

## Quinoa in Egypt - Plant Density Effects on Seed Yield and Nutritional Quality in Marginal Regions

Sayed S. Eisa<sup>1</sup>, E.H. Abd El-Samad<sup>2</sup>, S.A. Hussin<sup>1</sup>, E.A. Ali<sup>3</sup>, M. Ebrahim<sup>1</sup>, Juan A. González<sup>4</sup>, Mariano Ordano<sup>4,5</sup>, Luis E. Erazzú<sup>6</sup>, N.E. El-Bordeny<sup>1</sup> and A.A. Abdel-Ati<sup>7</sup>

<sup>1</sup>Faculty of Agriculture, Ain Shams University, P.O. Box 68, Hadayek Shoubra, 11241, Shoubra El-Kheima, Cairo, Egypt.

<sup>2</sup>Vegetable Research Department, Agricultural & Biological Research Division, National Research Centre, 33 El-Buhouth St., 12622, Dokki, Giza, Egypt.

<sup>3</sup>Plant Protection Department, Ecology and Dry Land Agriculture Division, Desert Research Center (DRC), Cairo, Egypt.

<sup>4</sup>Instituto de Ecología, Fundación Miguel Lillo, Miguel Lillo 251, Tucumán, Argentina.

<sup>5</sup>Unidad Ejecutora Lillo, Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Fundación Miguel Lillo, Miguel Lillo 251, Tucumán, Argentina.

<sup>6</sup>Instituto Nacional de Tecnología Agropecuaria (INTA), Famaillá, Facultad de Agronomía y Zootecnia, Universidad Nacional de Tucumán, Tucumán, Argentina.

<sup>7</sup>Plant Production Department, Ecology and Dry Land Agriculture Division, Desert Research Center (DRC), Cairo, Egypt.

Received: 26 Feb. 2018 / Accepted: 30 April 2018/ Publication date: 17 May 2018

### ABSTRACT

Grain quinoa is a halophyte crop with potentially increasing cultivation area. Yet, no standards exist for optimum plant density in arid-regions. The aim of this work was to evaluate the effect of planting density on Peruvian valley type of *Chenopodium quinoa* Willd. cv. CICA from the standpoint of yield and seed quality in marginal area. Two Field experiments were conducted over two consecutive seasons viz., 2015-2016 in a marginal land at El-Fayoum oasis, Egypt with one quinoa cultivar and two planting densities namely, 56.000 plant ha<sup>-1</sup> (Low) and 167.000 plant ha<sup>-1</sup> (High). A complete randomized block design with six replicates was used. Seed yield increased by 34.7% with increase of plant density from 56.000 plant ha<sup>-1</sup> to 167.000 plant ha<sup>-1</sup>. The increase of plant density significantly decreased weight of 1000-seeds and weight of hectoliter. Protein and ash concentrations in seeds increased at low planting density, whereas carbohydrate concentration decreased. However, there were no significant differences between the two planting densities on the seed concentration of the crude fiber or total fat. Regarding effects of plant density on mineral content in quinoa seeds, the calcium and magnesium contents significantly increased at low density compared with high planting density. Meanwhile, no significant effects of plant density on phosphorus, potassium, iron and zinc content in quinoa seeds were detected. Thus, the present study concludes that the plant density that gives higher seed yield is associated with significant reduction in seed quality in terms of protein content. On the other hand, low plant density significantly increased weight of 1000-seeds and hectoliter, which is reflected on the grain size. The latter is considered as a very important parameter for quinoa global market preference.

**Keywords:** Quinoa, Planting density, Seed yield and quality, Mineral contents.

### Introduction

Dry land salinity increasingly affected large tracts of agricultural lands, particularly in arid and semi-arid regions, causing significant reduction in agricultural production. This problem is more severe in marginal lands and causes poverty and other related social and economic issues. Therefore, efforts are hence needed to find alternate solutions to allow farmers to make productive use of dry-saline lands. Quinoa is a facultative halophyte originating from Andean region of South America and provides a

