combined means of 2018 and 2019 seasons)

Treatments	Biological yield (kg/fed.)	Seed yield (kg/fed.)	Straw yield (kg/fed.)	1000-seed weight (g)	Harvest index (%)
Zero N					
20,000 plants/fed	379.9	161.1	218.7	2.91	42.5
36,000 plants/fed	590.4	280.0	310.4	3.03	47.5
50 kg N/fed					
20,000 plants/fed	563.8	260.2	303.6	3.30	46.2
36,000 plants/fed	925.2	442.9	482.3	3.09	47.9
100 kg N/fed					
20,000 plants/fed	752.8	341.0	411.8	3.38	45.3
36,000 plants/fed	1141.8	550.1	591.7	3.25	48.2
L.S.D. ($_{0.05}$)	45.5	13.7	33.8	N.S	2.7

as an average for the seasons. It increased significantly with increasing nitrogen applications. The weight of 1000-seed reached 3.32 g. under nitrogen rate of 100 kg/fed., which were significantly greater than nitrogen rates of 50 and 0 kg/fed. (3.19 and 2.97 g.), whereas these increases reached about 7.41 and 11.78%, respectively, compared with nil nitrogen. As for plant density, from data pointed out in Table 3, it was noticed that 1000-seed weight was not significantly affected by this factor. Also, the weight of 1000- seed was not effected significantly by the interaction between nitrogen rates and plant densities (Table 4).

Harvest index (%)

Harvest index was not significantly affected by nitrogen application treatments as an average of both seasons (Table 2). On the other hand, this character had significantly affected by plant densities, whereas the highest mean value (47.84%) was achieved under 36,000 plant per fed. as un average for both seasons (Table 3). The interaction between the two studied factors was significant for harvest index, whereas the maximum value (48.2%) was recorded under the high dose of nitrogen and the high plant density as shown in Table 4.

Seed nitrogen content (%)

Nitrogen fertilization had a significant effects on seed nitrogen content (Table 5). Under nitrogen application treatment, seed nitrogen contents for 0, 50, 100 kg/fed. treatments were 1.76%, 1.99% and 2.03%, respectively. Plant density did not affect nitrogen content significantly (Table 6). Planting density and effects on nitrogen percentage in seeds were not significant. The interaction between nitrogen doses and plant densities as shown in Table 7 was significant for the percentage of nitrogen in seeds.

Seed protein content (%)

As for the protein % in seeds, the results in Table 5 indicated that the differences in protein % were significant with regard to this chemical content; there was a gradually significant increase with increasing the nitrogen supply at 100 kg N/fed., and the highest value was 12.7 followed by 12.45 for 100 and 50 kg N/fed. with present increase of 13.39 and 15.66 compared with control, respectively. Such results are in agreement with those reported by Ning et al. (2020). Protein uptake in seeds behaved the same trend of seed nitrogen percentage as effected by planting density, which were not significant as shown in Table 6. The interaction between nitrogen fertilizer and plant densities was significant for seed protein content (Table 7).

Table 5 Means of quinoa seed chemical contents as affected by N fertilization (combined means of 2018 and 2019 seasons)

Nitrogen fertilization	N (%)	P (%)	K (%)	Seed protein content (%)	Protein yield (kg/fed.)
Zero N	1.76	0.18	1.02	10.98	24.74
50 kg N/fed	1.99	0.20	0.99	12.45	43.32
100 kg N/fed	2.03	0.25	0.98	12.70	56.05
L.S.D. ($_{0.05}$)	0.1	0.03	N.S	0.62	4.32

Table 6 Means of quinoa seed chemical contents as affected by plant densities (combined means of 2018 and 2019 seasons)

Plant densities	N (%)	P (%)	K (%)	Seed protein content (%)	Protein yield (kg/fed.)
20,000 plants/fed	1.94	0.21	0.99	12.10	31.71
36,000 plants/fed	1.92	0.21	1.01	11.99	51.02
L.S.D. ($_{0.05}$)	N.S	N.S	0.06	N.S	5.13

Seed phosphorus content (%)

Phosphorus percentage in quinoa seeds was significantly affected due to nitrogen applications. It was noticed that the high values of phosphorus (0.25%) as shown in Table 5 were recorded by using 100 k N/fed. treatment. But there were no significant effects due to plant density on phosphorus contents in quinoa seeds (Table 6). The interaction between nitrogen doses and plant densities was significant for seed phosphorus contents.

