INFLUENCE OF PLANT DENSITY ON GROWTH AND YIELD OF QUINOA (*Chenopodium quinoa* Willd.)

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INFLUENCE OF PLANT DENSITY ON GROWTH AND YIELD OF QUINOA (*Chenopodium quinoa* Willd.)

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CERTIFICATE

This is to certify that the thesis entitled **''INFLUENCE OF PLANT DENSITY ON GROWTH AND YIELD OF QUINOA (*Chenopodium quinoa* Willd.)''** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN AGRONOMY**, embodies the result of a piece of *bona fide* research work carried out by **LOPA RANI GHOSH**, Registration number: **14-05862** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information as has been availed of during this investigation has duly been acknowledged.

Dated:

Dhaka, Bangladesh

Prof. Dr. Parimal Kanti Biswas

Supervisor

DEDICATED TO MY BELOVED PARENTS

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The Author

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ABSTRACT

The experiment was carried out in Sher-e-Bangla Agricultural University during the period from November 2019 to February 2020 to evaluate the influence of plant density on growth and yield of quinoa. The experiment was laid out in a Randomized Complete Block design (factorial) with three replications having three rows spacing as 30 cm (L_1), 40 cm (L_2) and 50 cm (L_3) and four plant spacing as 15 cm (P_1), 20 cm (P_2), 25 cm (P_3) and 30 cm (P_4). Data on different growth parameters, yield components and yield were recorded. The collected data were statistically analyzed. Seed yield, straw yield and biological yield were significantly affected by closer row spacing (L_1) but plant height, number of branches plant^{-1}, number of leaves plant^{-1}, dry weight plant^{-1}, effective inflorescences plant^{-1}, ineffective inflorescences plant^{-1}, seed weight plant^{-1}, husk weight plant^{-1}, 1000-seed weight and harvest index were not significantly affected by row spacing. For plant spacing, 1000-seed weight, seed yield, straw yield, biological yield and harvest index were not significantly affected but all other parameters significantly influenced by plant spacing. Results showed that the highest plant height (67.96 cm at 50 DAS), number of leaves plant^{-1} (16.17 at 25 DAS), number of branches plant^{-1} (1.26, 11.44, 16.00 at 25, 50 and at harvest, respectively), effecetive inflorescences plant^{-1} (16.13), seed weight plant^{-1} (11.33 g), dry weight plant^{-1} (0.17 g at 30 DAS), ineffective inflorescences plant^{-1} (1.42), husk weight plant^{-1} (2.61 g) were recorded from wider spacing of P_3 and lowest ineffective inflorescence plant^{-1} (0.70) was found from plant spacing of P_4. Considering interaction effect of row and plant spacing, 1000-seed weight was insignificant but all other parameters were significantly affected where the highest seed yield (2.15 t ha^{-1}) and straw yield (1.59 t ha^{-1}) was recorded in lower row spacing 30 cm (L_1) with 20 cm plant spacing.

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ABBREVIATIONS AND ACRONYM

AEZ	=	Agro-Ecological Zone
BV	=	Biological value
cm	=	Centimeter
CV %	=	Percent Coefficient of Variation
DAS	=	Days After Sowing
dS/m	=	Deci Siemens per metre
e.g.	=	exempli gratia (L), for example
et al.,	=	And others
etc.	=	Etcetera
EC	=	Electrical conductivity
FAO	=	Food and Agriculture Organization
g	=	Gram
GF	=	Grain filling period
GYP	=	Grain yield per plant
i.e.	=	id est (L), that is
IYQ	=	International year of quinoa
Kg	=	Kilograms
LSD	=	Least Significant Difference
M.S.	=	Master of Science
m^2	=	Meter squares
NaCl	=	Sodium Chloride
No.	=	Number
%	=	Percentage
SAU	=	Sher-e-Bangla Agricultural University
WHO	=	World Health Organization

CHAPTER I

INTRODUCTION

Quinoa (*Chenopodium quin*oa Willd.) is an annual dicotyledonous herbaceous crop of the Amaranthaceae family. It is a grain crop (Pseudocereal) that is grown for its edible seeds and pronounced as KEEN-Wah. It has been cultivated in Andean region including Bolivia, Peru, Chile, and Ecuador for 7000 years and now in other countries (about 95) of the world (FAO, 2013). At global level, there are more than 6000 varieties of quinoa cultivated by farmers (Rojas *et al*., 2015). *Chenopodium quinoa* Willd., a high-quality grain crop, is resistant to abiotic stresses (drought, cold and salt) and adapted to diverse agroecological condition worldwide (Ruiz *et al*., 2014).

From at least 7000 years ago until the beginning of the 1980s, quinoa has only been connected to the Andes & in Inka (ruling) peoples. The number of countries growing quinoa rapidly from 8 in 1980 to 75 in 2014, with further 20 countries which showed quinoa for the first time in 2015 (Bazile and Baudron, 2015).

Today, cultivated *Chenopodium* – especially *C. quinoa* – are gaining importance due to the excellent quality of their proteins (good balance of all amino acids) and their high content of a variety of minerals and vitamins (Vega-Galvez *et al*., 2010).

Quinoa grains contain about 14% protein, 6.3% fat, 64% carbohydrate. It is good source of B vitamins, riboflavin, folic acid, P, K, Mn, Cu, Fe & Zn compared to other grains (Greg and David, 1993). Quinoa seeds are gluten free and low glycemic index (53) compared to that of white rice (73) which favors for diabetic patients as well as for obesity (Atkinson *et al*., 2008).

For human and animal nutrition the quality of protein is determined by its biological value (BV), which serves as an indicator of protein intake by relating nitrogen uptake to nitrogen excretion. The highest value of BV corresponds to proteins of whole egg (93.7%) and cow milk (84.5%). The protein of quinoa has a

BV of 83% which is higher than that of fish (76%), beef (74.3%), soybean (72.8%), wheat (64%), rice (64%) and corn (60%) proteins. According to the FAO/WHO nutritional requirements for 10-12 -year -old children the protein of quinoa possesses adequate levels of phenylalanine, tyrosine, histidine, isoleucine, threonine, and valine. For its credentials in nutritional composition and relevance, it was selected by NASA as a preferred food for its astronauts on board space missions (Gonzales *et al*., 2012). Quinoa leaves can be eaten as a leaf like an amaranth, grain quinoa can be used inside dishes similarly to rice, flaked as a breakfast cereal, added to snack foods and pasta. Quinoa is gluten free (Bhathal *et al*., 2018) and easy to digest.

Quinoa constitutes a strategic crop with potential to contribute to food security and sovereignty due to nutritional quality, genetic variability, adaptability to adverse climate and soil conditions and low production cost. The cultivation of quinoa provides an alternative for countries with limited food production, especially in countries where the population has no access to protein sources or where production conditions are limited by low humidity, reduced availability of inputs and aridity.

The thirty-seventh session of the General Conference of FAO adopted a resolution recommending the declaration of 2013 as the International Year of Quinoa. Quinoa’s genetic diversity can play in terms of world food security and the eradication of extreme poverty and hunger thus contributing to the Millennium Development Goals-MDG’s (PRONIPA, 2011).

Quinoa is a strategic crop in the Andean region that can grow under diverse agroecological zones (coastal, valley, highlands, salt flats, and sub tropic) and is tolerant to frost, salinity, and drought (Jensen *et al*., 2000; Jacobsen *et al*., 2005; Adlof *et al*., 2013; Tapia, 2014). It can be grown from about sea level up to 4000 m and withstand temperature extremes -4 to 38 degree Celsius. It is a facultative halophytic plant species with varieties being able to cope with salinity levels as high as those present in sea water electrical conductivity (EC) of approximately 50 dS/m (corresponding to about 600 mM NaCl). Quinoa has an exceptional capacity to grow in water-deficient soil due to its inherent low water requirement and the ability to resume its photosynthetic rate and maintain its leaf area after a period of drought (Gonzales *et al*., 2012). This crop has the potential to ameliorate global challenges with respect to increase in global population, effects of climate change, desalinization, phytoremediation, satisfying nutrient deficiency and alleviating poverty.

Plant density is an important agronomic factor that manipulates microenvironment of the field and affects growth, development, and yield formation of crops. Within certain limits, increase of plant density decreases the growth and yield per plant but reverse occurs for yield per unit area (Caliskan *et al*., 2007). Seed yield of quinoa increased by 34.7% with increase of plant density from 56.000 plant ha^{-1} 167.000 plant ha^{-1}. The increase of plant density significantly decreased weight of 1000-seed 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 (Gonzalez, 2018).

As quinoa is a new crop in Bangladesh it is urgent need to find out the optimum plant population for its maximum yield. The present study was undertaken with the following objectives:

i. To determine the optimum row spacing of quinoa.
ii. To find out the optimum plant spacing of quinoa.
iii. To determine the interaction effect of row and plant spacing on growth, yield and other crop characters of quinoa.

CHAPTER II

REVIEW OF LITERATURE

In this chapter an attempt has been made to review the pertinent literature on the influence of plant density on growth, yield attributes, yield of quinoa, which is related to the present investigation.

2.1 Plant density

A study was conducted by Zulkadir (2021) to evaluate row spacing and sowing date of Quinoa suitable for Mediterranean climate condition, in Kahramanmaras. Four sowing dates 15-days interval between March 15 and May with (20,40 and 60 cm) row spacing. The study demonstrated that the plant emergent at 5.0-21.0 DAS, 50% flowering period at 44.7- 67.3 DAS, grain- filling period (GF) at 3.2 - 31.0 DAS, the grain yield 9.8-323.9 kg ha^{-1}. It was concluded that early or late April sowing, highest grain and plant yield obtained at 20 cm spacing.

Geren *et al*. (2015) recommended that row spacing of 20 cm-60 cm led to change in yield 221.655-69.776 kg day^{-1}. It was suggested that decrease in number of plants led to decrease grain yield.

Hirich *et al*. (2014) explained that temperature affect the plant emergence period. They analyzed that longer emergence period observed in March due to maximum and minimum temperature induced the later germination of plant. On the contrary, high temperature affect the seedling development and emergence period in May, which enhanced weed growth in this period.

Christiansen *et al*. (2010) reported that later sowing date and longer day gets the grain filling period longer. while the impact of row spacing on grain filling, it was demonstrated that the shoot did not develop in dense sowing (20 cm spacing) and 40 cm row spacing was the ideal for grain filling.

Two different experiments were carried out by Dao *et al*. (2020) in Burkina Faso to observe the performance of different genotypes (Titicaca, Puno, Pasankalla and Negra Collana) to multiple planting methods (ridges, dibbling, broadcasting, transplanting, traditional-pits, and flat sowing) and sowing density rates (from 80,000 to 200,000 plants ha^{-1}). The results showed significant differences among genotypes in terms of growth attributes, with higher yields when sown in ridges (10.7, 8.4 and 5.7 g $plant^{-1}$ of Puno, Pasankalla and Titicaca, respectively). In addition, higher yields were observed under low density rates, with plant spacing being compensated by changes in branch system. However, higher yields were reported per unit area (Titicaca with 98.8 g m^{-2}) under high density treatments (200,000 plants ha^{-1}). As a conclusion, the use of short cycle varieties (Titicaca and Puno) sown in ridges at high density rates was recommended.

Plants develop a wider but less compacted panicles among largely spaced plants. In this case, plants are displaying an intermediate shape between glomerulate (compacted) and Amaranti form (loose) panicles (Rojas *et al*., 2015).

Jacobsen (2015) highlights the ability of quinoa to compensate the remaining spaces between plants by changing the agro-morphological structure of its branches. Other studies in tropical environments, show a decrease in plant height with an increase in plant density (from 100,000 to 600,000 plants ha^{1}), and an increase of the branching system under low sowing density rates (Spehar and Rocha, 2009). Similar pattern was realized with Titicaca and Negra Collana having the highest plants under low sowing density rates.

This research findings show more productive plants per unit area (e.g., Titicaca with 98.8 g m^{-2}) at high density rates (D_1: 200,000 plants ha^{-1}); but not in terms of GYP, with highest GYP under low density rates. This relationship (between production per unit area and density rate) was evident for Titicaca, but not as strong for Negra Collana nor Pasankalla. However, as highlighted by Jacobsen

(2015), relatively high-density rates were preferred to secure uniform plants and similar time to maturity. High plant density rates can also slow down and prevent the development of diseases (Gandarillas *et al*., 2015).

Large distance between plants (20 and 25 cm) resulted in a differentiated architecture of the branching system, with a typically branch to second third panicle as described by Rojas and Pinto (2013).

Other studies confirm that the optimum sowing density rates for obtaining the highest yields was 70-140 plants m^{-2}, with 12.5 cm row spacing and the equivalent of 8-10 kg seeds ha^{-1} (Piva *et al*., 2015). However, drawbacks of high-density rates emerge in those locations where sowing, harvesting, thinning and weeding was done mechanically, as the distance required for preparing the furrows is approximately 80 cm (Peralta *et al*., 2012).

In general, a common response of plants is to grow new branches in existing gaps. This is because canopy gaps and changes in red/far-red ratios of light are reflected by neighboring plants. Therefore, it increases stem elongation properties besides affecting branch orientation. These results are in harmony with those reported by Risi and Galwey (1991), showing an increase in the number of branches under low density rates for Amarilla de Marangani, Blanca de Junin and Baer.

A field experiment was carried out at EI-Fayoum oasis marginal land in Egypt during 2015-2016 to investigate plant density effects on seed yield and nutritional quality of quinoa in marginal regions of Egypt. The obtained result showed that the seed yield per hectare under high density significantly increased by 34.7% as compared with the low planting density. Ebrahim *et al*. (2018) studied reported that higher plant density increases seed yield per area that mainly contributed to reduce branching and produced higher proportion of seed yield from main panicle while, lower plant density led to increase of plant branching and around 50-60% of seed yield produced by secondary panicles.

Erazzu *et al*. (2016) found that increasing plant density from 70,000 to 460,000 ha^{-1} led to decrease grain yield from 5,389 to 3,049 kg ha^{-1}. They also found that protein and ash concentration in seeds increased at low planting density whereas carbohydrate concentration decreased. In contrast with Rahman and Hossain (2011) they indicated that phosphorous content was higher with low planting density of 7 plants/m^2 than 46 plants /m^2.

Spehar and Rocha (2009) studied the increasing effect of plant densities (100,000-600,000 plants ha^{-1}) on quinoa genotype 4.5 in Brazilian Savannah conditions and they found that increasing plant density resulting non -significant effects on 1000-seed weight, biomass, and grain yield, whereas low plant density increase 1000-seed weight.

Risi and Galwey (1991) reported that higher plant density significantly decreased 1000-seed weight and weight of hectoliter and highest sowing rate (30 kg seed/ha) produced a higher seed yield.

A field experiment was conducted by Pourfarid *et al*. (2014) at college farm, college of Agriculture, Hyderabad, India during 2015-2016 to evaluate Quinoa at different dates of sowing and planting density in semi -arid regions of Telangana. They reported that the number of panicles per plant recorded at 60cm × 10cm (15.6) and 45cm×10cm (14.7) which were significantly higher than 15cm × 10cm (9.9) and 30cm × 10cm (12.0). They also found that spacing of 15cm ×10 cm recorded higher panicle weight (677.9 gm^{-2}), seed yield (2070 kg ha^{-1}) and stalk yield (2417 kg ha^{-1}) which were significantly higher than above other spacing. Protein content of Quinoa insignificant with the spacing. Nevertheless, protein content higher at 30cm×10cm (14.0%) spacing and similar with the 15cm×10cm (13.8%), 45cm×10cm (13.9%), 60cm×10cm (13.8%) spacing. Seed yield of Quinoa decreased with the increased crop spacing from narrow (15cm×10cm) to wider (60cm×10cm). The experiment revealed that the 15

October date of sowing, dibbling method of sowing and the drip irrigation method logged higher growth, yield, and yield attributes of Quinoa.

Field experiments were conducted at Ismailia Agriculture Research Station, Agriculture Research Center, Ismailia, Egypt for two winter successive seasons of 2012/2013., 2013/2014 to regulate the best planting procedures where three inter row spacing (20, 30 and 40 cm) and three intra plant spacing (10,15 and 20 cm) and their combination. Results showed that the highest grain yield of quinoa was produced when using the narrowest inter spaces of rows (20 cm) and the narrowest intra spaces of plants (20 cm) with substantial interaction effect in each of the two seasons. This result could be accepted due to the well even dispersal of plants, which reduced the competition for all prevailing enormous essential requirements of plants as germination, seed emergence, growth and development, which reflected on production and quality. A significant reduction of grain yield was obtained by increasing intra spacing between plants i.e.,10, 15, 20 cm. This reduction was noticed only at the lowest inter spacing of rows at 20 cm. Though, at wider inter spaces of plant i.e., 30 and 40 cm, increases of intra spaces between plants i.e.,10, 15 and 20 cm cause sub stand increase in grain yield in the first and second seasons with significant differences in the first seasons. It could be concluded that the best treatment for growing quinoa produced from the inter and intra spacing were the lowest spacing. This may be accredited to the appropriate distribution of plants, which decrease competition among plants and allows it to maximum were of the circumstance surrounding it in the caption (Sief *et al*., 2015).