**Corresponding Author:** E.H. Abd El-Samad, Vegetable Research Department, Agricultural & Biological Research Division, National Research Centre, 33 El-Buhouth St., 12622, Dokki, Giza, Egypt. E-mail: emadhassanein@hotmail.com

promising alternative for dry-saline lands. It has been cultivated as the main staple food crops for Andes people for hundreds of years (Brinegar *et al.*, 1996). Recently, quinoa has received a great attention worldwide, because of its ability to be productive under various environmental stresses (Choukr-Allah *et al.*, 2016; Eisa *et al.*, 2017). Quinoa seed has an extraordinary nutritional value, as its grains have an excellent balance of carbohydrates, lipids and protein for human nutrition (Maradini-Filho *et al.*, 2017). Quinoa protein has balanced essential amino acids profile, it contains lysine and sulfur amino acids, which are rare in plant origin (Abugoch, 2009 and Escuredo *et al.*, 2014). In addition, the grains provide a rich source of a wide range of minerals (Ca, P, Mg, Fe and Zn), vitamins (B1, B2, C and E), and natural antioxidants (Koyro and Eisa 2008; Abugoch *et al.*, 2009; Vega-Galvez *et al.*, 2010). The nutritional value of quinoa seeds is reported to meet and surpass the daily intake requirements that recommended by the World Health Organization (WHO) (Castelli3n *et al.*, 2010; Hirose *et al.*, 2010). Due to its high nutritional value, it has been chosen by Food and Agriculture Organization of The United Nations (FAO, 2013) as one of the crop destined for confirming food security in this century.

Planting density is one of the most important agricultural practices affecting crop yield (Leskovar *et al.*, 2000; Cha *et al.*, 2016). Plant density alters growth and developmental patterns thereby influence carbohydrate production and partition (Casal *et al.*, 1985). A key factor for successful crop production is the capacity to produce sufficient yield from the lowest possible area, volume and energy inputs such as light intensity (Beaman *et al.*, 2009). The amount of light reaching the plant canopy and absorbed by photosynthesis process changes mainly with plant density (Francescangeli *et al.*, 2006). Higher plant density needs to ensure that all inputs are optimized to reduce potential plant-to-plant competition (Abd El-Hamed and Elwan, 2011). 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). For instance in the USA, the commercial quinoa cultivation has been based on initial populations of 150.000 plant ha<sup>-1</sup> (Johnson and Ward, 1993). In Central-Southern Chile, 240.000 plant ha<sup>-1</sup> has been recommended. While, in Argentina, the optimum plant density for short-cycle cultivars is no less than 330.000 plant ha<sup>-1</sup> (or higher) are required for a reasonable crop production (Bertero and Ruiz 2008). In general, seed yield per area increased with increasing plant density but seed yield per plant and thousand seeds weight decreased as plant density increased. Erazzú *et al.* (2016) reported that with increasing plant sowing density from 70.000 to 460.000 plants h<sup>-1</sup>, quinoa grain yield decreased from 5389 to 3049 kg ha<sup>-1</sup>, respectively, in “cv. CICA”. Moreover, the increment of grain diameter was associated with low planting density. Grain size character is very important for market demand. Also they added that leaf N and P contents were increased with low planting density (7 plants/m<sup>2</sup>) than high planting density (46 plants/m<sup>2</sup>). However, focused researches regarding the effects of plant density on seed quality are inadequate yet.

Therefore, the main objective of the present study was to establish, for the first time, the effects of planting density (low and high) on seed yield and nutritional quality of quinoa grown under marginal land conditions in Egypt.

## Materials and Methods

Field experiments were conducted over two consecutive winter seasons of 2015/2016 and 2016/2017 to evaluate the response of seed yield and seed quality of *Chenopodium quinoa* cv. CICA to different planting densities (Low 56.000 and High 167.000 plant ha<sup>-1</sup>) in marginal area of Egypt. The experimental site was located in Monshaat Tantaway village, Senoures, Fayoum oasis, Egypt, latitude 29° 29' 19" N and longitude 30° 50' 08" E. The experimental area is arid with an average annual precipitation of 20 mm yr<sup>-1</sup>, with 100% of the rainfall occurring from October to April. The average degrees of monthly temperature during the growing seasons (November to March) were 20.13, 14.37, 17.25 °C and 20.31, 14.69, 17.50 °C for maximum, minimum and mean temperatures in the first and second seasons, respectively. The electrical conductivity was 5.3 dSm<sup>-1</sup> for irrigation water and 3.8 dSm<sup>-1</sup> for soil paste. The soil texture was sandy loam. Experimental soil was prepared by land plough and ridges construction. Organic matter as compost with a rate of 10 t ha<sup>-1</sup> and phosphorus at rate of