Seed potassium percentage (%)

Data presented in Table 5 showed that potassium percentage was not affected by nitrogen applications. On the

Table 7 Means of quinoa seed chemical contents as affected by the interaction between N fertilization plant densities (combined means of 2018 and 2019 seasons)

Treatments	N (%)	P (%)	K (%)	Seed protein content (%)	Protein yield (kg/fed.)
Zero N					
20,000 plants/fed	1.62	0.19	1.01	10.13	16.31
36,000 plants/fed	1.90	0.18	1.03	11.84	33.17
50 kg N/fed					
20,000 plants/fed	2.07	0.20	0.99	12.94	33.64
36,000 plants/fed	1.92	0.20	1.00	11.97	52.99
100 kg N/fed					
20,000 plants/fed	2.12	0.25	0.97	13.25	45.19
36,000 plants/fed	1.95	0.25	0.99	12.16	66.91
L.S.D. ($_{0.05}$)	0.10	0.03	N.S	0.52	8.89

other hand, this trail was significantly affected by plant density (Table 6). Also, potassium percentage was not significantly effected due to the interaction between the two studied factors in this investigation (Table 7).

Protein yield (kg/fed.)

Protein yield of quinoa had significantly affected by nitrogen fertilization as shown (Table 5). The highest mean values (56.05 kg/fed.) were obtained by the high dose of nitrogen (100 kg N/fed.), and the percentage increase was 75.1 and 126.56%, respectively, compared with control. Also plant densities had significant effect on protein yield (Table 6), whereas the maximum value (51.02) was recorded under density of 36,000 plant per feddan. Protein yield was significantly affected by the interaction between nitrogen fertilization and plant density as shown in Table 7. The highest value (66.91 kg/fed.) was obtained by the interaction treatment (100 kg N/fed. with 36,000 plant per fed.). The increase in protein yield kg/fed. may be due to the increase in the sink capacity and seed yield kg/fed.

Discussion

Yield and yield components

Quinoa is a new crop that could be employed in new lands or problem soils; therefore, it is very important to find out the most suitable agronomic practices including planting density and N fertilization to ensure the sustainability of this crop. From the study, the crop yield and yield components seemed to respond well to either N fertilization or plant density as well as the interaction between them. The increase in straw yield due to increasing the plant density may be due to the larger stand/unit area. Similarly, straw yield was significantly affected by the interaction between nitrogen fertilizers and plant densities.

The increase in biological yield could be attributed to the increase in the straw yield under the same treatments and conditions which was confirmed by Gomaa (2013), Basra et al. (2014) and Geren (2015).

Regarding the increase in the seed yield since N could be attributed to N functions in plant; this fact is described according to Weisany et al. (2013). These results were in line with those obtained by Ning et al. (2020). They showed that seed yield increased by 10%–15% with increasing nitrogen application up to 160 kg ha^{-1}). Also, the increase in planting density led to significant increase in seed yield per area, especially under high density. These results were in harmony with those obtained by Risi and Galwey (1991); they reported that quinoa produced a higher seed yield at highest sowing rate which is surpassing quinoa planting under low target population densities. Also, Sayed et al. (2018) demonstrated that seed yield of quinoa increased by 34.7% with increasing plant density from 56.000 plant ha^{-1} to 167.000 plant ha^{-1}. Other yield components like weight of 1000-seed and Harvest index (%) results indicated that subjecting plants to nitrogen rates caused significant effects on 1000-grain weight since N has many functions in plant; this fact is described according to Weisany et al. (2013). The negligible effect for nitrogen on 1000-seed weight was obtained by Gomaa (2013), Basra et al. (2014) and Geren (2015).