Quinoa is a pseudo-cereal crop with high potential and is considered as an alternative cash crop in lowland area of Chiang Mai-Lumphun valley. However, no existing understanding of how a selected variety responds to management at the field level. Five quinoa varieties were planted in the plants nursery to test emergence percentage. Temuco has shown the maximum percentage of emergence at 59.8% among another four varieties, namely, Cherry Vanilla (48.5%), Rainbow (27.7%), Brilliant Bright Rainbow (22.3%) and Black quinoa (3.5%). Temuco variety was selected for further testing of its responses to plant spacings. A randomized complete block design having three spacing treatments with four replications was used in the study. The spacings included 30x10, 40x10, and 50x10 cm (row x between plants). The three-week old seedlings were transplanted to the plot to investigate dry weights of different plant parts namely leaves stems, seeds, inflorescences, and total plant dry weights. Plant total dry weights were 15,267 kg ha^{-1}; 9,938 kg ha^{-1}; and 10,560 kg ha^{-1} for the 30, 40 and 50 cm plant spacing treatments, respectively. Seed dry weight also showed that the 30 cm plant spacing treatments produced the highest seed dry weight of 7,067 kg ha^{-1}, whereas the 40 and 50 row spacing treatments produced 4,400 and 5,520 kg ha^{-1}, respectively.

Dry weights of the quinoa variety (Temuco) as affected by the three row spacing treatments at Mae Hia Agricultural Research and Training Center, Chiang Mai, Thailand. Growing duration 92 days from 30th November 2013 to 6 February 2014. Seed dry weight of the 30 cm row spacing was approximately 7,000 kg DM ha^{-1}, which was close to that was obtained in Peru (7,500 kg DM ha^{-1}). Therefore, Temuco quinoa variety and the 30 cm row spacing could be used to conduct field experiments in Chiang Mai-Lumphun valley to get better understandings of other agronomic practices. The be obtained data set could be useful for commercial purposor subsistence for small-scale farmers (Suracheth, 2014).

Temuco quinoa originates from lowland/ coastal areas in Chile where the average humidity is 79.6%, and the average cold and warm temperatures are between 6.6°C to 17.4 °C. According to the emergence percentage test carried out between the end of rainy season and beginning of winter in northern Thailand which was the time that had high humidity and cool weather in the morning. This might be the reason why emergence percentage of Temuco was highest. Conclusions and Suggestions Growing quinoa in Chiang Mai lowland with three row spacing treatments has shown high potential for introduction and domestication. The Temuco variety was grown in 30 cm row spacing in lowland Chiang Mai, Thailand. Additionally, there were several factors that affect the emergence percentage such as photoperiod and temperature (Bertero *et al*., 2001).

The highest seed yield of quinoa was reported as 6,960 kg ha^{-1} in row spacing of 20 cm with a sowing density of 20 kg seed ha^{-1} (Risi and Galwey, 1991).

Bhargava *et al*. (2007) conducted an experiment at NBRI, Lucknow, India to evaluate the effect of sowing date and row spacing on yield and quality components of quinoa. Results revealed that highest foliage yield was obtained in increasing row spacing at maximum 25 cm for 15 Nov. sowing date. Lowest yield was obtained on 15 December for all the spacing. Maximum protein content was observed at 15 cm spacing for 30 Nov. sowing date. Protein content lowest in the plant at 25 cm spacing for all the sowing date. Increasing row spacing decreased carotenoid content for all the sowing date. Too early or late planting showed lowest carotenoid in quinoa.

Sardana and Narwal (2000) obtained similar results while working on berseem, another forage crop. Foliage yield generally increased with increase in row spacing and was maximum at 25 cm spacing. In 2003-04, this increase was approximately 53,75 and 2.3% for first, second and third cutting respectively for 25 cm spacing as compared to 15 cm. The same trend was observed in 2004-05 for 25 cm spacing, although the increase was considerably less. Thus, the plant distribution provided by wider rows is more beneficial when the occurrence of low temperatures imposes limitations on biomass production.

In both the experimental years, maximum protein content was observed in the second sowing date at 15 cm spacing. The mean protein content of the 4 harvests was minimum for the 15 December sowing date in all row spacings for both the years. Higher protein content in narrow row spacings has been earlier reported in other forage crops like mott elephant grass (Yasin *et al*., 2003).

2.2 Nutrition

Parul *et. al*. (2021) conducted research on Quinoa and reported that it is a highly nourishing pseudo cereal with high significance in healthy daily lifestyle. Because of India's sole set of issues such as malnutrition, nutrition imbalance in diet, health of newborn unhealthy child and lactating mothers, thrilling whether events such as drought etc. Quinoa presents its claim to be adopted in the staple diet of the people of this sub-continent. This review paper studies the nutritional properties of *Chenopodium quinoa* Willd. and its suitability to the Indian population in their diet.

The Population of India had 21.9% people living below poverty line (Census of India, 2011). Relevant data for the population of India (specifically Children below age 5) was given as below (Aijaz, 2017) for the period of 2015-16. The population of India tolerates the burden of 24% of world's malnourished population and 30% of world's underdeveloped population of children under the age of 5 (Global Nutrition Report, 2018). This problem of malnutrition is triggering numerous diseases in the population affecting their quality of their life. Maximum of them is from the below poverty line population (Global Hunger Report, 2020) which barely gets two squared meals to satisfy their hunger. Quinoa has the potential of mitigating malnutrition problem in India.

Quinoa seeds have the perfect balance of amino acids rich in thionic amino acids and lysine, making quinoa to be among the few crops that supply almost all the amino acids necessary for human life. As such, contrary to most cereal, quinoa, high in most amino acids especially in lysine and its proteins are accepted as high-quality proteins (Filho *et al*., 2017; Kakabouki *et al*., 2018).

Pereira *et al.* (2019) reported that quinoa as the excellent choice for the consumers diet showing not only an exceptional nutritional profile but also a composition in molecules of high interest, such as, tocopherols and organic acids, which promotes bioactive benefits for the organism. Hence the vastness of quinoa in terms of nutrition compared to other crops has recently been known by scientists and researchers, and the demand for quinoa has increased over the years, more especially in the developed countries where people are more conscious of the food they eat and how important diet is to their health (Maliro and Guwela, 2015).

Numerous findings have shown that Quinoa has mineral and vitamin which makes the absorption of proteins from grains more effective and suitable, as fruits complement grains, thus making quinoa a good package for consumption (Minocha, *et al*., 2017). The primary vitamins and minerals present are magnesium, iron, B group vitamins, Iron potassium, calcium, phosphorus and vitamin E. The exceptional quality of this grains is its high anti-oxidant nature (Filho, 2017).

CHAPTER III

MATERIALS AND METHODS

The present investigation entitled **"**Influence of plant density on growth and yield of Quinoa" was carried out during Rabi season at the Agronomy field of Sher-e-Bangla Agricultural University, Dhaka-1207**.** The details of materials used, experimental procedures followed, and techniques adopted during investigation are being described in this chapter. Climatic and edaphic conditions prevailing during crop season, selection of site, cropping history of field and other experimental details are also being presented.

3.1 Location and time

The experiment was carried out at the Agronomy field under the Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka (90°35' E longitude and 23°77' N latitude) during the period from November 2019 to February 2020. As per the Bangladesh Meteorological Department, Agargaon, Dhaka-1207 the altitude of the location was 8 m from the sea level.

3.2 Weather and climate

The geographical location of the experimental site was under the subtropical climate, characterized by three distinct seasons, winter season from November to February and the pre-monsoon period or hot season from March to April and monsoon period from May to October (Edris *et al*., 1979).

3.3. Soil characteristics

The research work was conducted in a high land belonging to the AEZ 18. Madhupur tract (Tejgaon soil series). The structure of the soil was fine with an organic carbon content of 0.45%. The texture was silty clay with a pH of 5.6. The general soil type was non-calcareous dark grey. The experimental area was flat having available irrigation and drainage system and above flood level. The selected plot was medium high land. The experimental site has been presented in Appendix I.

3.4 Planting materials

Seeds of quinoa variety 'SAU Quinoa-1' was collected from Agronomy department of Sher-e-Bangla Agricultural University. Before sowing, the seed was tested for germination.

3.5 Germination test

Germination test was done before sowing the seeds in the field. Filter paper was placed on petridishes and the papers were soaked with water. Seeds were distributed at random in petridishes. The seed emergence was observed after 24 hours and completed by 48 hours. The percentage of germination was found to be over 80% for the variety.

3.6 Experimental treatments

The experimental treatments were as follows:

Factor A: Row spacing: 3

i. 30 cm (L_1)

ii. 40 cm (L_2)

iii. 50 cm (L_3)

Factor B: Plant spacing: 4

i. 15 cm (P_1)

ii. 20 cm (P_2)

iii. 25 cm (P_3)

iv. 30 cm (P_4)

3.7 Experimental design and layout

The experiment was laid out in a randomized complete block (factorial) design having three row spacing and four plant spacing with three replications. The experimental design has been shown in Appendix II.

3.8 Land Preparation

The experimental field was ploughed on 27th October 2019 with the help of a tractor drawn disc plough, later 1st November the land was irrigated and prepared by three successive ploughing and cross ploughing with a tractor drawn plough and laddering. All weeds were removed from the field. The field layout was made on 6th November 2019 according to experimental specification.

3.9 Crop establishment and management

Quinoa seeds were sown in the experimental plot on 6th November 2019 by line sowing method at a spacing of row-to-row distance (30 cm, 40 cm and 50 cm) and plant to plant distance (15 cm, 20 cm, 25 cm and 30 cm).

3.10 Management practices

3.10.1 Fertilizer application

Urea (150 kg N ha^{-1}), TSP (100 kg ha^{-1}), MoP (100 kg ha^{-1}), Gypsum (55 kg ha^{-1}) and $ZnSO_4$ (5 kg ha^{-1}) were used for this experiment. One third urea and the entire amounts of other fertilizers and cowdung (10 t ha ^{1}) was applied into the experimental field during final land preparation. Rest amount of urea was top-dressed in two equal installments at 25 and 45 days after sowing (DAS).

3.10.2 Weeding and irrigation

The crop was infested with some weeds during the early stage of crop establishment. First weeding was done at 15 DAS followed by second weeding at 30 DAS. Third weeding was done at 15 days after second weeding. To maintain optimum soil moisture all plots were irrigated as and when necessary. The first irrigation was done at 20 DAS followed by second irrigation at 30 DAS, third irrigation 45 DAS and fourth irrigation were done 20 days before harvesting.

3.10.3 Thinning

First emergence of Quinoa was observed at 24 hours of sowing. First thinning was done 15 DAS followed by final thinning at 25 DAS.

3.10.4 Pest and disease management

No pesticide and insecticides were applied as the crop was not infected by any insect pests and diseases.

3.11 Harvesting and processing

The experimental crop was harvested at maturity when 80% of the inflorescence turned reddish yellow in color. Harvesting was done in the morning. The crop was sun dried properly by spreading them over floor and seeds were separated from the inflorescence by beating the bundles with the help of bamboo sticks. The seeds thus collected were dried in the sun for reducing the moisture in the seed to about 9% level. The husk and straws were also dried in the sun and weight was recorded. The biological yield was calculated as the sum of the seed yield and straw yield.

3.12 Data collection

The following data on growth and yield of Quinoa were collected

1. Plant height at different days
2. Number of leaves plant $^{-1}$ at different days
3. Number of branches plant $^{-1}$ at different days
4. Dry weight plant^{-1} at different days
5. Effective inflorescences plant $^{-1}$
6. Ineffective inflorescences plant^{-1}
7. Seed weight plant^{-1}
8. Husk weight plant^{-1}
9. 1000- seed weight
10. Seed yield
11. Straw yield
12. Biological yield
13. Harvest index

3.13 Procedure of recording data

3.13.1 Plant height

Plant height was measured in centimeter (cm) by using a scale at 25, 50 DAS (days after sowing) and at harvest. The height of five tagged quinoa plants in net plot area was measured from the base of the plant to the tip of the plant and averaged.

3.13.2 Number of leaves plant^{-1}

Total numbers of leaves from five tagged plant of each plot was counted at 25, 50 DAS and at harvest and average was recorded as number of leaves plant^{-1}.

3.13.3 Number of branches plant^{-1}

The number of branches was counted and recorded from five tagged plant of each plot at 25, 50 DAS and at harvest. Average value was recorded as number of branches plant $^{-1}$.

3.13.4 Dry weight plant^{-1}

Dry weight of plant was recorded from five randomly selected plants of each plot at 30, 60 DAS and at harvest. Average value was recorded as dry weight plant^{-1}.

3.13.5 Effective inflorescences plant^{-1}

Effective inflorescence plant^{-1} was counted and recorded from five randomly selected plant of each plot at harvest. The inflorescence having seed was considered as effective one. Average value was recorded as effective inflorescence plant^{-1}.

3.13.6 Ineffective inflorescences plant^{-1}

Ineffective inflorescence plant^{-1} was counted and recorded from five randomly selected plants of each plot at harvest. The inflorescence having no seed considered as ineffective one. Average value was recorded as ineffective inflorescence plant^{-1}.

3.13.7 Seed weight plant^{-1}

Total weight of seed of five plants was weighed, averaged, and recorded as seed weight plant^{-1} in gram.

3.13.8 Husk weight plant^{-1}

Total weight of husk of five plants was weighed, averaged and recorded as husk weight plant^{-1} in gram.

3.13.9 1000- seed weight

The 1000 cleaned and dried seeds were counted manually from the seeds sample of each plot. The seeds were then weighed in an electrical balance. Finally, data were recorded in gram.

3.13.10 Seed yield

Total seed yield was weighed and recorded based on total harvested area plot^{-1} leaving the boarder lines and was expressed as t ha^{-1} basis.

3.13.11 Straw yield

Total straw yield was recorded based on total harvested straw plot^{-1} leaving the boarder lines and the straw of harvested area from each plot was sun dried and the weight of straw was taken and converted the yield as t ha^{-1} basis.

3.13.12 Biological yield

The summation of seed yield and straw yield was regarded as biological yield. The biological yield was calculated with the following formula:

Biological yield = Seed yield + Straw yield.

3.13.13. Harvest index

The harvest index was calculated by the ratio of seed yield to biological yield of quinoa for each plot and expressed in percentage.

$$\text{Harvest index (HI)} = \frac{\text{Seed yield}}{\text{Biological yield}} \times 100$$

3.14 Statistical Analysis

The data obtained for different parameters were statistically analyzed following computer-based software STATISTIX 10 and mean differences among treatments were tested with LSD test at 5% level of significance.

CHAPTER IV

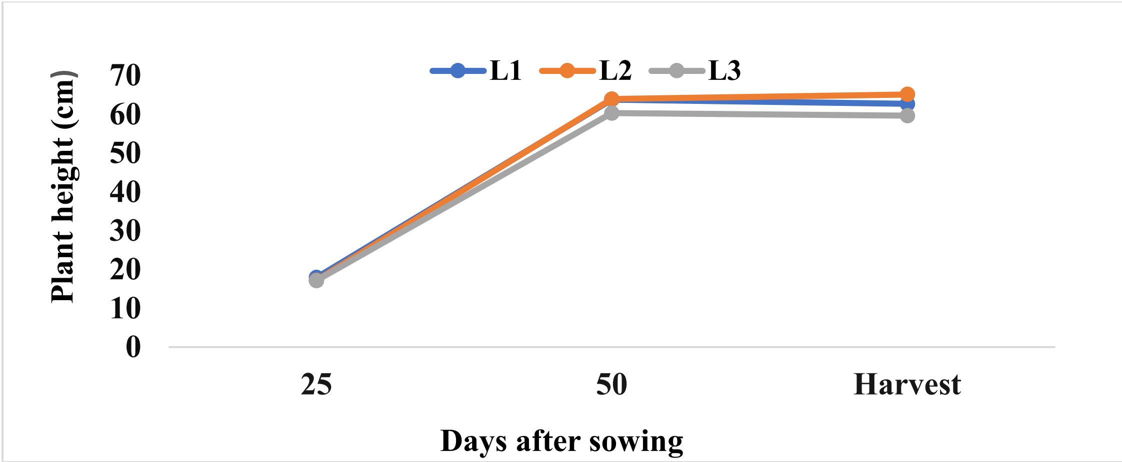
RESULTS AND DISCUSSION

The experiment was conducted to find out the influence of plant density on growth and yield of quinoa. The analyses of variance (ANOVA) of the data on different parameters are also given in the appendices. The results have been presented and discussed and possible interpretations have been given under the following headings:

4.1 Plant height

4.1.1 Effect of row spacing

There were no significant variations of plant height recorded for different row spacing (Figure 1 and Appendix III). At 25 DAS, no significant variations of plant height observed among the treatments though numerically maximum plant height (17.92 cm) recorded from closer row spacing (L_1) and the minimum plant height (17.16 cm) recorded from wider row spacing (L_3). Similar trend was also observed for other studied durations (50 DAS and at harvest). These results were similar with the findings of Spehar and Rocha (2009) who reported that plant height slightly decreased with widening distances between rows up to 40 cm apart but with insignificant difference for plant grown between 20 and 40 cm.