120 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> as calcium super phosphate (15.5% P<sub>2</sub>O<sub>5</sub>) were added during the final preparation of land and thoroughly mixed with the soil. Nitrogen was added as side dressing at rate of 214 kg N ha<sup>-1</sup> as ammonium sulphate (20.6% N) in three equal doses at 30, 45 and 60 days after sowing date. Potassium was added once at rate of 110 kg K<sub>2</sub>O ha<sup>-1</sup> at flowering stage as potassium sulphate (48% K<sub>2</sub>O). Seeds of quinoa cv. CICA (Centro Internacional de Cultivos Andinos "CICA", originated from Peru) were sown on the first week of November and harvested on the third week of March in both seasons of study. Seeds surface were sterilized before sowing with ethanol 70% for 10 sec., then with sodium hypochloride solution (5% active chloride) for 10 minutes. Seeds were then washed with distilled water several times to ensure complete elimination of chloride traces and then the seeds were dried between two layers of tissue paper before planting. About 8-10 seeds per hill were sown. A complete randomized block design with six replicates (experimental plots) was used, with an average of 18 m<sup>2</sup> for each plot (6 ridges with 5 m length and 0.6 m width). After 4 weeks from sowing date, seedlings were thinned to one seedling per hill and crop practice managements of hoeing, fertilization, controlling of pest, disease and weed were regularly carried out.