The same trend of biological yield, seed yield and straw yield as affected by nitrogen application may be because nitrogen supply increases the nitrogen in the above ground plant portion, and thus stimulated the metabolic activity of plant, and was reflected in the dry matter of leaves because of the increase in intercepted light; this causes the increase in the straw yield and consequently the biological yield. Plant density significantly increased straw yield per fed. Nitrogen affects chlorophyll concentration of leaf which results in improved photosynthetic efficiency, and outcome is in the form of improved and completion of early vegetative growth phases (Amaliotis et al. 2004).

The increase in growth and yield attribute characters gradually with increasing N-levels may be attributed to the role of nitrogen in improving quinoa growth by enhancement meristematic cell division and expansion (Roggatz et al. 1999; Basra et al. 2014), activity and metabolic, photosynthesis processes and forming filled grains consequently producing heavier grains (Abou-Amer and Kamel 2011; Shams 2012; Basra et al. 2014). These results are in agreement with those obtained by Schulte et al. (2005a, b), Kakabouki et al. (2014) and Hakan (2015). Their results demonstrated that quinoa grain yield increased with the increase in N-levels from 50 to 150 kg N/ha.

The increase in seed yield per area may be mainly attributed to reduce branching at the higher plant density, and therefore, a higher proportion of seed yield has been produced from main panicle, while a lower plant density led to an increase in plant branching.

Awadalla and Morsy (2017) found that nitrogen at 150 kg N/fad produced the maximum values of plant, No. of branches/plant, No. of leaves/plant, No. of inflorescence/plant, 1000 seeds weight, weight of seeds and dry. The application of nitrogen fertilizer 50, 100 and 150 kg N/fad increased grain and biological yields compared with control treatment.

Chemical composition of quinoa seeds

Regarding chemical composition of quinoa seeds, the gradual significant increase in seed protein content (%) with increasing the nitrogen supply over the control is in agreement with those reported by Ning et al. (2020). Protein uptake in seeds behaved the same trend of seed nitrogen percentage as effected by planting density. Gimplinger et al. (2008) and Spehar and Rocha (2009) found similar results.

Phosphorus percentage in quinoa seeds was significantly affected due to nitrogen applications, while Erazzú et al. (2016) indicated that phosphorus content was higher with low planting density of 7 plants/m^2 than planting density of 46 plants/m^2. The interaction between nitrogen doses and plant densities was significant for seed phosphorus contents.

Potassium percentage was not affected by nitrogen application. Decreasing of seeds K-content may be due to the competition (Antagonism) between K and other elements. Protein yield of quinoa was significantly affected by nitrogen fertilization. Also plant densities had significant effect on protein yield. Decreasing of seeds K-content may be due to the competition (Antagonism) between K and other elements (i.e. Na) on the soil exchange complex as well as the compression on exchange sites of roots account for plant K decrease.

Protein yield was significantly affected by the interaction between nitrogen fertilization and plant density. In this respect, Attia (2005) on wheat and Kenawy (2014) on barley found the similar results.

Conclusions

It can be concluded from this study that the quinoa crop responds to the increase in nitrogen fertilization which increases productivity and quality when fertilizing at a rate of 100 kg nitrogen per fed was applied. Quinoa is one of the recent crops cultivated in Egypt's land. It needs more studies to know the best agricultural practices for it to reach the highest yield and quality, because of its high nutritional advantages quinoa can aid Egypt's food self-sufficiency, as the greatest threat to humanity's survival is the widening gap between population growth and food availability.

Abbreviation

Fed.: Feddan = 4200 m^2.

Acknowledgements

The authors would like to thank the staff of Experimental Station, Borg E-l Arab, Alexandria Governorate, Egypt, for their facilitation during this work.

Authors' contributions

AMW and MKK: conceived and designed the experiments, OMI and MKK performed the experiments, analyzed the data, AMW, OMI, MKK and EMA, MSA and AW: wrote the paper, reviewed the manuscript. All authors read and approved the final manuscript.

Funding

The work was self-funded by the authors.

Availability of data and materials

The data sets supporting the results are included within the article.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Received: 1 November 2021 Accepted: 6 February 2022

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