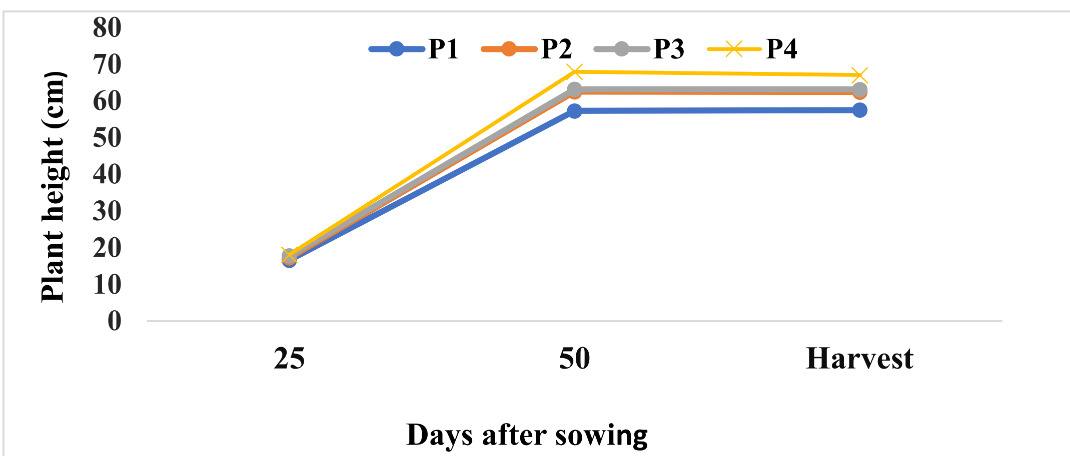


L_1 = 30 cm, L_2 = 40 cm, L_3 = 50 cm

Figure 1. Plant height of quinoa as influenced by row spacing ($LSD_{(0.05)}$ at 25, 50 DAS and at harvest = NS).

4.1.2 Effect of plant spacing

The result showed that the effect of plant spacing on plant height was significant at 50 DAS but insignificant at 25 DAS and at harvest (Figure 2 and Appendix III). At 50 DAS, the highest plant height (67.96 cm) recorded from wider plant spacing (P_4) which was statistically similar with the height of P_2 (62.52 cm) and P_3 (63.17 cm). The lowest plant height (57.23 cm) was recorded from closer plant spacing (P_1). Similar trend was observed in other durations.



P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm, and P_4 = 30 cm

Figure 2. Plant height of quinoa as influenced by plant spacing ($LSD_{(0.05)}$ at 25, 50 and at harvest = NS, 10.621, NS respectively).

4.1.3 Interaction effect

Interaction of row and plant spacing showed statistically significant effect on the plant height at 25, 50, and at harvest (Table 1 and Appendix III). At 25 DAS, the tallest plant (19.36 cm) was found in L_3P_4 which was statistically similar with all treatment except L_3P_1 (14.10 cm). The shortest plant (14.10 cm) was found in L_3P_1, which was statistically similar with L_2P_2 (15.94 cm), L_3P_2 (16.61 cm), L_1P_3 (16.73 cm), L_1P_4 (17.14 cm), L_2P_1 (17.21 cm), L_2P_4 (17.73 cm) and L_2P_3 (18.09 cm). At 50 DAS, the tallest plant (72.28 cm) was observed in L_2P_3, which was statistically similar with all treatment except L_3P_1 (46.33 cm) and L_1P_3 (51.32 cm). The shortest plant (46.33 cm) was observed in L_3P_1, which was statistically similar with L_1P_3 (51.32 cm), L_2P_2 (57.44 cm), L_2P_1 (58.61 cm), L_3P_2 (62.02 cm) except L_3P_3 (65.90 cm), L_1P_1 (66.76 cm), L_3P_4 (67.13 cm), L_2P_4 (67.51 cm), L_1P_2 (68.12 cm), and L_1P_4 (69.24 cm). At harvest, the tallest plant (74.27 cm) was obtained in L_2P_3, which was statistically similar with all treatment except L_3P_1 (44.46 cm) and L_1P_3 (50.06 cm). The shortest plant (44.46 cm) was obtained in L_3P_1, which was statistically similar with L_1P_3 (50.06 cm), L_2P_2 (58.40 cm) and L_2P_1 (61.00 cm).

Table 1. Combined effect of row and plant spacing on plant height of quinoa at different days after sowing

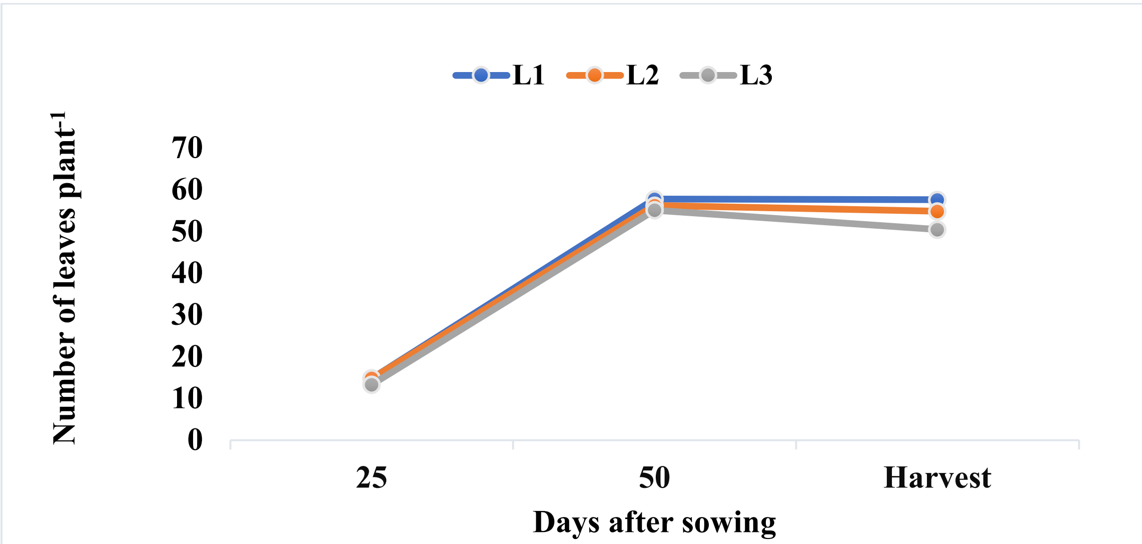
Treatments	Plant height (cm) at		
	25 DAS	50 DAS	Harvest
L_1P_1	18.48 a	66.76 ab	67.04 ab
L_1P_2	19.32 a	68.12 ab	65.93 ab
L_1P_3	16.73 ab	51.32 bc	50.06 bc
L_1P_4	17.14 ab	69.24 ab	67.70 ab
L_2P_1	17.21 ab	58.61 abc	61.00 abc
L_2P_2	15.94 ab	57.44 abc	58.40 abc
L_2P_3	18.09 ab	72.28 a	74.27 a
L_2P_4	17.73 ab	67.51 ab	67.00 ab
L_3P_1	14.10 b	46.33 c	44.46 c
L_3P_2	16.61 ab	62.02 abc	63.00 ab
L_3P_3	18.57 a	65.90 ab	65.07 ab
L_3P_4	19.36 a	67.13 ab	66.26 ab
LSD $_{(0.05)}$	3.263	18.396	18.364
CV (%)	10.91	17.10	17.12

L_1 = 30 cm, L_2 = 40 cm, L_3 = 50 cm, P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm, and P_4 = 30 cm

4.2 Number of leaves plant^{-1}

4.2.1 Effect of row spacing

Number of leaves plant^{-1} of quinoa at different growth stages had no significant variation for different row spacing because number of leaves for wider and closer spacing statistically similar (Figure 3 and Appendix IV). The numerically maximum number of leaves plant^{-1} (14.81, 57.75, 57.60 at 25 DAS, 50 DAS and at harvest, respectively) was observed from closer spacing (L_1) compared to wider spacing (L_3). The minimum number of leaves plant^{-1} (13.33, 55.11, 50.46 at 25, 50 and at harvest) was observed from wider spacing (L_3). Bhargava *et al.* (2006b) obtained similar trends while assessing leaf quality in *C. album* and *A. tricolor* respectively.

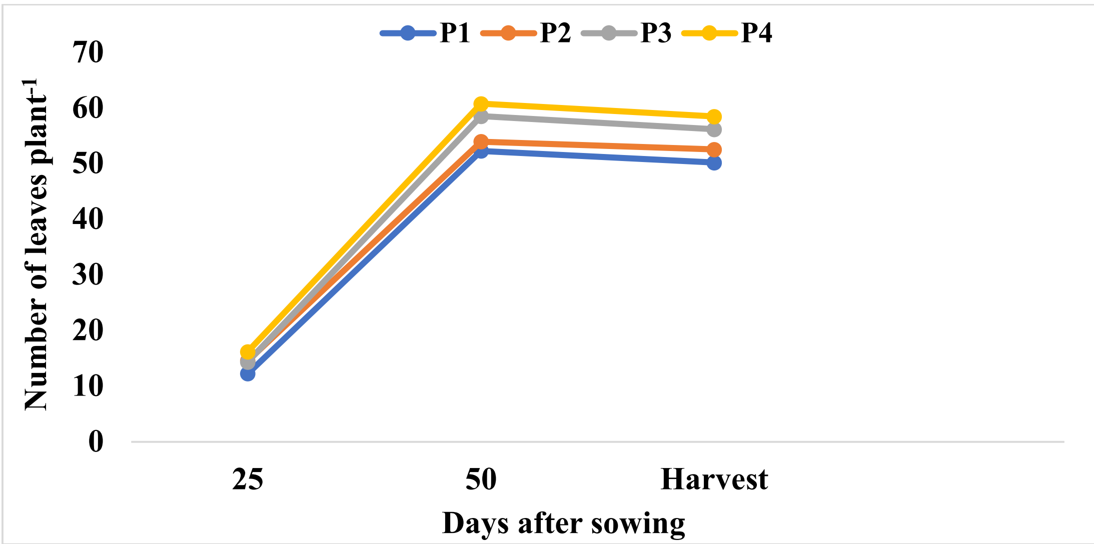


L_1 = 30 cm , L_2 = 40 cm , L_3 = 50 cm

Figure 3. Number of leaves plant^{-1} of quinoa as influenced by row spacing (LSD $_{(0.05)}$ at 25, 50 and at harvest = NS).

4.2.2 Effect of plant spacing

There was no significant variation observed on number of leaves plant^{-1} of quinoa at 50 and at harvest except 25 DAS (Figure 4 and Appendix IV). At 25 DAS, the highest number of leaves plant^{-1} (16.17) was recorded in wider spacing (P_4) which statistically similar with all treatment except closer spacing (P_1). The lowest number of leaves plant^{-1} (12.24) was found in closer spacing (P_1) which was statistically similar with the spacing of P_3 (14.33) and P_2 (14.53). At 50 DAS, the numerically highest number of leaves plant^{-1} (60.75) was recorded in wider spacing P_4 and lowest number of leaves plant^{-1} (52.26) in closer spacing P_1. At harvest, highest number of leaves plant^{-1} (58.42) in wider spacing in P_4 and lowest number of leaves plant^{-1} found in closer spacing of P_1. These results were similar with the findings of Bertero *et al*. (2001) who reported that the rate of leaf appearance was controlled by temperature and photoperiod.



P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm, and P_4 = 30 cm

Figure 4. Number of leaves plant^{-1} of quinoa as influenced by plant spacing (LSD $_{(0.05)}$ at 25, 50 and at harvest = 2.381, NS and NS respectively).

4.2.3 Interaction effect

The recorded data on number of leaves plant^{-1} was significantly influenced by interaction of row and plant spacing (Table 2 and Appendix IV). At 25 DAS, the highest number of leaves plant (18.26) was observed in L_1P_2 spacing which was statistically similar with L_2P_1 (13.60), L_3P_3 (14.40), L_1P_4 (15.73), L_2P_4 (16.00), L_2P_3 (16.66) and L_3P_4 (16.80). The lowest number of leaves plant^{-1} (9.80) observed in L_3P_1 which was statistically similar with L_1P_3 (11.93), L_3P_2 (12.33), L_2P_2 (13.00) and L_1P_1 (13.33). At 50 DAS, the highest number of leaves plant^{-1} (65.53) was recorded in L_2P_3 spacing which was statistically similar with all treatments except L_3P_1 (43.00). At harvest, the highest number of leaves plant^{-1} (66.66) was observed in L_2P_3 which was statistically similar with all treatment combinations except L_1P_3 (42.46) and L_3P_1 (45.53). The lowest number of leaves observed in L_1P_3 (42.46) which was statistically similar with L_3P_1 (45.53), L_1P_2 (49.53), L_2P_1 (51.60) and L_2P_2 (52.86).

Table 2. Combined effect of row and plant spacing on number of leaves plant^{-1} of quinoa at different days after sowing

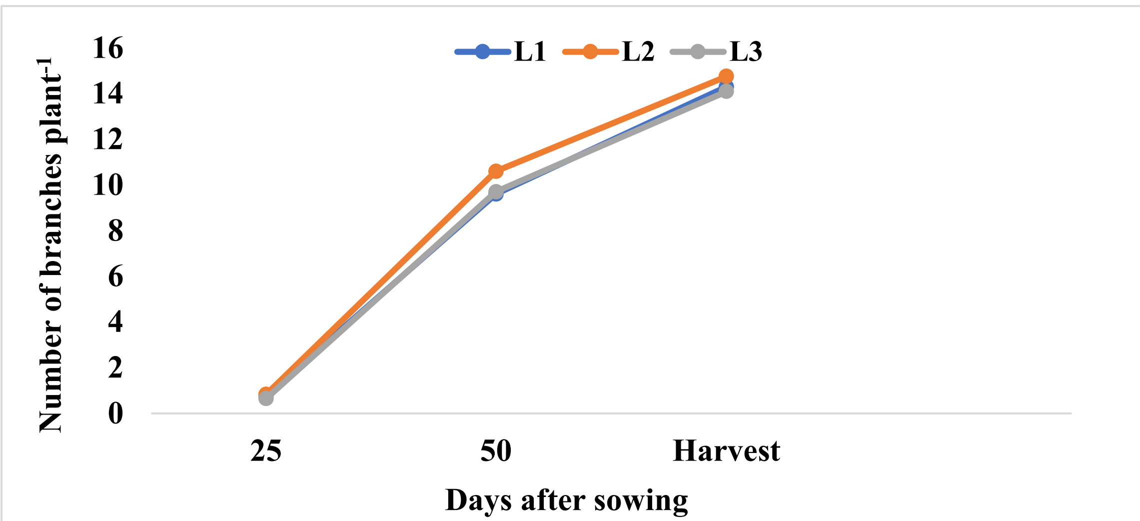
Treatments	Leaf no. plant^{-1} at		
	25 DAS	50 DAS	Harvest
L_1P_1	13.33 bcd	61.00 ab	53.26 ab
L_1P_2	18.26 a	60.66 ab	49.53 ab
L_1P_3	11.93 cd	48.80 abc	42.46 b
L_1P_4	15.73 abc	60.53 ab	56.60 ab
L_2P_1	13.60 abcd	52.80 abc	51.60 ab
L_2P_2	13.00 bcd	46.73 bc	52.86 ab
L_2P_3	16.66 abc	65.53 a	66.66 a
L_2P_4	16.00 abc	59.80 abc	59.26 ab
L_3P_1	9.80 d	43.00 c	45.53 b
L_3P_2	12.33 cd	54.40 abc	55.13 ab
L_3P_3	14.40 abc	61.13 ab	59.26 ab
L_3P_4	16.80 ab	61.93 ab	59.40 ab
LSD $_{(0.05)}$	4.124	17.304	16.373
CV (%)	16.79	17.90	17.58

L_1 = 30 cm, L_2 = 40 cm, L_3 = 50 cm, P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm, and P_4 = 30 cm

4.3 Number of branches plant^{-1}

4.3.1 Effect of row spacing

There were no significant variations in number of branches plant^{-1} of quinoa recorded for different row spacing (Figure 5 and Appendix V). At 25 DAS, no significant variations of number of branches plant^{-1} observed among the treatments however numerically maximum number of branches plant^{-1} (0.83) recorded from closer row spacing (L_2) and the minimum number of branches plant^{-1} (0.65) recorded from wider row spacing (L3). Similar trend was also observed for other studied durations (50 DAS and at harvest). Spehar and Rocha (2009) found the increase of the branching system under low sowing density rates.