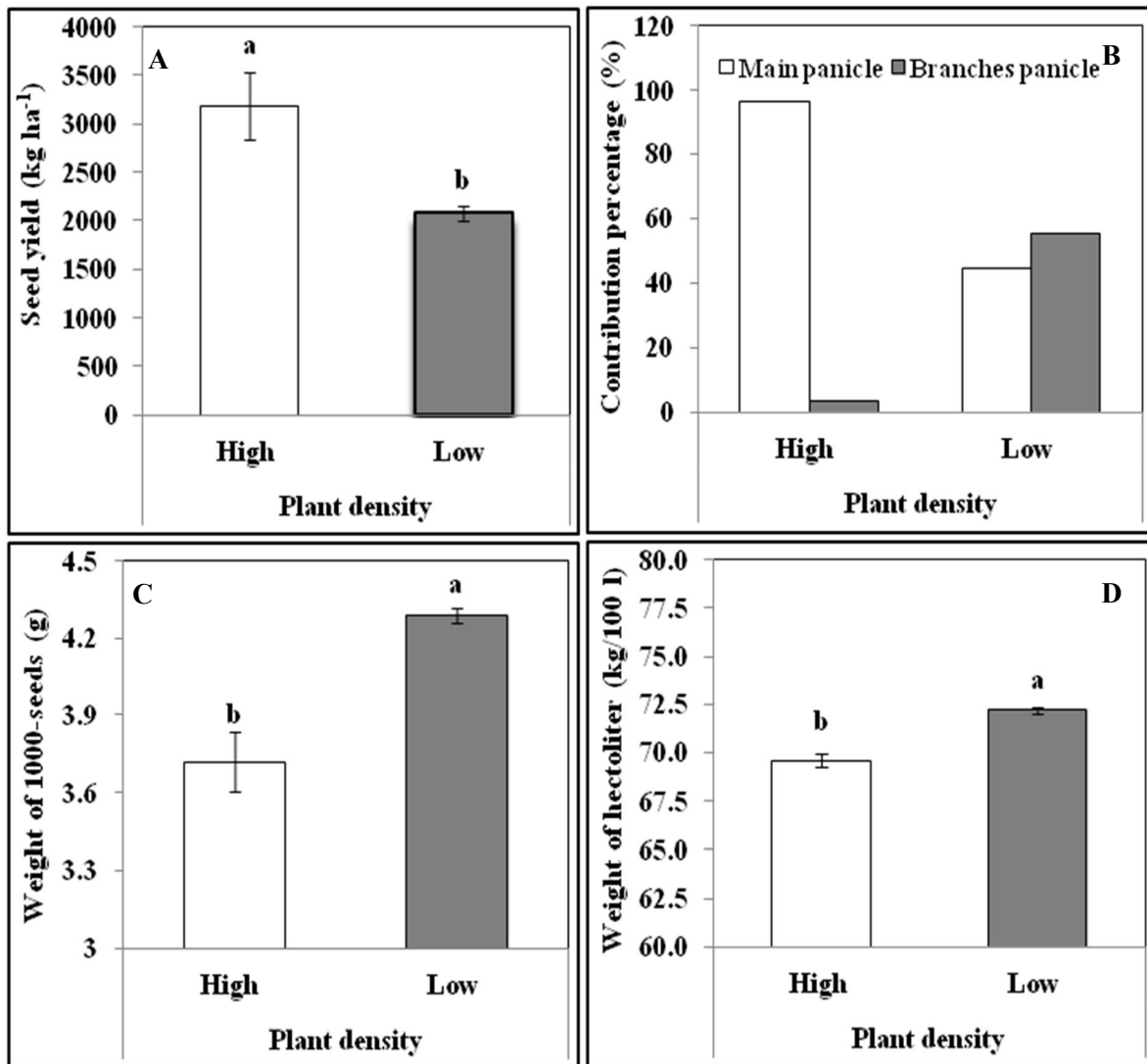
At harvesting stage, quinoa plants in each experimental plot were cut at 3 - 5 cm above the soil surface, then plants were left to air dried for 7 days. The dried panicles for each experimental plot were threshed and winnowed by hand. After that, seed yield (kg ha<sup>-1</sup>) and weight of 1000-seeds (g) as well as weight of hectoliter (kg/100 l), were estimated. Seed samples were dried in an oven at 65 °C till constant weight, then dried seed samples were grinded in a high speed grinder stainless-steel miller to a fine powder. Afterward, samples were wet digested to be used for determining of mineral contents. Total nitrogen was determined using micro Kjeldahl method (UDK 139 Semi-Automatic Kjeldahl Distillation Unit, VELP Scientific, Inc., Bohemia, NY, USA). In addition, phosphorus percentage was assayed according the modified colorimetric (molybdenum blue) method using spectrophotometer (SPECTRONIC 20D, Milton Roy Co. Ltd., USA) according to the procedures described by Cottenie *et al.* (1982). While, potassium percentage was measured using flame photometer method (JENWAY, PFP-7, ELE Instrument Co. Ltd., UK) as described by Chapman and Pratt (1982). Atomic absorption (ANALYST 200, Parkin Elmer, Inc., MA, USA) was used to determine Ca, Mg, Fe and Zn as described by Chapman and Pratt (1982). Moreover, crude protein was calculated by multiplying total N value by conversion factor of 6.25. Moisture percentage and ash content were determined according to the methods described in AOAC (1995). Ash content was carried out in a muffle furnace (M110, Heraeus Instruments, Hanau, Germany) at 525 ± 25 °C for 12 h, using 5 g of seed dried sample. Crude fiber was measured using ANKOM Fiber Analyzer A-200 with ANKOM fiber filter bags F-57 (ANKOM Technology, Macedon, NY, USA). Crude fat was measured using VELP solvent extractors unit SER 148/3 with VELP cellulose thimbles 33x80mm for 90 min using petroleum ether with a boiling range of 40-60 °C, as the extraction solvent (VELP Scientific, Inc., Bohemia, NY, USA). The residue obtained was dried for 2 h at 103 ± 2 °C, until constant weight. Furthermore, total carbohydrates content was calculated by the difference.

All data sets were tabulated and subjected to statistical analysis of variance procedure using one-way-ANOVA of the SAS software (SAS, 1998). The main factor was planting density with two levels. Values are given as averages of six replicates ± SD. Duncan's multiple range test was employed to compare the significant differences among mean of the treatments at 95 % level of confidence.