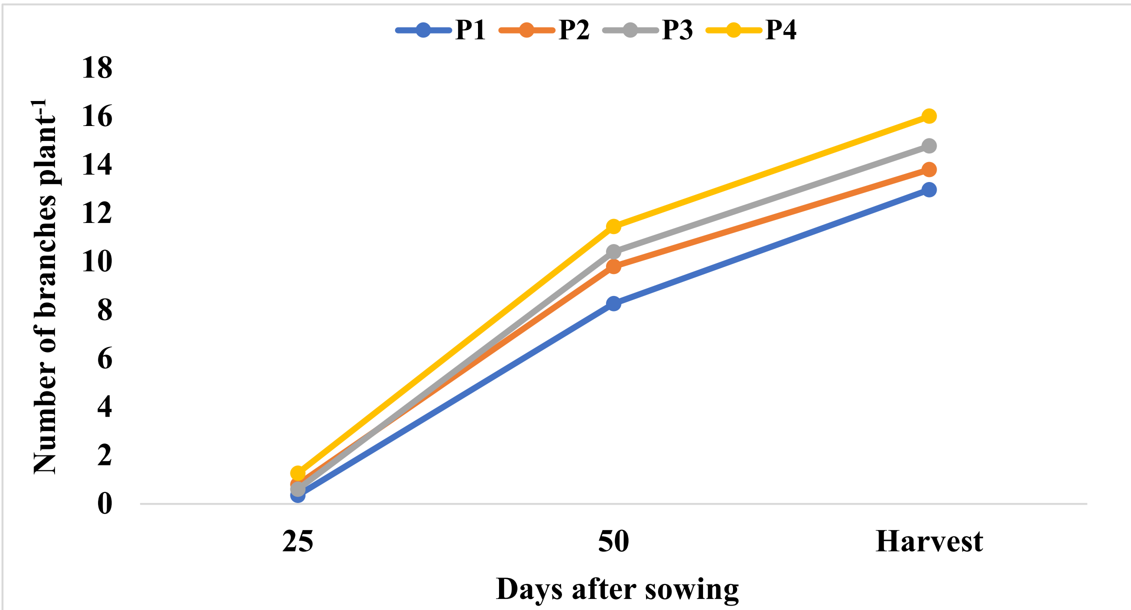


L_1 = 30 cm, L_2 = 40 cm, L_3 = 50 cm

Figure 5. Number of branches plant^{-1} of quinoa as influenced by row spacing (LSD $_{(0.05)}$ at 25, 50 and at harvest = NS).

4.3.2 Effect of plant spacing

Number of branches plant^{-1} of quinoa was significantly influenced by plant spacing (Figure 6 and Appendix V). At 25 DAS, the highest number of branches plant^{-1} (1.26) was recorded from wider spacing (P_4) which was statistically similar with closer spacing P_1 (0.35), P_3 (0.60) and P_2 (0.80). At 50 DAS, the highest number of branches plant^{-1} (11.44) was recorded in wider spacing of P_4 and lowest number of branches plant^{-1} (8.26) in closer spacing of P_1. At harvest, the highest number of branches plant^{-1} (16.00) was recorded in wider spacing (P_4) and lowest number of branches plant^{-1} (12.97) in closer spacing (P_1).



P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm, and P_4 = 30 cm

Figure 6. Number of branches plant^{-1} of quinoa as influenced by plant spacing (LSD $_{(0.05)}$ at 25, 50 and at harvest = 0.703, 2.733, 2.114, respectively).

4.3.3 Interaction effect

Combination of row and plant spacing significantly influenced number of branches plant^{-1} (Table 3 and Appendix V). At 25 DAS, no significant variations of number of branches plant^{-1} observed among the treatment combinations. However numerically maximum number of branches plant^{-1} (1.60) recorded from L_2P_4 spacing and the minimum number of branches plant^{-1} (0.00) recorded from L_3P_1 spacing. At 50 DAS, the highest number of branches plant^{-1} (12.66) was observed in L_2P_3 spacing which was statistically similar with L_2P_2 (8.66), L_2P_1 (9.20), L_1P_1 (9.93), L_3P_2 (10.06), L_1P_4 (10.46), L_1P_2 (10.66), L_3P_3 (11.13), L_2P_4 (11.86) and L_3P_4 (12.00) except L_3P_1 (5.66) and L_1P_3 (7.40). At harvest, the highest number of branches plant^{-1} (16.46) was observed in L_2P_3 which was statistically similar with all treatment combinations except L_3P_1 (10.53) and L_1P_3 (12.73). The lowest number of branches observed in L_3P_1 (10.53) which was statistically similar with L_1P_3 (12.73), L_2P_2 (12.80) and L_1P_2 (14.13).

Table 3. Combined effect of row and plant spacing on branch no. plant^{-1} of quinoa

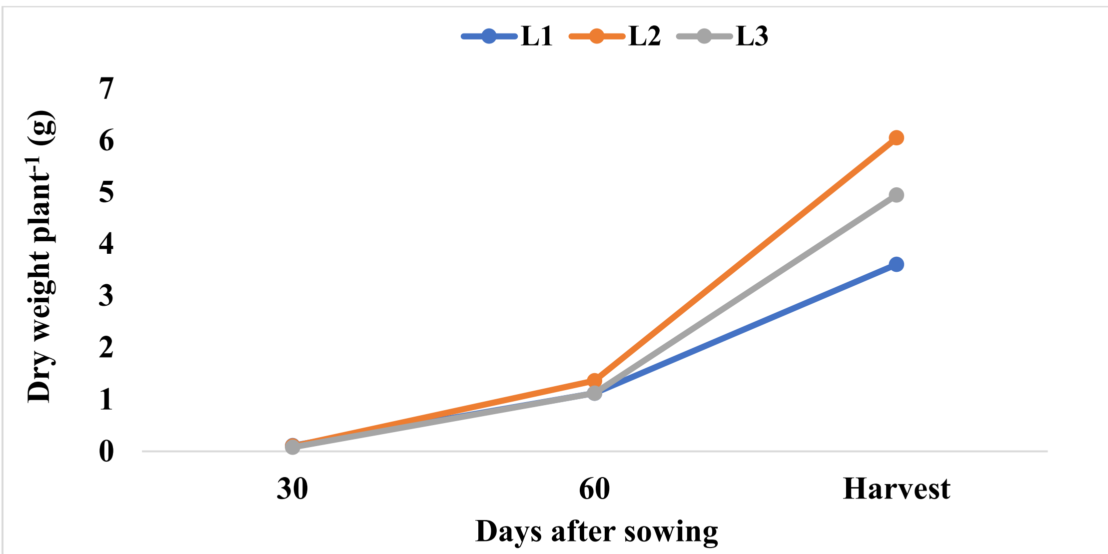
Treatments	Branch no. plant^{-1} at		
	25 DAS	50 DAS	Harvest
L_1P_1	0.66	9.93 abc	14.26 ab
L_1P_2	1.60	10.66 abc	14.13 abc
L_1P_3	0.00	7.40 bc	12.73 bc
L_1P_4	0.86	10.46 abc	16.06 ab
L_2P_1	0.40	9.20 abc	14.13 abc
L_2P_2	0.40	8.66 abc	12.80 abc
L_2P_3	0.93	12.66 a	16.46 a
L_2P_4	1.60	11.86 ab	15.66 ab
L_3P_1	0.00	5.66 c	10.53 c
L_3P_2	0.40	10.06 abc	14.46 ab
L_3P_3	0.86	11.13 ab	15.13 ab
L_3P_4	1.33	12.00 ab	16.26 ab
$LSD_{(0.05)}$	NS	4.734	3.662
CV (%)	94	27.66	14.84

L_1 = 30 cm, L_2 = 40 cm, L_3 = 50 cm, P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm, and P_4 = 30 cm, NS = non-significant

4.4 Dry weight plant^{-1}

4.4.1 Effect of row spacing

Dry weight plant^{-1} of quinoa showed non- significant variations at 30, 60 and harvest due to different row spacing (Figure 7 and Appendix VI). At 30 DAS, the maximum dry weight plant^{-1} (0.11g) was recorded from narrower spacing L_1 and the minimum dry weight plant^{-1} (0.08 g) was recorded from wider spacing L_3. At 60 DAS and harvest, the higher dry weight plant^{-1} (1.36 g and 6.05 g) found in wider spacing L_2 and the lower dry weight plant^{-1} (1.12g and 3.61g) found in narrower spacing (L_1).

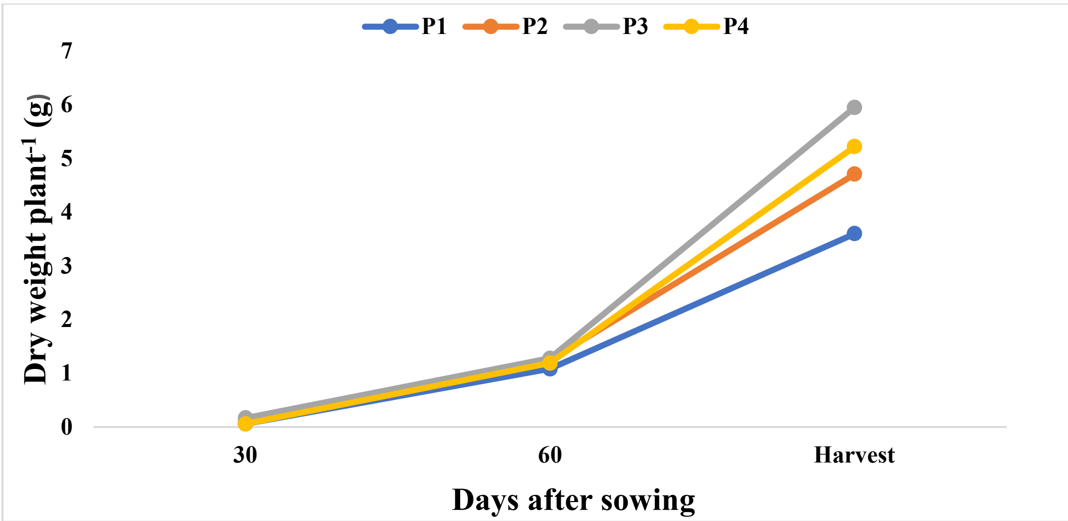


L_1 = 30 cm, L_2 = 40 cm, and L_3 = 50 cm

Figure 7. Dry weight plant^{-1} of quinoa as influenced by row spacing (LSD $_{(0.05)}$ at 30, 60 and at harvest = NS).

4.4.2 Effect of plant spacing

Dry weight plant^{-1} of quinoa showed significant variation at 30 DAS but non-significant at 60 DAS and at harvest for different plant spacing (Figure 8 and Appendix VI). At 30 DAS, the highest dry weight plant^{-1} (0.17 g) was recorded from wider spacing (P_3) and the lowest dry weight plant^{-1} (0.06 g) obtained from closer spacing (P_1). At 60 DAS and at harvest, the highest dry weight plant^{-1} (1.28 g and 5.95 g) was recorded in wider spacing P_3 and lowest dry weight plant^{-1} (1.08 g and 3.60 g) in closer spacing (P_1).



P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm, P_4 = 30 cm

Figure 8. Dry weight plant^{-1} of quinoa as influenced by plant spacing ($LSD_{(0.05)}$ at 30, 60 DAS and at harvest = 0.05, NS and NS respectively).

4.4.3 Interaction effect

Dry weight plant^{-1} of quinoa was significantly influenced by interaction of row and plant spacing (Table 4 and Appendix VI). At 30 DAS, the highest dry weight plant^{-1} (0.19 g) observed from L_2P_3. The lowest dry weight plant^{-1} (0.4 g) obtained from L_3P_1 which was statistically similar with L_2P_1 (0.5 g), L_2P_4 (0.6 g), L_3P_2 (0.7 g), L_1P_4 (0.8 g) and L_2P_2 (0.10 g). At 60 DAS, the highest dry weight plant^{-1} (1.64 g) was observed in L_2P_3 spacing. The lowest dry weight plant (0.77g) observed in L_3P_1 spacing which was statistically similar with L_1P_3 (1.03 g), L_1P_4 (1.04 g), L_1P_2 (1.17 g), L_3P_3 (1.19 g) and L_3P_4 (1.22 g). At harvest, the highest dry weight plant^{-1} (10.26 g) was recorded in L_2P_3 spacing which was statistically similar with L_3P_4 (5.53 g), L_3P_3 (5.60 g), L_2P_4 (5.93 g) and L_3P_2 (6.40 g). The lowest dry weight plant^{-1} (2.00 g) obtained from L_1P_3 spacing.

Table 4. Combined effect of row and plant spacing on dry weight plant^{-1} of quinoa

Treatments	Dry weight plant^{-1} (g) at		
	30 DAS	60 DAS	Harvest
L_1P_1	0.08 cde	1.24 a	4.33 b
L_1P_2	0.16 abc	1.17 b	3.93 b
L_1P_3	0.14 abcd	1.03 b	2.00 b
L_1P_4	0.08 cde	1.04 b	4.20 b
L_2P_1	0.05 de	1.23 a	4.20 b
L_2P_2	0.10 bcde	1.27 a	3.80 b
L_2P_3	0.19 a	1.64 a	10.26 a
L_2P_4	0.06 de	1.30 a	5.93 ab
L_3P_1	0.04 e	0.77 b	2.26 b
L_3P_2	0.07 cde	1.32 a	6.40 ab
L_3P_3	0.18 ab	1.19 ab	5.60 ab
L_3P_4	0.04 e	1.22 ab	5.53 ab
$LSD_{(0.05)}$	0.088	0.446	5.220
CV (%)	48.72	21.59	62.46

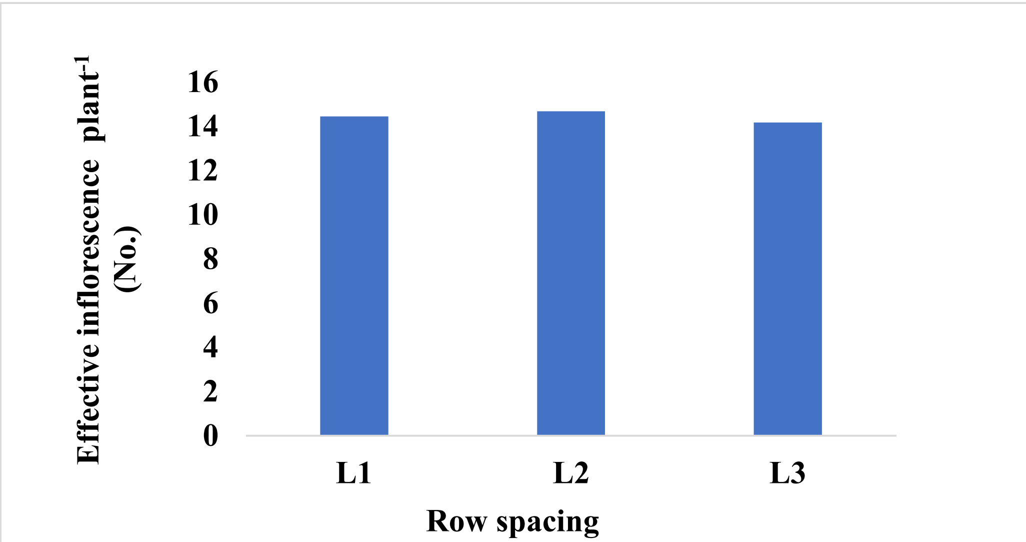
L_1 = 30 cm, L_2 = 40 cm, L_3 = 50 cm, P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm, and P_4 = 30 cm

4.5 Yield contributing parameters and yield

4.5.1 Effective inflorescence plant^{-1}

Effect of row spacing

There was no significant variation on inflorescence plant^{-1} of quinoa for different row spacing (Figure 9 and Appendix VII). The maximum number of inflorescence plant^{-1} (14.68) was found from the wider spacing (L_2) and the minimum number of inflorescence plant^{-1} (14.18) from wider spacing (L_3).

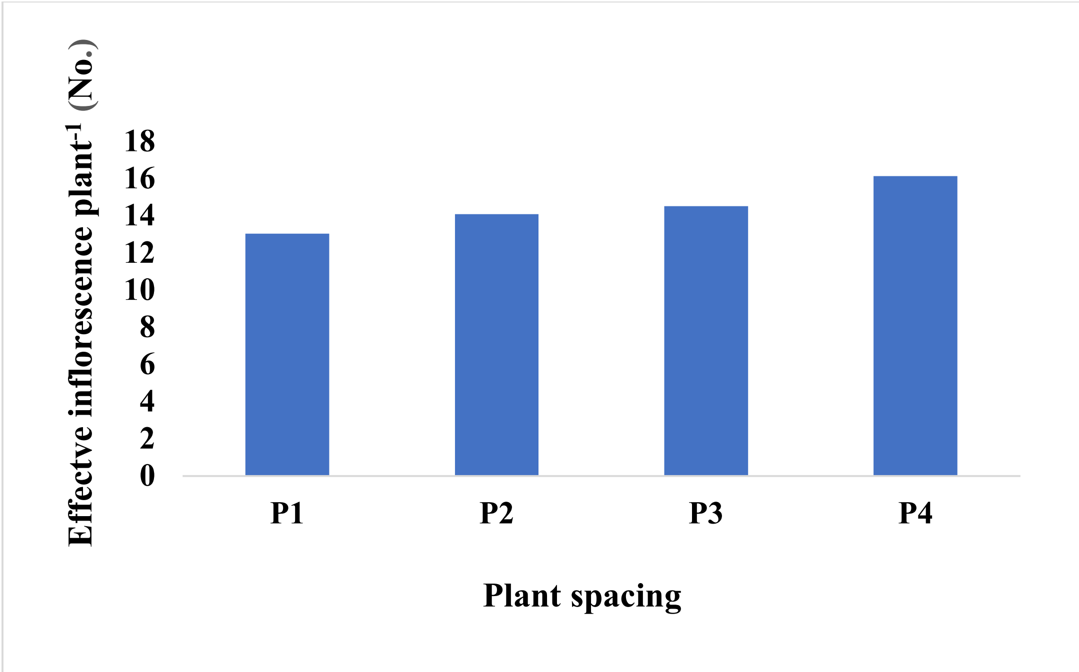


L_1 = 30 cm, L_2 = 40 cm and L_3 = 50 cm

Figure 9. Effect of row spacing on effective inflorescence plant^{-1} (LSD $_{(0.05)}$ = NS).

Effect of plant spacing

Significant influence was noted on effective inflorescence present plant^{-1} that affected by plant spacing (Figure 10 and Appendix VII). The highest number of inflorescence plant^{-1} (16.13) was found in wider spacing (P_4) which statistically similar with all treatments except closer spacing (P_1). The lowest number of inflorescence plant^{-1} (13.02) obtained from closer spacing (P_1).



P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm and P_4 = 30 cm

Figure 10. Effect of plant spacing on effective inflorescence plant^{-1} (LSD $_{(0.05)}$ = 2.663).

Interaction effect

Significant variation was observed on inflorescence plant^{-1} as influenced by interaction effect of row and plant spacing (Table 5 and Appendix VII). The highest number of effective inflorescence plant^{-1} (16.33) was found in L_2P_4 which was statistically similar with all treatment combinations except L_3P_1. The lowest number of effective inflorescence present plant^{-1} (10.46) obtained from L_3P_1.

Table 5. Combined effect of row and plant spacing on number of effective and ineffective inflorescence plant^{-1} of quinoa

Treatments	Effective inflorescence plant^{-1} (No.)	Ineffective inflorescence plant^{-1} (No.)
Row spacing		
L_1	14.45	0.74
L_2	14.68	0.75
L_3	14.18	1.52
$LSD_{(0.05)}$	NS	NS
Plant spacing		
P_1	13.022 b	0.88 b
P_2	14.089 ab	1.01 ab
P_3	14.511 ab	1.42 a
P_4	16.133 a	0.70 b
$LSD_{(0.05)}$	2.663	0.529
Combined effect		
L_1P_1	14.06 ab	0.73 c
L_1P_2	15.66 a	0.66 c
L_1P_3	12.20 ab	0.93 bc
L_1P_4	15.86 a	0.63 c
L_2P_1	14.53 ab	0.93 bc
L_2P_2	12.80 ab	0.66 c
L_2P_3	15.06 a	1.26 abc
L_2P_4	16.33 a	0.13 d
L_3P_1	10.46 b	1.00 bc
L_3P_2	13.80 ab	1.70 ab
L_3P_3	16.26 a	2.06 a
L_3P_4	16.20 a	1.33 ab
$LSD_{(0.05)}$	4.614	0.917
CV (%)	18.63	53.19

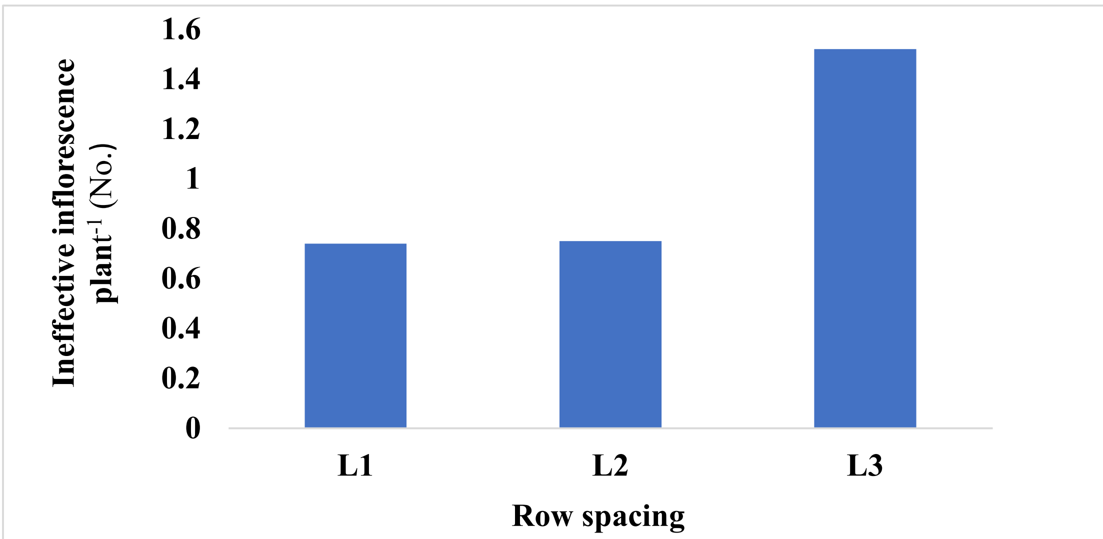
L_1 = 30 cm, L_2 = 40 cm, L_3 = 50 cm, P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm, P_4 = 30 cm and

NS = Nonsignificant

4.5.2 Ineffective inflorescence plant^{-1}

Effect of row spacing

Ineffective inflorescence plant^{-1} of quinoa was not significantly affected by different row spacing (Figure 11 and Appendix VII). The numerically maximum number of ineffective inflorescences plant^{-1} (1.52) was found from the wider spacing (L_3) and the minimum number of ineffective inflorescence plant^{-1} (0.74) from closer spacing (L_1).

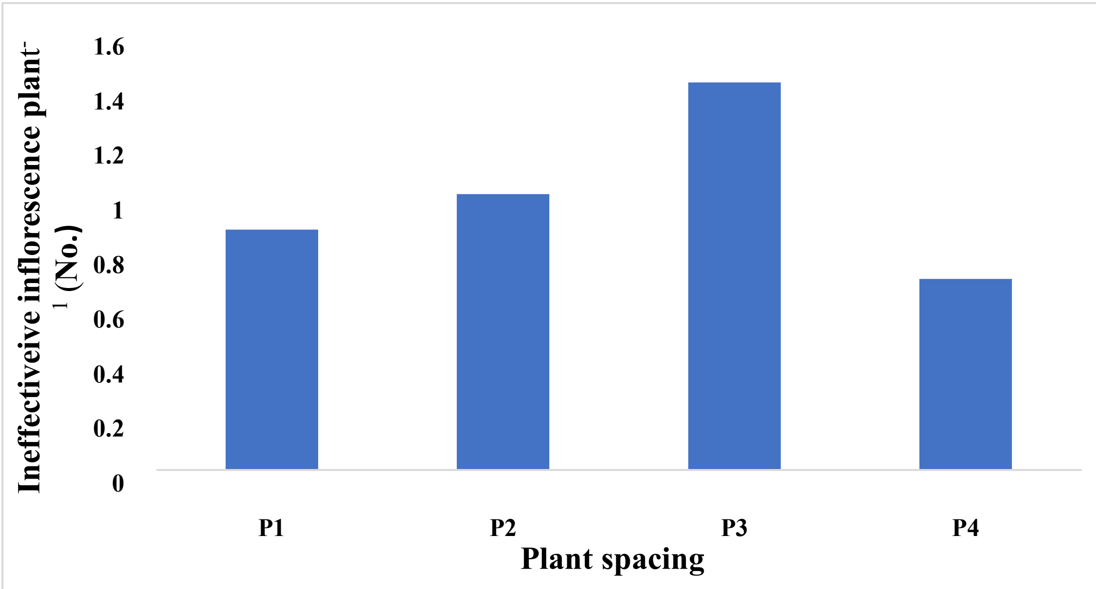


L1 = 30 cm, L2 = 40 cm, and L3 = 50 cm

Figure 11. Effect of row spacing on ineffective inflorescence plant^{-1} ($LSD_{(0.05)}$ = NS).

Effect of plant spacing

Number of ineffective inflorescence plant^{-1} was significantly influenced by plant spacing (Figure 12 and Appendix VII). The highest number of ineffective inflorescences plant^{-1} (1.42) was found in wider spacing (P_3) and the lowest number of inflorescence plant^{-1} (0.70) obtained from wider spacing (P_4).



P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm and P_4 = 30 cm

Figure 12. Effect of plant spacing on ineffective inflorescence plant^{-1} (LSD $_{(0.05)}$ = 0.529).

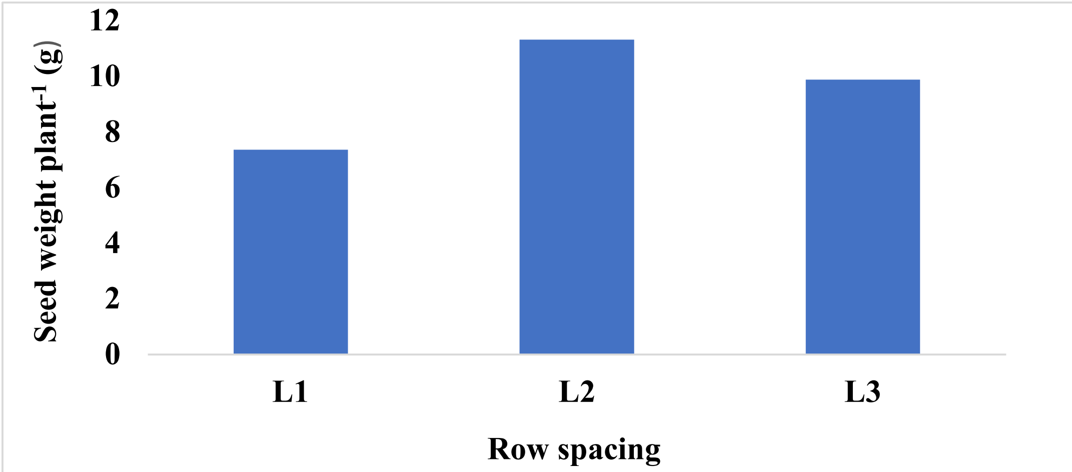
Interaction effect

Significant variation was observed on ineffective inflorescence plant^{-1} by interaction effect of row and plant spacing (Table 5 and Appendix VII). The highest number of ineffective inflorescences plant^{-1} (2.06) was found in L_3P_3 which was statistically similar with L_2P_3 (1.26), L_3P_4 (1.33) and L_3P_2 (1.70). The lowest number of inflorescences plant^{-1} (0.13) obtained from L_2P_4.

4.5.3 Seed weight plant^{-1}

Effect of row spacing

The recorded data on seed weight plant^{-1} was not influenced significantly by different row spacing (Figure 13 and Appendix VIII). The numerically maximum seed weight plant^{-1} (11.30 g) was found from wider spacing L_2 and the minimum seed weight plant^{-1} (7.35 g) was found from closer spacing from L_1.

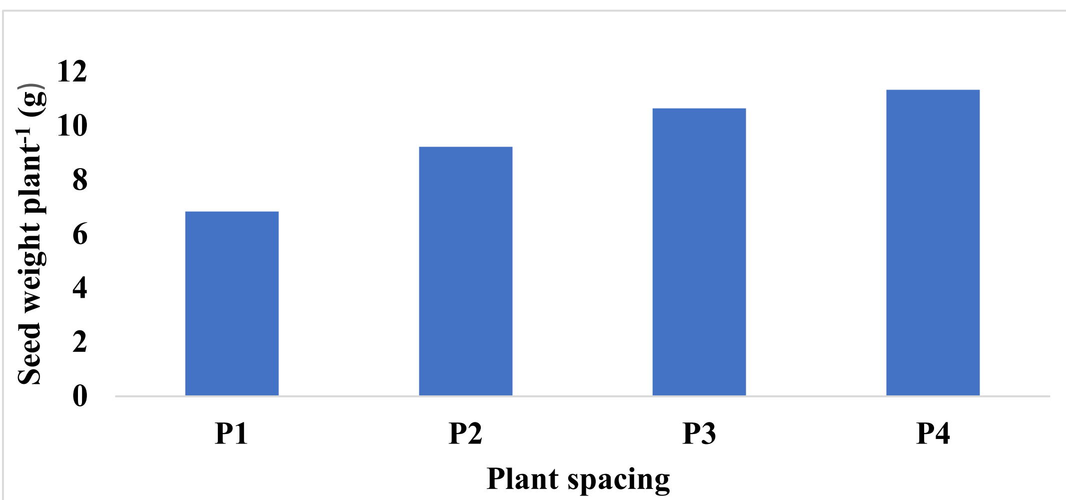


L_1 = 30 cm, L_2 = 40 cm, and L_3 = 50 cm

Figure 13. Seed weight plant^{-1} of quinoa as influenced by row spacing ($LSD_{(0.05)}$ = NS).

Effect of plant spacing

Substantial influence was detected on seed weight plant^{-1} of quinoa for different plant spacing (Figure 14 and Appendix VIII). The highest seed weight plant^{-1} (11.33 g) was found in wider spacing P_4 which statistically similar with all treatments except P_1. The lowest seed weight plant^{-1} (6.83 g) was found in closer spacing (P_1).



P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm, P_4 = 30 cm

Figure 14. Seed weight plant^{-1} of quinoa as influenced by plant spacing ($LSD_{(0.05)}$ = 3.623).

Interaction effect

Noteworthy variation was recognized on seed weight of quinoa due to the interaction effect of row and plant spacing (Table 6 and Appendix VIII). The highest seed weight plant^{-1} (15.23 g) was found from the treatment combination of L_2P_3 which statistically similar with the treatment combination of L_2P_2, L_3P_2, L_3P_3, L_3P_4 and L_2P_4 except L_1P_3. The lowest seed weight plant (5.20 g) was found from treatment combination of L_1P_3.