## Results and Discussion

Successful quinoa cultivation in marginal areas of Egypt relies on the adaptation of variety to its climate and soil conditions. The optimum population density for selected genotypes should be managed properly for maximal plant growth as well as economical and commercial yield. The results of plant density on seed yield per hectare, 1000-seeds weight, weight of hectoliter and the percentage of seed yield per main and secondary panicles are illustrated in Fig. (1). The obtained results clearly showed that the increase in planting density led to significant increase in seed yield per area. The seed yield per hectare under high density significantly increased by 34.7% as compared with the low planting density (Fig. 1A). The cultivar of CICA originating from the inter-Andean valleys of Peru, are characterized by producing secondary branches and somewhat highly adapted for cultivation under Egyptian conditions (Ebrahim *et al.*, 2018). At the present study, the increase in seed yield per area was 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, lower plant density led to increase of plant branching and consequently around 50 – 60% of seed yield produced by secondary panicles (Fig. 1B). Similar observation for Peruvian valley type of quinoa has been reported by Risi and Galwey (1991), they reported that the variety Amarilla de Marangani, from the inter-Andean valleys of Peru, produced a higher seed yield at highest sowing rate (30 kg seed/ha), which is surprising since valley varieties are normally sown with low target population densities. On the other hand, the increase of plant density significantly decreased weight of 1000-seeds and weight of hectoliter (Fig. 1C and D).



**Fig. 1.** Effects of planting density (low, 56.000 and high, 167.000 plant ha<sup>-1</sup>) on seed yield (A), yield contribution percentage of main and secondary panicle (B), weight of 1000-seeds (C) and weight of hectoliter (D) of quinoa plants cv. CICA grown in marginal conditions in Egypt. Combined data for both seasons of 2015/2016 and 2016/2017. Statistical significant differences between means ( $P \leq 0.05$ ) are indicated by different letters above columns according to Duncan's multiple range test.

Similar results were obtained on amaranth by Pourfarid *et al.* (2014). They reported that increasing plant population led significantly to decrease weight of 1000-seeds. Also, seed yield of soybean plants increased with increase of plant density from 20 up to 100 plant/m<sup>2</sup> but the increase in plant density decreased yield components such as 100-seeds weight (Rahman and Hossain, 2011). Whereas, an opposite trend was obtained by Erazzú *et al.* (2016) on quinoa. They found that increasing plant sowing density from 70.000 to 460.000 plants h<sup>-1</sup>, led to decrease grain yield from 5,389 to 3,049 kg ha<sup>-1</sup>,

respectively. The increment of grain diameter was associated with low planting density. Thousand seeds weight decreased as plant density increased and this is a possible explanation for the vigor loss. This may be also attributed to the potential plant-to-plant competition on available resources, water and nutrients as reported by Abd El-Hamed and Elwan (2011). The plant populations which produced the greatest seed yield (40 plants/m<sup>2</sup> or higher) produced lower quality seed than plant populations below 40 plants/m<sup>2</sup> (Rahman *et al.*, 2005). On the other hand, Spehar and Rocha (2009) studied the effect of increasing of densities in the range of 100,000 to 600,000 plants ha<sup>-1</sup> on quinoa genotype 4.5, in Brazilian Savannah conditions and they found that the analyses of 1000-seeds weight, biomass and grain yield were not affected by increasing plant density, resulting non-significant effects. As a result of low plant density a higher weight of 1000-seeds was attained in relative to high plant density. Such increase in weight of 1000-seeds was associated with the increment in seed diameter. Seed size character is very important for global market demand for quinoa (Erazzú *et al.*, 2016).

Regarding planting density effects on seed chemical composition and its mineral contents (Table 1 and Fig. 2), it is clear that protein and ash concentrations in seeds increased at low planting density, whereas carbohydrate concentration decreased. The obtained results are in coincidence with Rahman and Hossain (2011). They reported that increasing plant density led to decrease protein content in soybean seeds while reverse occurred for seed yield. However, there were no significant differences between the two planting densities on the seed concentration of the crude fiber or total fat (Table 1). Regarding effects of planting density on mineral content in quinoa seeds, the calcium and magnesium contents significantly increased at low density compared with high planting density. Meanwhile, no significant effects of plant density on phosphorus, potassium, iron and zinc contents in quinoa seeds. In contrast, Erazzú *et al.* (2016) indicated that phosphorus content was higher with low planting density of 7 plants/m<sup>2</sup> than planting density of 46 plants/m<sup>2</sup>.

Protein and mineral contents in quinoa seeds are very important constituents in commercial value. However, the researches concerning the effects of plant density on quinoa seed components are very inadequate.

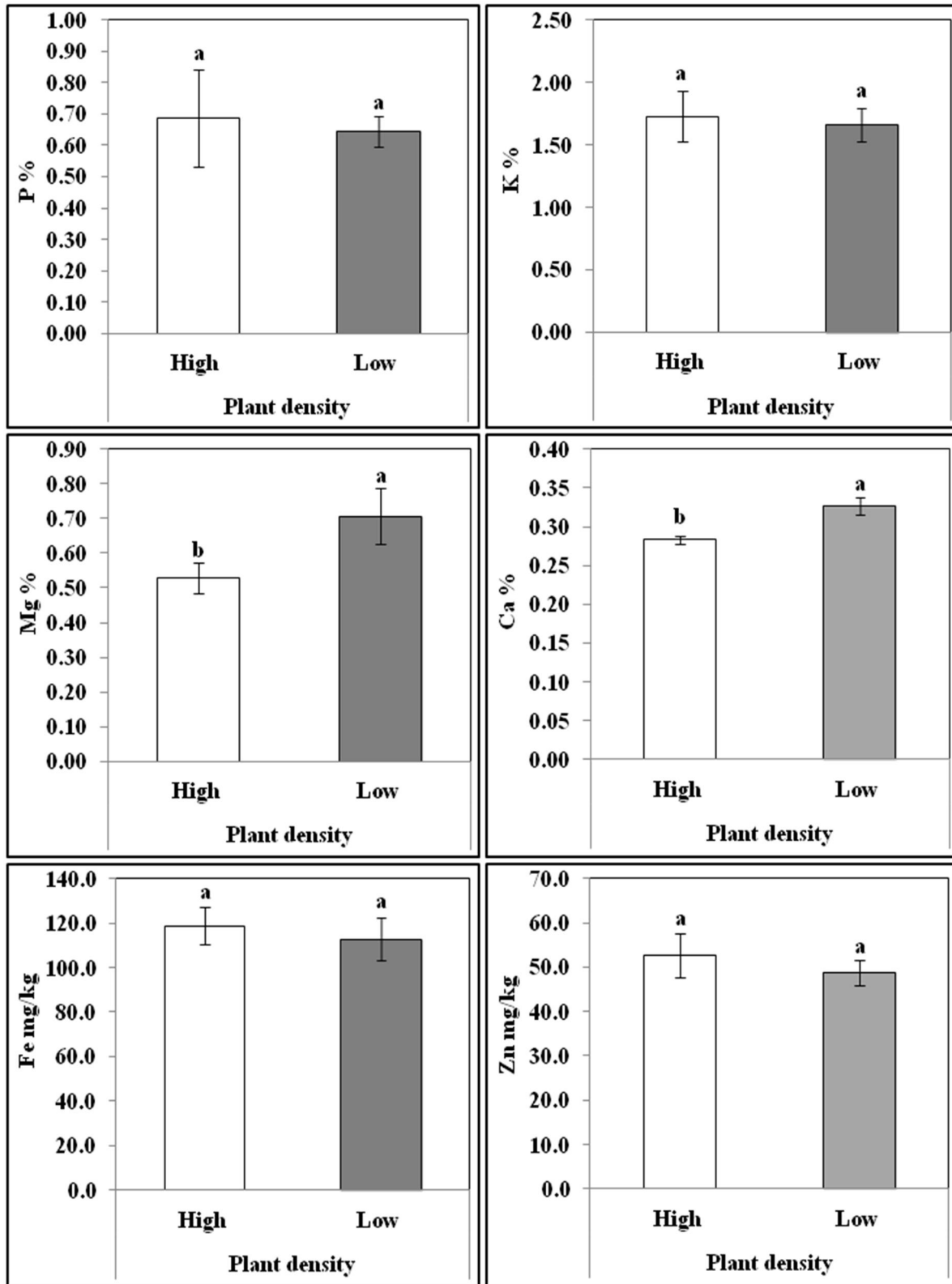
**Table 1:** Effects of planting density (low, 56.000 and high, 167.000 plant ha<sup>-1</sup>) on seed quality of quinoa cv. CICA grown in marginal conditions in Egypt. Combined data for both seasons of 2015/2016 and 2016/2017.