Table 6. Combined effect of row and plant spacing on seed weight plant^{-1}, husk weight plant^{-1} and 1000-seed weight of quinoa

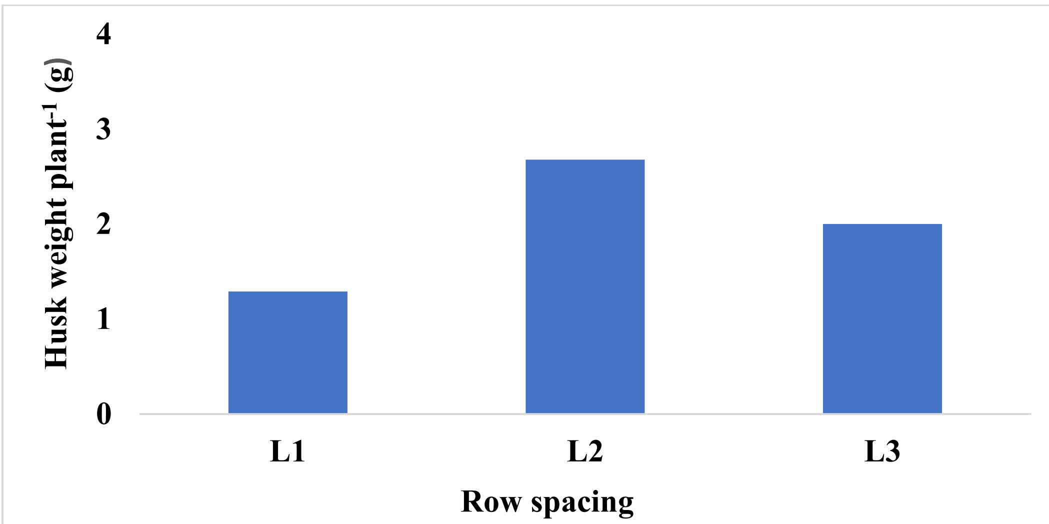
Treatments	Seed weight plant^{-1} (g)	Husk weight plant^{-1} (g)	1000-seed weight (g)
L_1P_1	7.80 bc	1.23 b	3.79
L_1P_2	7.70 bc	1.40 b	3.70
L_1P_3	5.20 c	1.00 b	3.89
L_1P_4	8.70 bc	1.53 b	3.75
L_2P_1	7.36 bc	1.20 b	4.35
L_2P_2	9.10 abc	1.83 b	3.80
L_2P_3	15.23 a	4.66 a	4.24
L_2P_4	13.50 ab	3.03ab	3.56
L_3P_1	5.33 c	0.96 b	3.82
L_3P_2	10.86 abc	2.13 b	3.76
L_3P_3	11.50 ab	2.16 b	3.60
L_3P_4	11.80 ab	2.76 ab	3.60
$LSD_{(0.05)}$	6.275	1.919	NS
CV (%)	8.47	6.09	16.90

L_1 = 30 cm, L_2 = 40 cm, L_3 = 50 cm, P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm, P_4 = 30 cm

4.5.4 Husk weight plant^{-1}

Effect of row spacing

There was no variation observed on husk weight plant^{-1} by the influenced of row spacing (Figure 15 and Appendix VIII). The numerically maximum husk weight plant^{-1} (2.68 g) was found from wider spacing L_2 and the minimum husk weight plant^{-1} (1.29 g) was found from closer spacing L_1.

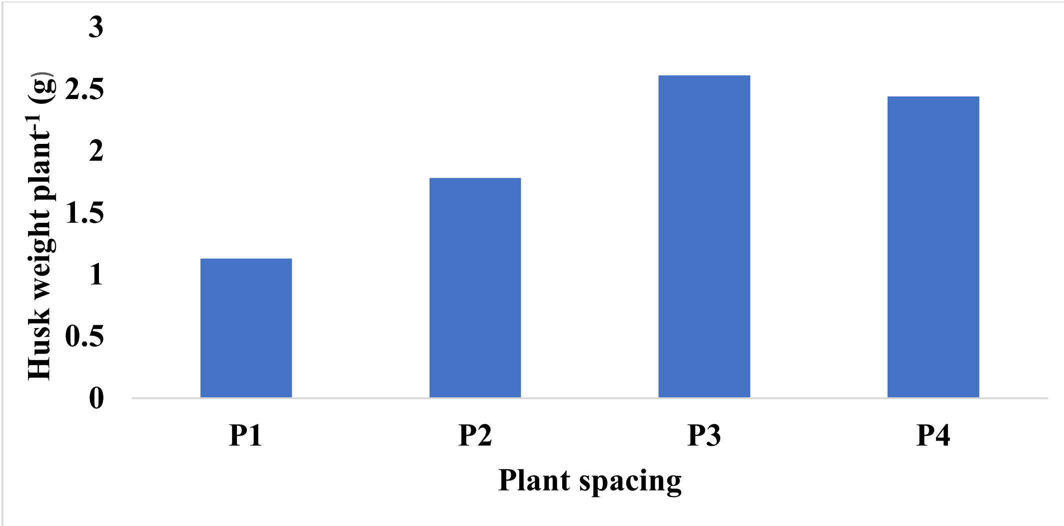


L_1 = 30 cm, L_2 = 40 cm, and L_3 = 50 cm

Figure 15. Husk weight of quinoa as influenced by row spacing ($LSD_{(0.05)}$ = NS).

Effect of plant spacing

Considerable influence was observed on husk weight plant^{-1} of quinoa by different plant spacing (Figure 16 and Appendix VIII). The highest husk weight plant^{-1} (2.61 g) was recorded from P_3 which statistically similar with other treatments except P_1.



P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm, P_4 = 30 cm

Figure 16. Husk weight of quinoa as influenced by plant spacing ($LSD_{(0.05)}$ = 1.108).

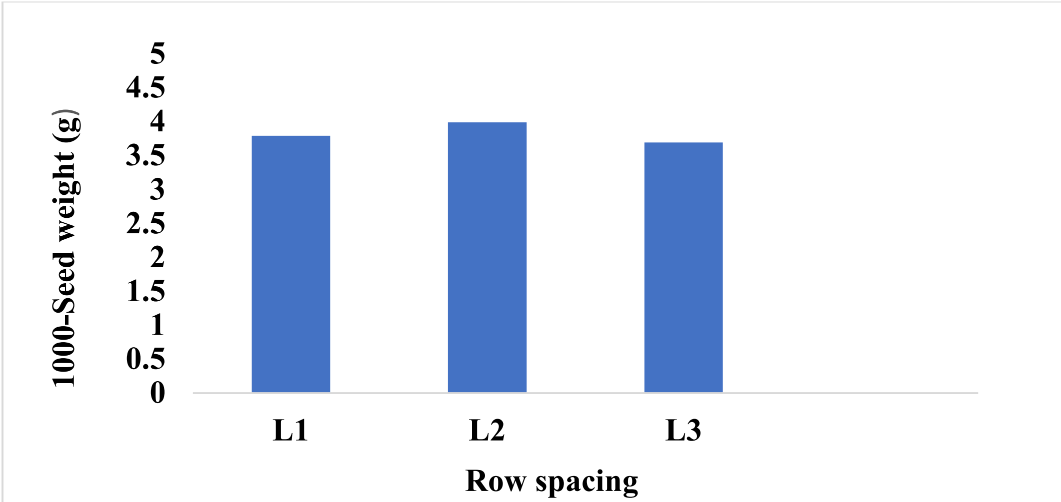
Interaction effect

Remarkable variation was observed on husk weight plant^{-1} persuaded by combination effect of row and plant spacing (Table 6 and Appendix VIII). The highest husk weight plant^{-1} (4.66 g) was found treatment combination of L_2P_3 which statistically dissimilar with all treatment combinations except L_2P_4 and L_3P_4. The lowest husk weight plant^{-1} (0.96 g) was found from treatment combination of L_3P_1.

4.5.5 1000-seed weight

Effect of row spacing

The 1000-seed weight was not varied significantly for different row spacing (Figure 17 and Appendix VIII). The maximum weight of 1000-seed (3.99 g) was obtained in L_2 and the minimum weight of 1000-seed (3.69 g) was obtained in L_3.

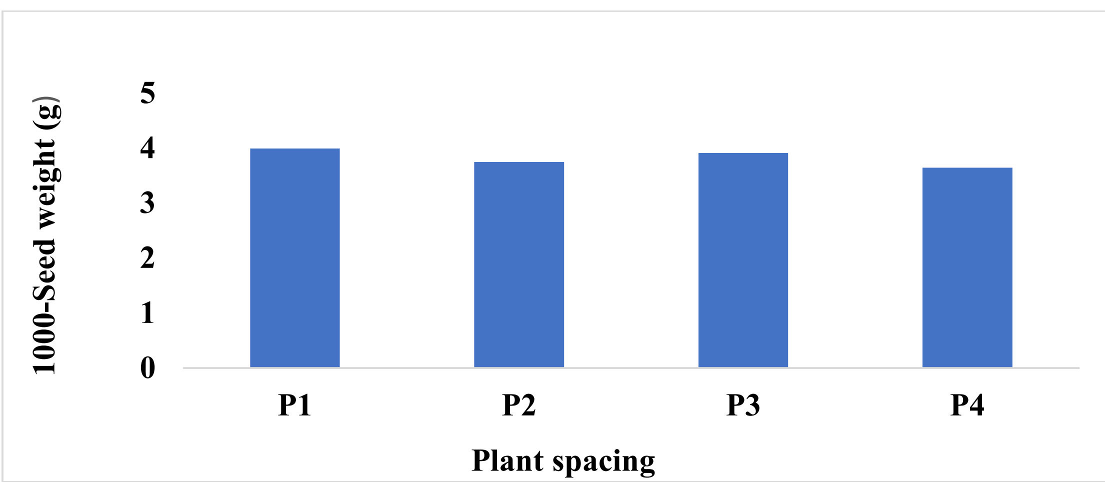


L_1 = 30 cm, L_2 = 40 cm, L_3 = 50 cm

Figure 17. 1000-seed weight of quinoa as influenced by row spacing ($LSD_{(0.05)}$ = NS).

Effect of plant spacing

There was no significant variation observed on 1000-seed weight due to plant spacing (Figure 18 and Appendix VIII). The maximum weight of 1000-seed (3.99 g) was observed from narrower spacing P_1 and the minimum weight of 1000-seed (3.64 g) was observed from wider spacing P_4.



P_1 = 15cm, P_2 = 20 cm, P_3 = 25 cm, P_4 = 30 cm

Figure 18. 1000-seed weight of quinoa as influenced by plant spacing ($LSD_{(0.05)}$ = NS).

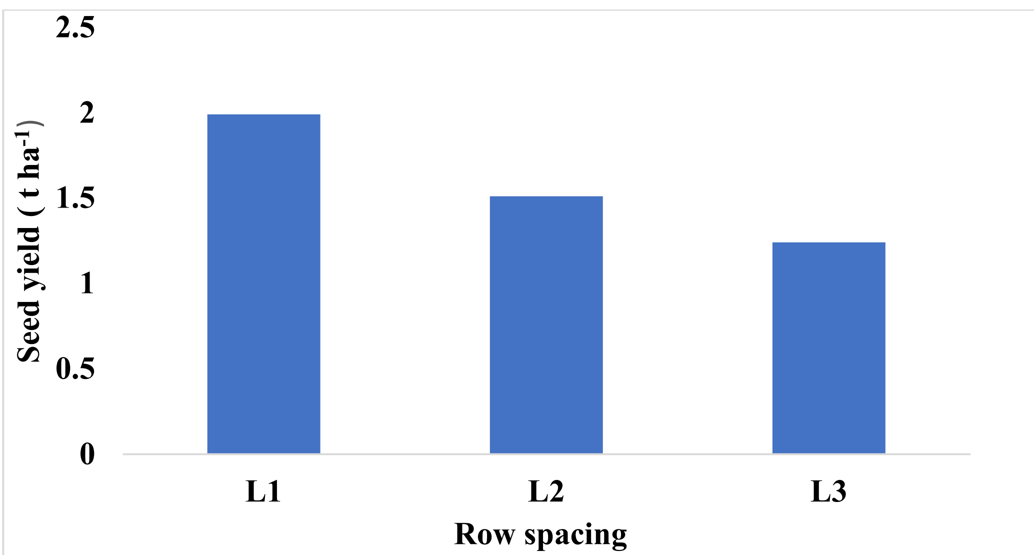
Interaction effect

Significant variation was not remarked on 1000-seed weight for the interaction effect of row and plant spacing (Table 6 and Appendix VIII). The maximum weight of 1000-seed (4.35 g) was observed from interaction treatment of L_2P_1 which was statistically similar with all treatment and the minimum weight of 1000-seed weight (3.56 g) was observed from interaction treatment of L_2P_4.

4.5.6 Seed yield

Effect of row spacing

Seed yield of quinoa was significantly influenced by different row spacing (Figure 19 and Appendix IX). The highest seed yield (1.99 t ha^{-1}) was detected from closer spacing L_1 which statistically dissimilar with other treatment and the lowest seed yield (1.24 t $^{-1}$ha) was detected from wider spacing L_3 which statistically similar with treatment L_2.

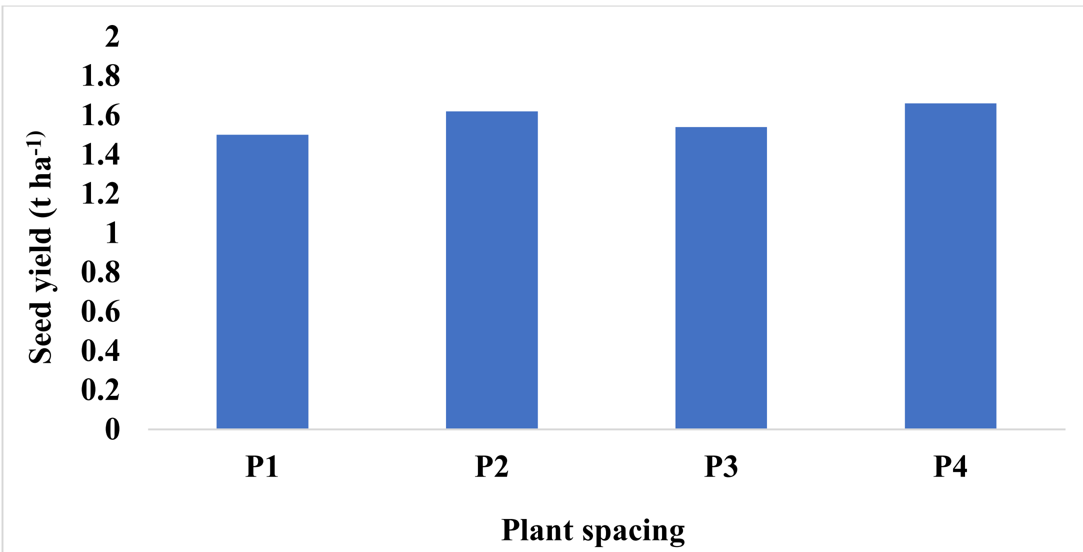


L_1 = 30 cm, L_2 = 40 cm, L_3 = 50 cm

Figure 19. Seed yield of quinoa as influenced by row spacing ($LSD_{(0.05)}$ = 0.425)

Effect of plant spacing

Plant spacing showed no significant difference on seed yield of quinoa (Figure 20 and Appendix IX). The wider (P_4) spacing produced highest seed yield (1.66 t ha^{-1}) which was similar with P_1, P_2 and P_3 spacings and the lowest seed yield (1.50 t ha^{-1}) was recorded from closer spacing of P_1.



P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm, P_4 = 30 cm

Figure 20. Seed yield of quinoa as influenced by plant spacing ($LSD_{(0.05)}$ = NS).

Interaction effect

The interaction between row and plant spacing significantly affected the seed yield of quinoa (Table 7 and Appendix IX). The highest seed yield (2.15 t ha^{-1}) was obtained from combination treatment of L_1P_2 which was similar with L_1P_1 (2.09 t ha^{-1}) and L_1P_4 (2.11 t ha^{-1}). The lowest seed yield (1.04 t ha^{-1}) was found from combination treatment of L_3P_1 which was similar with L_3P_4 (1.28 t ha^{-1}), L_3P_2 (1.29 t ha^{-1}), L_3P_3 (1.36 t ha^{-1}), L_2P_1 (1.38 t ha^{-1}) and L_2P_2 (1.42 t ha^{-1}).