%						
Plant density	Moisture	Protein	Carbohydrate	Fiber	Ash	Fat
<b>High</b>	8.92 b ± 0.04	12.26 b ± 0.06	67.95 a ± 0.22	2.49 a ± 0.11	3.83 b ± 0.29	4.55 a ± 0.05
<b>Low</b>	9.18 a ± 0.01	14.13 a ± 1.10	62.61 b ± 1.06	2.49 a ± 0.09	6.20 a ± 0.35	5.39 a ± 0.01

Values represent mean + SD for six replicates per each planting density.

Means within each column followed by the same letter are not significantly different ( $P \leq 0.05$ ) according to Duncan's multiple range test.

Ultimately, it could be concluded that the above mentioned results of the present work indicated that quinoa seeds protein, ash, calcium and magnesium contents decreased, whereas, seed carbohydrate content increased, at the planting density that gives higher seed yield. Meanwhile, no significant effects of planting density on the contents of the crude fiber, total fat, phosphorus, potassium, iron and zinc in quinoa seeds.



**Fig. 2.** Effects of planting density (low, 56.000 and high, 167.000 plant ha<sup>-1</sup>) on seed mineral contents of quinoa plants cv. CICA grown in marginal conditions in Egypt. Combined data for both seasons of 2015/2016 and 2016/2017. Statistical significant differences between means ( $P \leq 0.05$ ) are indicated by different letters above columns according to Duncan's multiple range test.

## Acknowledgements

This research was partially supported by the Ministerio de Relaciones Exteriores y Culto, Buenos Aires, Argentina through the south-south cooperation project “Development of quinoa crop in marginal areas of Egypt”, FO.AR-6429 and Fundación Miguel Lillo, Tucumán, Argentina.

## References

- Abd El-Hamed, K. El-Sayed and M.W.M. Elwan, 2011. Dependence of pumpkin yield on plant density and variety. *Amer. J. Plant Sci.*, 2: 636-643.
- Abugoch, L., E. Castro, C. Tapia, M.C. Anón, P. Gajardo and A. Villarroel, 2009. Stability of quinoa flour proteins (*Chenopodium quinoa* Willd.) during storage. *Int. J. Food. Sci. Tech.*, 44: 2013-2020.
- AOAC, 1995. Official Methods of Analysis of AOAC International. 16<sup>th</sup> edition. Arlington, Virginia, 22201 USA.
- Beaman, A.R., R.J. Gladon and J.A. Schrader, 2009. Sweet basil requires an irradiance of biomass production. *HortSci.*, 44: 64-67.
- Bertero, H.D. and R.A. Ruiz, 2008. Determination of seed number in sea level quinoa (*Chenopodium quinoa* Willd.) cultivars. *Euro. J. Agronomy*, 28: 186-194.
- Brinegar, C., B. Sine and L. Nwokocha, 1996. High cysteine 2S seed storage proteins from quinoa (*Chenopodium quinoa*). *J. Agric. Food Chem.*, 44: 1621-1623.
- Carbone-Risi, J.J.M., 1986. Adaptation of the Andean grain crop quinoa for cultivation in Britain. PhD Thesis, University of Cambridge, Cambridge, UK.
- Casal, J.J., V.A. Deregibus and R.A. Sanchez, 1985. Variations in tiller dynamics and morphology in *Lolium multiflorum* Lam. vegetative and reproductive plants as affected by differences in red/far-red irradiation. *Ann. Bot. London*, 56: 533-559.
- Castellón, M., M. Silvia, B. Pilar and M. Sara, 2010. Protein deterioration and longevity of quinoa seeds during long-term storage. *Food Chem.*, 121: 952-958.
- 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.
- Chapman, H.D. and P.F. Pratt, 1982. Methods of plant analysis, I. Methods of analysis for soil, plant and water. Chapman Publishers Riverside California, USA.
- Choukr-allah, R., N.K. Rao, A. Hirich, M. Shahid, A. Alshankiti, K. Toderich, S. Gill and K.R. Butt, 2016. Quinoa for marginal environments toward future food and nutritional security in MENA and central Asia regions. *Front. Plant Sci.*, 7: 346.
- Cottenie, A., M. Verloo, L. Kickens, G. Velghe and R. Camerlynck, 1982. Chemical analysis of plant and soils. Laboratory of Analytical and Agrochemistry, State University, Chent, Belgium, pp. 63.
- Ebrahim, M.E.A., S.A. Hussin, A.A. Abdel-Ati, S.H. Ali and S.S. Eisa, 2018. Evaluation of some *Chenopodium quinoa* cultivars under saline soil conditions in Egypt. *Arab Univ. J. Agric. Sci.*, 26(1): 337-347.
- Eisa, S., M.A. Eid, E.H. Abd El-Samad, S.A. Hussin, A.A. Abdel-Ati, N.E. El-Bordeny, S.H. Ali, M.A. Al-Sayed, Hanan, M.E. Lotfy, A.M. Masoud, A.M. El-Naggar and M. Ebrahim, 2017. *Chenopodium quinoa* Willd. A new cash crop halophyte for saline regions of Egypt. *Aust. J. Crop Sci.*, 11: 343-351.
- Erazzú, L.E., J.A. González, S.E. Buedo, 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.
- Escuredo, O., M.I.G. Martín, G.W. Moncada, S. Fischer and J.M.H. Hierro, 2014. Amino acid profile of the quinoa (*Chenopodium quinoa* Willd.) using near infrared spectroscopy and chemometric techniques. *J. Cereal Sci.*, 60(1): 67-74.
- FAO (2013). Launch of the international year of quinoa: UN celebrates Andean super food. <http://www.fao.org/quinoa-2013/press-room/news/detail/en/>