Table 7. Combined effect of row and plant spacing on seed yield, straw yield, biological yield and harvest index of quinoa

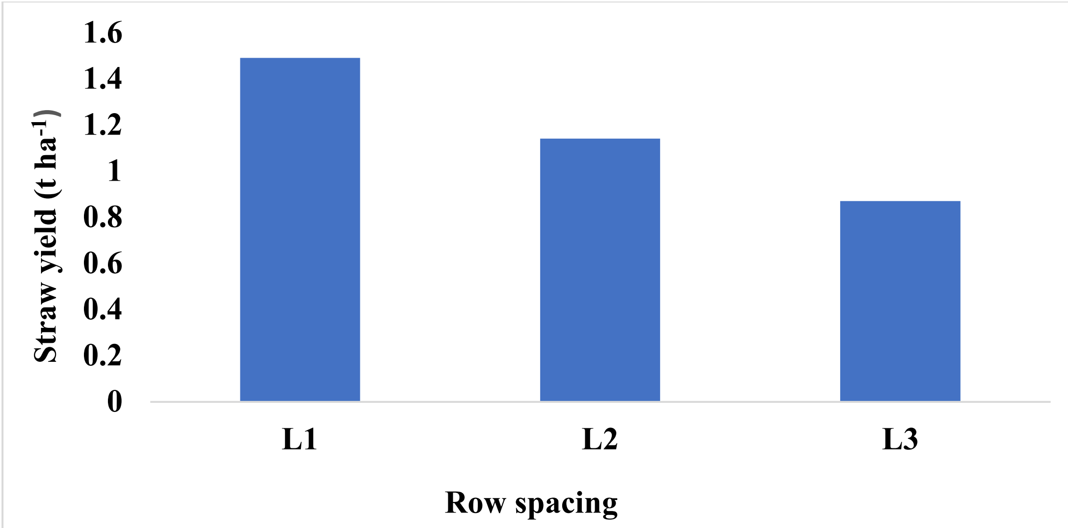
Treatments	Seed yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
L_1P_1	2.09 abc	1.54 a	3.63 a	57.49 abc
L_1P_2	2.15 a	1.59 a	3.74 a	57.56 abc
L_1P_3	1.63 c	1.33ab	2.96 ab	55.34 bc
L_1P_4	2.11 ab	1.52 a	3.63 a	58.40 abc
L_2P_1	1.38 de	1.02 bc	2.40 bc	56.65 abc
L_2P_2	1.42 de	1.10 b	2.52 bc	56.41 abc
L_2P_3	1.64 b	1.45 ab	3.10 ab	53.88 c
L_2P_4	1.59 d	0.99 c	2.58 bc	61.82 ab
L_3P_1	1.04 e	0.63 c	1.67 c	62.19 a
L_3P_2	1.29 de	1.00 bc	2.30 bc	56.23 abc
L_3P_3	1.36 de	0.95 c	2.31 bc	59.35 abc
L_3P_4	1.28 de	0.91 c	2.20 bc	58.42 abc
$LSD_{(0.05)}$	0.464	0.449	0.846	6.110
CV (%)	17.08	22.33	17.90	6.16

L_1 = 30 cm, L_2 = 40 cm, L_3 = 50 cm, P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm, P_4 = 30 cm

4.5.7 Straw yield

Effect of row spacing

Straw yield was significantly influenced by row spacing (Figure 21 and Appendix IX). The treatment having closer spacing (L_1) produced the highest straw yield (1.49 t ha^{-1}). The wider spacing L_3 produced the lowest yield (0.87 t ha^{-1}).

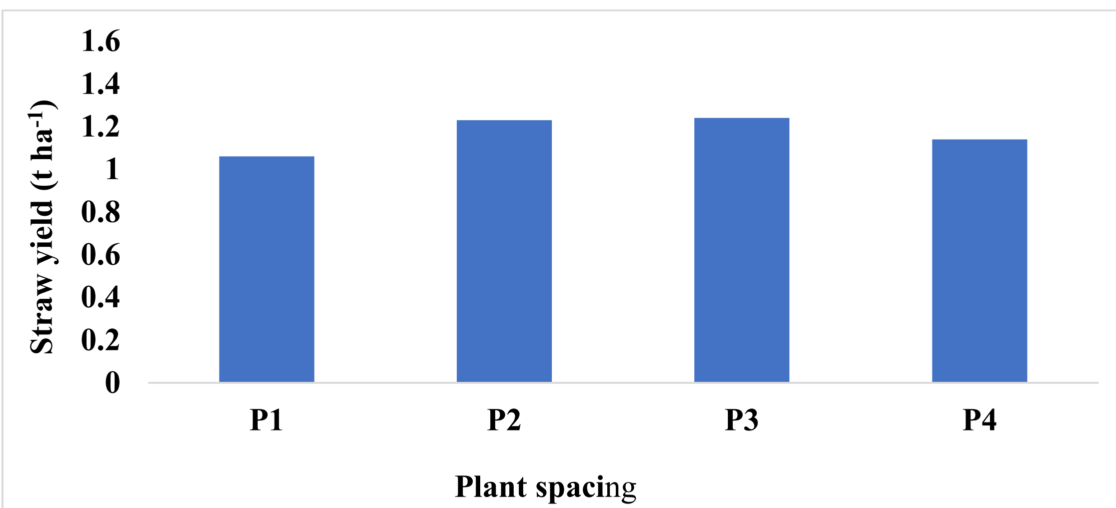


L_1 = 30 cm, L_2 = 40 cm, L_3 = 50 cm

Figure 21. Straw yield of quinoa as influenced by row spacing ($LSD_{(0.05)}$ = 0.362).

Effect of plant spacing

Quinoa straw yield was not significantly influenced by plant spacing (Figure 22 and Appendix IX). The highest straw yield (1.24 t ha^{-1}) was obtained from P_3 spacing which similar with all treatment and the lowest straw yield (1.06 t ha^{-1}) obtained from P_1 spacing.



P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm, P_4 = 30 cm

Figure 22. Straw yield of quinoa as influenced by plant spacing ($LSD_{(0.05)}$ = NS).

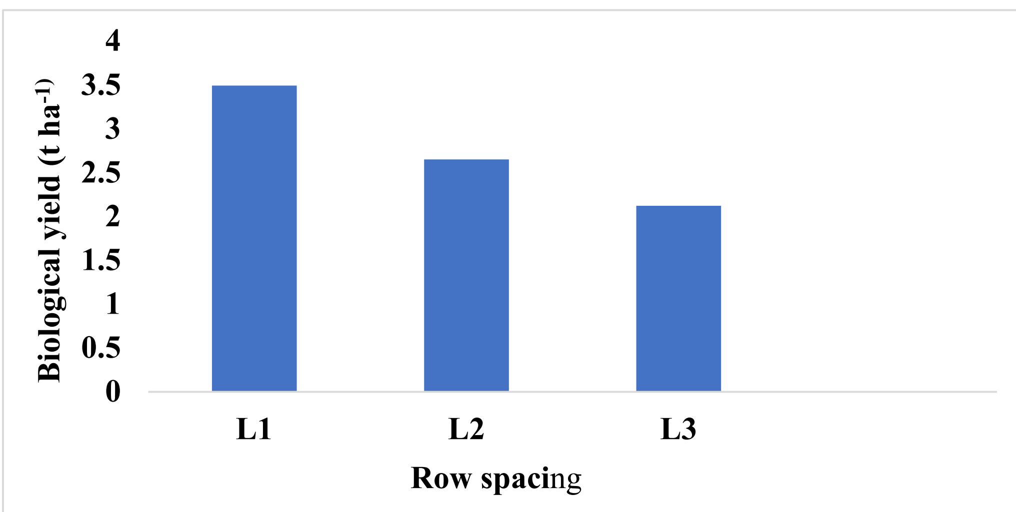
Interaction effect

Significant observation on straw yield of quinoa influenced by combination effect of row and plant spacing (Table 7 and Appendix IX). The highest straw yield (1.59 t ha^{-1}) was detected in treatment combination of L_1P_2 which was similar with L_3P_4 (0.91 t ha^{-1}), L_3P_3 (0.95 t ha^{-1}), L_2P_4 (0.99 t ha^{-1}), L_3P_2 (1.00 t ha^{-1}), L_2P_1 (1.02 t ha^{-1}) and L_2P_2 (1.10 t ha^{-1}). The lowest yield (0.63 t ha^{-1}) was found in L_3P_1.

4.5.8 Biological yield

Effect of row spacing

The biological yield of quinoa was not significantly influenced by different row spacing (Figure 23 and Appendix IX). The numerically highest biological yield (3.49 t ha^{-1}) was recorded from closer spacing L_1 and lowest biological yield (2.12 t ha^{-1}) was recorded from wider spacing L_3.

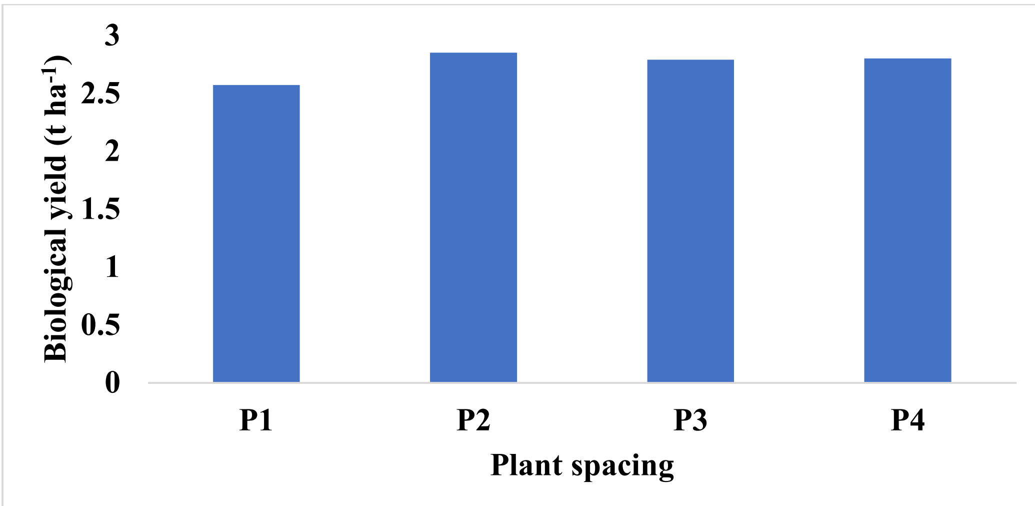


L_1 = 30 cm, L_2 = 40 cm, L_3 = 50 cm

Figure 23. Biological yield of quinoa as influenced by row spacing ($LSD_{(0.05)}$ = NS).

Effect of plant spacing

Plant spacing did not show significant difference on biological yield (Figure 24 and Appendix IX). The highest biological yield (2.85 t ha^{-1}) was observed from the closer spacing (P_2) and the lowest biological yield (2.57 t ha^{-1}) was observed from spacing P_1.



P_1 = 15 cm, P_2 = 20 cm, P_3 = 25 cm, P_4 = 30 cm

Figure 24. Biological yield of quinoa influenced by plant spacing ($LSD_{(0.05)}$ = NS).

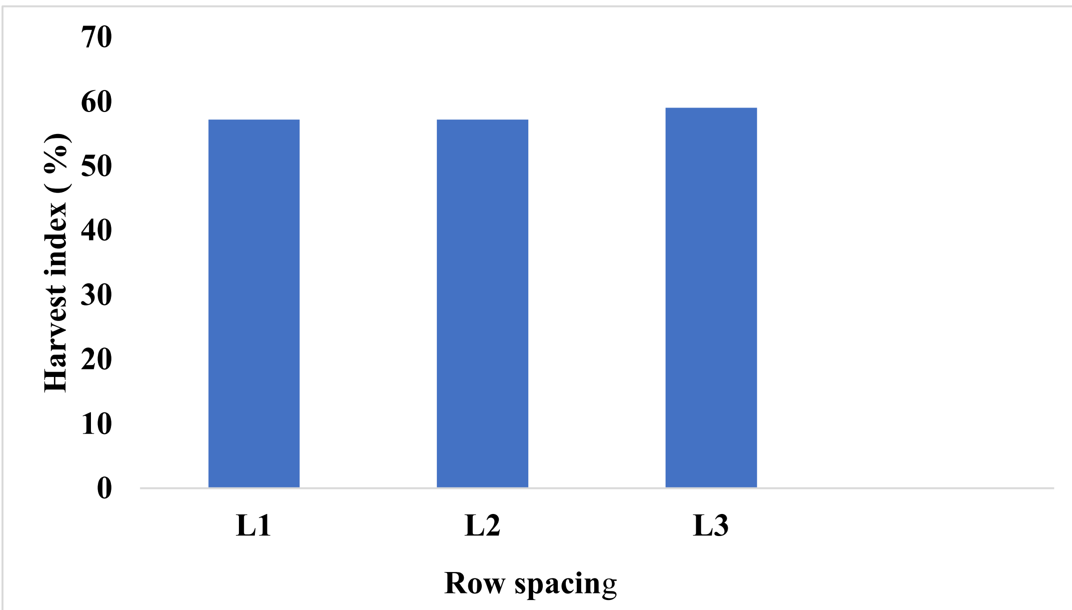
Interaction effect

Significant variation was observed on biological yield due to combination effect of row and plant spacing (Table 7 and Appendix IX). The highest biological yield (3.74 t ha^{-1}) was recorded from L_1P_2 which statistically similar with L_1P_3 (2.96 t ha^{-1}), L_2P_3 (3.10 t ha^{-1}) and L_1P_1 (3.63 t ha^{-1}) and the lowest biological yield (1.67 t ha^{-1}) was found on L_3P_1 which statistically similar with L_3P_4 (2.20 t ha^{-1}), L_3P_2 (2.30 t ha^{-1}), L_3P_3 (2.31 t ha^{-1}) , L_2P_1 (2.40 t ha^{-1}), L_2P_2 (2.52 t ha^{-1}) , L_2P_4 (2.58 t ha^{-1}).

4.5.9 Harvest index

Effect of row spacing

The harvest index of quinoa was not significantly influenced by different row spacing (Figure 25 and Appendix IX). The numerically maximum harvest index (59.04%) was recorded from wider spacing L_3 and minimum harvest index (57.19%) was recorded from closer spacing of L_2.

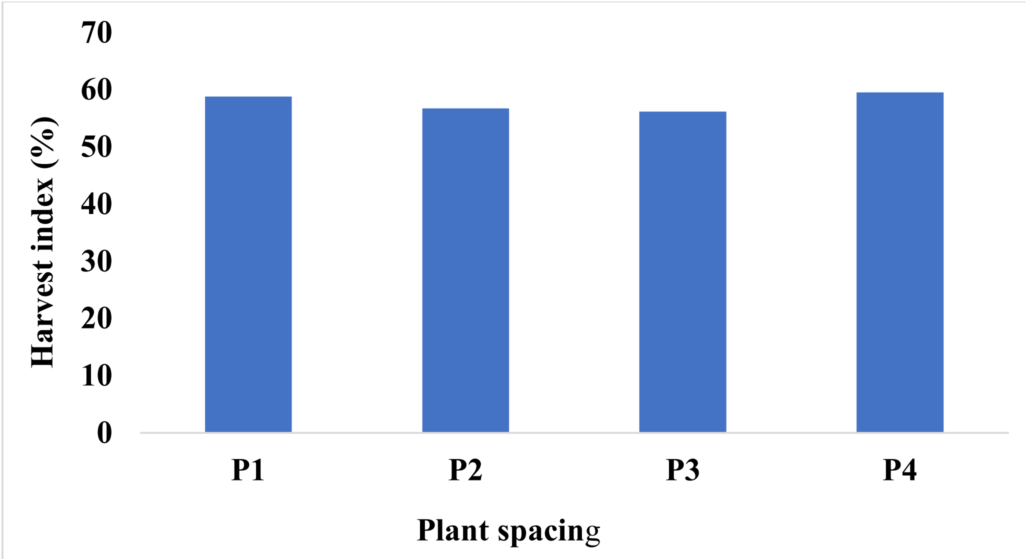


L_1 = 30 cm, L_2 = 40 cm, L_3 = 50 cm

Figure 25. Harvest index of quinoa as influenced by row spacing ($LSD_{(0.05)}$ = NS).

Effect plant spacing

There was no significant variation observed on harvest index of quinoa persuaded by plant spacing (Figure 26 and Appendix IX). The highest harvest index (59.54%) was found from wider plant spacing P_4 which similar with all treatment. The lowest harvest index (56.19%) was found from P_3.



$P_1 = 15$cm, $P_2 = 20$ cm, $P_3 = 25$ cm, $P_4 = 30$ cm

Figure 26. Harvest index of quinoa as influenced by plant spacing ($LSD_{(0.05)}$ = NS).

Interaction effect

Interaction effect of row and plant spacing was significant for harvest index (Table 7 and Appendix IX). The highest harvest index (62.19 %) was observed from the treatment L_3P_1 which statistically similar with all treatment except L_2P_3 (53.88 %) and L_1P_3 (55.34 %). The lowest harvest index (53.88 %) was observed from the treatment L_2P_3.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was carried out in Sher-e-Bangla Agricultural University, Dhaka during the period from November 2019 to February 2020 to evaluate the influence of plant density on growth and yield of quinoa (*Chenopodium quinoa* Willd.).

The experiment was laid out in a randomized complete block (factorial) design with three replications having row spacing and plant spacing. The experiment consists of two factors; Factor A: Row spacing-3 viz. 30 cm (L_1), 40 cm (L_2), 50 cm (L_3) and Factor B: Plant spacing – 4 viz. 15 cm (P_1), 20 cm (P_2), 25 cm (P_3) and 30 cm (P_4). Data on different growth parameters, yield components and yield of plants were recorded. The collected data were statistically analyzed and the differences among the means were evaluated by LSD at 5% level of significance.

Different parameters of quinoa were influenced by row spacing. Results showed that row spacing had significant effect on seed yield, straw yield and biological yield but plant height, number of branches plant^{-1}, number of leaves plant^{-1}, dry weight plant^{-1}, effective inflorescence plant^{-1}, ineffective inflorescence plant^{-1}, seed weight plant^{-1}, husk weight plant^{-1}, 1000-seed weight and harvest index were not significantly affected by row spacing. The maximum seed yield (1.99 t ha^{-1}) was recorded in closer row spacing L_1 and the minimum seed yield was found in wider row spacing L_3. The maximum straw yield (1.49 t ha^{-1}) was found in closer spacing L_1 and the minimum straw yield (0.87 t ha^{-1}) was observed in wider spacing L_3. The highest biological yield (3.49 t ha^{-1}) was recorded in closer spacing L_1, and the lowest biological yield (2.12 t ha^{-1}) was found in wider spacing L_3.

For plant spacing, 1000-seed weight , seed yield , straw yield , biological yield and harvest index was not significantly affected but all other parameter was significantly influenced by plant spacing. Results showed that the highest plant height (67.96 cm at 50 DAS), number of leaves plant^{-1} (16.17 at 25 DAS), number of branches plant^{-1} (1.26, 11.44, 16.00 at 25, 50 DAS and at harvest), effective inflorescence plant^{-1} (16.13), seed weight plant^{-1} (11.33 g) were found from wider spacing P_4 and the lowest plant height (57.23 cm at 50 DAS), number of leaves plant^{-1} (12.24 at 25 DAS), number of branches plant^{-1} (0.35, 8.26, 12.97 at 25, 50 DAS and at harvest), dry weight plant^{-1} (0.06 g at 30 DAS), effective inflorescence plant^{-1} (13.02), seed weight plant^{-1} (6.83 g), husk weight plant^{-1} (1.13 g) were observed from closer spacing P_1 but the highest dry weight plant^{-1} (0.17 g at 30 DAS), ineffective inflorescence plant^{-1} (1.42), husk weight plant^{-1} (2.61 g) were recorded from wider spacing P_3 and lowest ineffective inflorescence plant^{-1} (0.70) found from spacing P_4 .

Considering interaction effect of row and plant spacing , 1000-seed weight was insignificant. All the parameters under present study were significantly affected by interaction effect of row and plant spacing. Results showed that the highest plant height (72.28 and 74.27 cm at 50 DAS and at harvest, respectively), number of leaves plant^{-1} (65.53 and 66.66 at 50 DAS and at harvest), number of branches plant^{-1} (12.66 and 16.46 at 50 DAS and at harvest), dry weight plant^{-1} (0.19 g, 1.64 g, 10.26 g at 30, 60 DAS and at harvest), seed weight plant^{-1}(15.23 g), husk weight plant^{-1} (4.66 g) were found at the treatment interaction at L_2P_3 but lowest harvest index (53.88 %) found at this interaction L_2P_3. The lowest plant height (14.10, 46.33 and 44.46 at 25, 50 DAS and at harvest), number of leaves plant^{-1} (9.80 and 43.00 at 25 and 50 DAS), number of branches plant^{-1} (0.00, 5.66 and 10.53 at 25,50 DAS and at harvest), dry weight plant^{-1} (0.04 g, 0.77 g at 25 and 50 DAS), effective inflorescence plant^{-1} (10.46), husk weight plant^{-1} (0.96 g), seed yield (1.04 t ha^{-1}), straw yield (0.63 t ha^{-1}) and biological yield (1.67 t ha^{-1}) were observed at interaction of L_3P_1 but higher harvest index (62.19 %) at interaction of L_3P_1. Again, higher number of leaves $plant^{-1}$ (18.26 at 25 DAS), number of branches $plant^{-1}$ (1.60 at 25 DAS), seed yield (2.15 t ha^{-1}), straw yield (1.59 t ha^{-1}) and biological yield (3.74 t ha^{-1}) were recorded in L_1P_2 . The lower number of leaves $plant^{-1}$ (42.46 at harvest), number of branches $plant^{-1}$ (6.53 at 75 DAS), dry weight $plant^{-1}$ (2.00g at 60 DAS), seed weight $plant^{-1}$ (5.20 g) were found at treatment combination of L_1P_3 . Higher effective inflorescence $plant^{-1}$(16.33) at L_2P_4 but lower ineffective inflorescence $plant^{-1}$ (0.13) was found L_2P_4. Higher ineffective inflorescence $plant^{-1}$ (2.06) at L_3P_3 and highest plant height (19.36 at 25 DAS) was found from treatment combination of L_3P_4.

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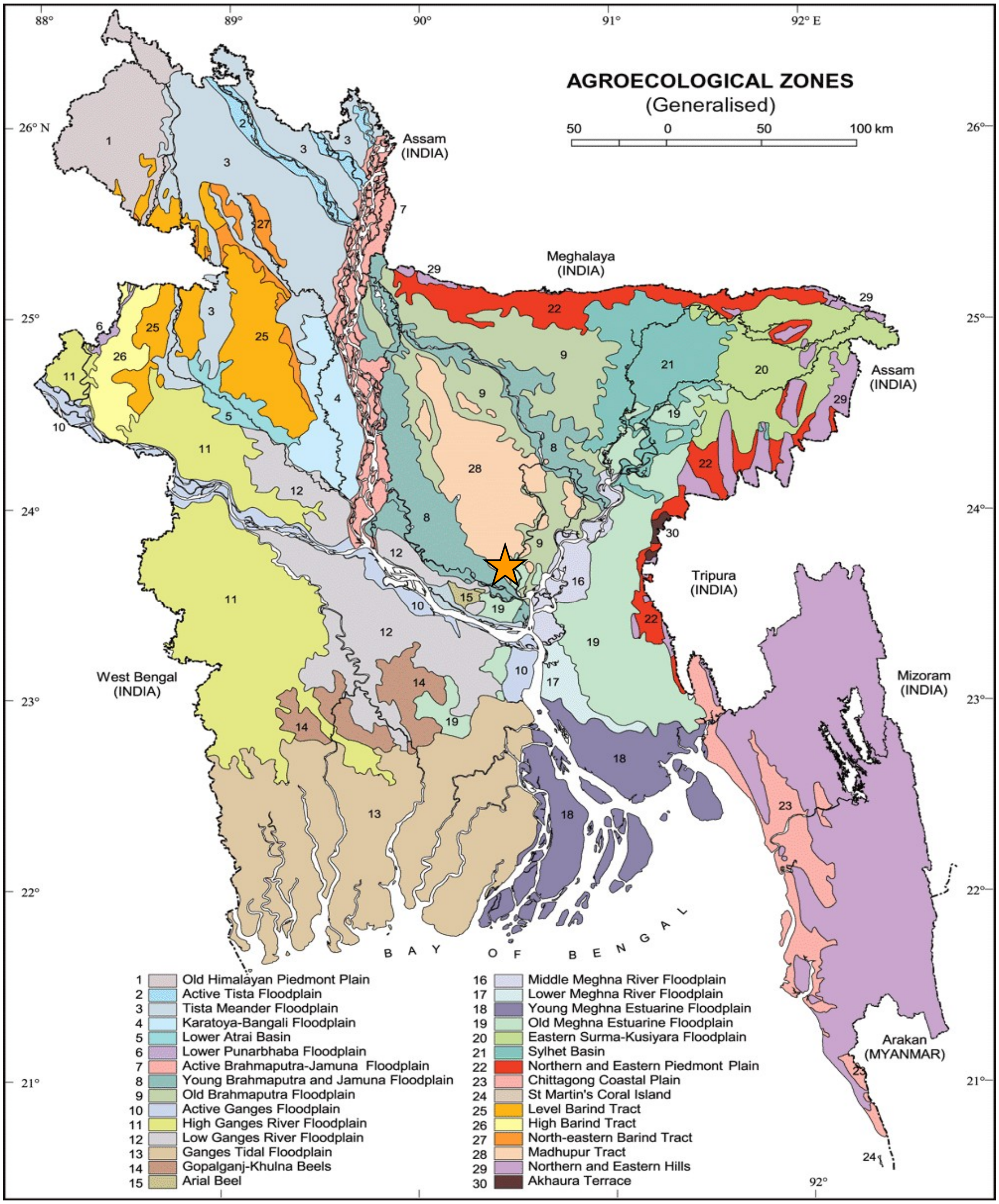
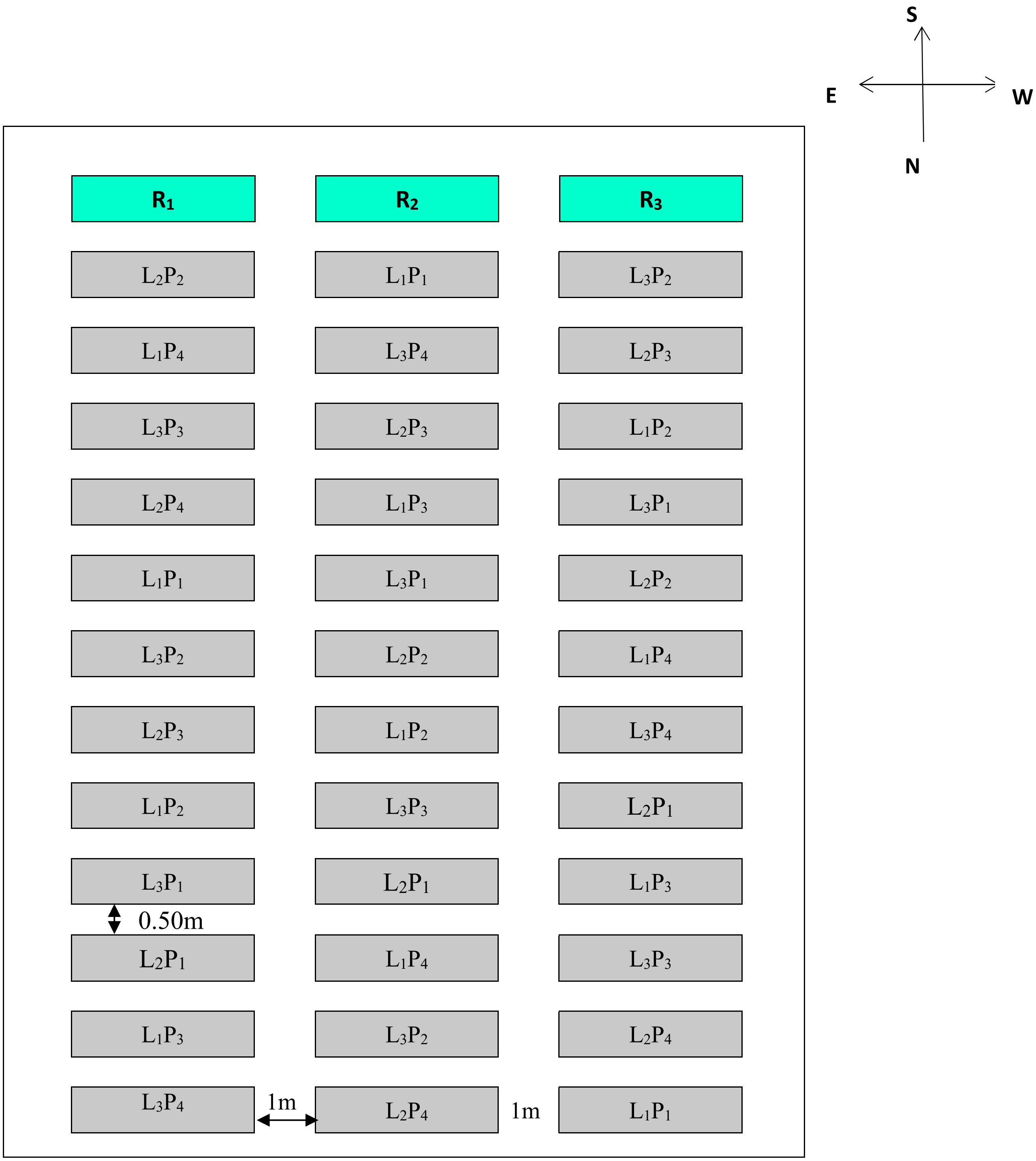
APPENDICES

Appendix I. Map showing the experimental sites under study



The experimental site under study

Appendix II. Layout of the experimental field



Field size: 9.5 m × 23.9 m

Block size: 2 m × 2.1 m

Block to Block distance: 0.5 m

Plot to plot distance: 1.0 m

Appendix III. Analysis of variance of the data on plant height of quinoa as influenced by row and plant spacing

Sources of variation	Degrees of freedom	Mean square value of plant height at		
		25 DAS	50 DAS	Harvest
Replication	2	8.96441	103.203	127.559
Row spacing	2	2.06014 NS	50.890 NS	89.907 NS
Plant spacing	3	3.78757 NS	173.333*	136.669 NS
Interaction (row×plant)	6	9.82170*	234.276*	270.834*
Error	22	3.61922	115.001	114.606

* Significant at 5% level, NS = non-significant

Appendix IV. Analysis of variance of the data on number of leaves plant^{-1} of quinoa as influenced by row and plant spacing

Sources of variation	Degrees of freedom	Mean square value of number of leaves plant^{-1} at		
		25 DAS	50 DAS	Harvest
Replication	2	18.6744	170.698	62.710
Row spacing	2	8.8011NS	20.991NS	155.213 NS
Plant spacing	3	23.4148*	139.491 NS	122.745 NS
Interaction (row×plant)	6	18.0426*	199.335*	129.030*
Error	22	104.060	1831.69	1639.85

* Significant at 5% level, NS = non-significant

Appendix V. Analysis of variance of the data on number of branches plant^{-1} of quinoa as influenced by row and plant spacing

Sources of variation	Degrees of freedom	Mean square value of number of branches plant^{-1} at		
		25 DAS	50 DAS	Harvest
Replication	2	0.38111	8.3078	0.2744
Row spacing	2	0.10778 NS	3.5144 NS	1.4044 NS
Plant spacing	3	1.34222*	15.8667*	15.2548*
Interaction (row×plant)	6	0.96556 NS	13.1456*	8.4681*
Error	22	0.50444	7.6181	4.5581

* Significant at 5% level, NS = non-significant

Appendix VI. Analysis of variance of the data on dry weight plant^{-1} of quinoa as influenced by row and plant spacing

Sources of variation	Degrees of freedom	Mean square value of dry weight plant^{-1} at		
		30 DAS	60 DAS	Harvest
Replication	2	0.00771	0.12243	7.2411
Row spacing	2	0.00300 NS	0.22803 NS	17.8178 NS
Plant spacing	3	0.02642*	0.07572 NS	8.8219 NS
Interaction (row×plant)	6	0.00253*	0.11961*	15.5452*
Error	22	0.00263	0.06770	9.2619

* Significant at 5% level, NS = non-significant

Appendix VII. Analysis of variance of the data on effective/ineffective inflorescence plant^{-1} of quinoa as influenced by row and plant spacing

Sources of variation	Degrees of freedom	Mean square values of	
		Effective inflorescence plant^{-1}	Ineffective inflorescence plant^{-1}
Replication	2	3.7011	1.03361
Row spacing	2	0.7511 NS	2.42861 NS
Plant spacing	3	15.0174*	0.84185*
Interaction (row×plant)	6	11.2430*	0.26824*
Error	22	7.2344	0.28611

* Significant at 5% level, NS = non-significant

Appendix VIII. Analysis of variance of the data on yield contributing parameter of quinoa as influenced row and plant spacing

Sources of variation	Degrees of freedom	Mean square values of		
		Seed weight plant^{-1}	Husk weight plant^{-1}	1000-seed weight
Replication	2	12.0933	1.12194	1.06337
Row spacing	2	48.0175 NS	5.81194 NS	0.268586 NS
Plant spacing	3	35.5766*	4.09963*	0.224566 NS
Interaction (row×plant)	6	19.8860*	2.36935*	0.123916 NS
Error	22	13.3829	1.25167	0.416979

* Significant at 5% level, NS = non-significant

Appendix IX. Analysis of variance of the data on yield of quinoa as influenced by row and plant spacing

Sources of variation	Degrees of freedom	Mean square values of			
		Seed yield	Straw yield	Biological yield	Harvest index
Replication	2	0.14678	0.20569	0.69301	11.7441
Row spacing	2	1.74828*	1.16100*	5.74789*	13.7149 NS
Plant spacing	3	0.04697 NS	0.06599 NS	0.14607 NS	23.2042 NS
Interaction (row×plant)	6	0.12103*	0.09729*	0.39780*	16.7498*
Error	22	0.07331	0.06856	0.24366	12.6883

* Significant at 5% level, NS = non-significant

LIST OF PLATES

Plate 1. Experimental details

Plate 2. Field view of a wider spaced (50 cm x 25 cm) plot at 45 DAS

Plate 3. Field view of a medium spaced (40 cm x 15 cm) plot at 45 DAS

Plate 4. Field view of a plot at 60 DAS

Plate 5. Field view of a plot at 75 DAS

Plate 6. Field view of a plot at harvest (85 DAS)