- Francescangeli, N., M.A. Sangiacomo and H. Martí, 2006. Effects of plant density in broccoli on yield and radiation use efficiency. *Sci. Hort.*, 110: 135-143.
- Hirose, Y., T. Fujita, T. Ishii and N. Ueno, 2010. Antioxidative properties and flavonoid composition of *Chenopodium quinoa* seeds cultivated in Japan. *Food Chem.*, 119(4): 1300-1306.
- Johnson, D.L. and S.M. Ward, 1993. Quinoa p. 219-221 In: Janick, J. and J.E. Simon, (Eds.) *New Crops*, John Wiley & Sons Ltd, New York, USA.
- Koyro, H.W. and S.S. Eisa, 2008. Effect of salinity on composition, viability and germination of seeds of *Chenopodium quinoa* Willd. *Plant Soil*, 302: 79-90.
- Leskovar, D.I., L.A. Stein and F.J. Dainello, 2000. Planting systems influence growth dynamics and quality of fresh market spinach. *HortSci.*, 35: 1238-1240.
- Maradini-Filho, A.M., M.R. Pirozi, J.T.S. Borges, H.M.P. Santana, J.B.P. Chaves and J.S.D. Reis Coimbra, 2017. Quinoa: nutritional, functional and anti-nutritional aspects. *Crit. Rev. Food Sci. Nutr.*, 57: 1618-1630.
- Pourfarid, A., B. Kamkar and G.A. Akbari, 2014. The effect of density on yield and some agronomical and physiological traits of Amaranth (*Amaranthus spp*). *Int. J. Farm Alli Sci.*, 3(12): 1256-1259.
- Rahman, M.M. and M.M. Hossain, 2011. Plant density effect on growth, yield and yield components of two soybean varieties under equidistant planting arrangement. *Asian J. Plant Sci.*, 10(5): 278-286.
- Rahman, M.M., J.G. Hampton and M.J. Hill, 2005. Growth response of cool tolerant soybean to variation in sowing date. *Agron. New Zealand*, 35: 81-96.
- Risi, J. and N.W. Galwey, 1991. Effects of sowing date and sowing rate on plant development and grain yield of quinoa (*Chenopodium quinoa*) in a temperate environment. *J. Agric. Sci.*, 117: 325-332.
- Sangoi, L., M. Ender and A.F. Guidolin, 2000. Evolução da resistência a doenças de híbridos de milho de diferentes épocas em três populações de planta. *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.
- SAS, 1998. SAS User's Guide, ed. SAS Institute Inc. Cary, North Carolina, USA.
- Spehar, C.R. and J.E.S. Rocha, 2009. Effect of sowing density on plant growth and development of quinoa genotype 4.5, in the Brazilian Savannah highlands. *BioSci. J.*, 25(4): 53-58.
- Vega-Galvez, A., M. Miranda, J. Vergara, E. Uribe, L. Puente and E.A. Martinez, 2010. Nutrition facts and functional potential of quinoa (*Chenopodium quinoa* willd.), an ancient Andean grain: A review. *Soc. Chem. Ind.*, 90: 2541-2547.