INFLUENCE OF PLANT DENSITY AND SOWING DATE 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 AND SOWING DATE 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 **SHANTA DEBNATH**, Registration number: **15-06692** 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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INFLUENCE OF PLANT DENSITY AND SOWING DATE ON GROWTH AND YIELD OF QUINOA (*Chenopodium quinoa* Willd.)

ABSTRACT

The experiment was carried out in Sher-e-Bangla Agricultural University during the period from October 2021 to March 2022 to evaluate the influence of plant density and sowing date on growth and yield of quinoa. The experiment was laid out in a Split-plot design with three replications having three plant density as 25 plants m^{-2} (P_1), 50 plants m^{-2} (P_2) and 75 plants m^{-2} (P_3) and six sowing dates as 30 October sowing (D_1), 15 November sowing (D_2), 30 November sowing (D_3),15 December sowing (D_4), 30 December sowing (D_5) and 15 January sowing (D_6). Data on different growth parameters, yield components and yield were recorded. The collected data were statistically analyzed. Number of branches $plant^{-1}$(except at harvest), effective branches $plant^{-1}$ at harvest were significantly affected by P_1; ineffective branches $plant^{-1}$ at harvest, dry weight $plant^{-1}$ (except at 25 DAS), 1000-seed weight were significantly affected by P_2 and seed yield and biological yield were significantly affected by P_3 and P_2 but plant height (except at 25 DAS), number of leaves $plant^{-1}$ (except 65 DAS) and harvest index were not significantly affected by plant density. All growth and yield parameters were significantly influenced by sowing date. The sowing date resulted highest plant height (70.71 cm), branches $plant^{-1}$ (16.93), effective branches $plant^{-1}$ (14.09) were obtained from D_4; leaves $plant^{-1}$ (82.23) was obtained from D_3 at harvest. At harvest, highest seed yield (3.23 t ha^{-1}) and biological yield (5.13 t ha^{-1}) were recorded from D_3 and highest straw yield (2.08 t ha^{-1}) was recorded from D_4. Considering interaction effect of plant density and sowing date, all parameters were significantly affected where the interaction of P_3 (75 plants m^{-2}) with 30 November sowing (D_3) resulted highest seed (3.56 t ha^{-1}) and biological yield (5.67 t ha^{-1}). Besides, P_2 (50 plants m^{-2}) with 30 November sowing (D_3) and also P_3 (75 plants m^{-2}) with 15 November sowing (D_2) ensured higher seed yield (3.27 t ha^{-1} and 3.20 t ha^{-1} respectively).

LIST OF CONTENTS

LIST OF CONTENTS (Cont'd)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Con’d)

LIST OF APPENDICES

LIST OF APPENDICES (Con'd)

LIST OF PLATES

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
EC	=	Electrical conductivity
e.g.	=	exempli gratia (L), for example
etc.	=	Etcetera
et al.	=	And others
FAO	=	Food and Agriculture Organization
fed^{-1}	=	Per feddan
g	=	Gram
GI	=	Glycemic Index
GYP	=	Grain yield per plant
ha	=	Hectare
i.e	=	id est (L), that is
kg	=	Kilograms
LSD	=	Least Significant Difference
m^2	=	Meter squares
mg	=	Milligram
MoP	=	Muriate of Potash
MS	=	Master of Science
No.	=	Number
NSB	=	National Seed Board
%	=	Percentage
SAU	=	Sher-e-Bangla Agricultural University
TSP	=	Triple Super Phosphate

CHAPTER I

INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd) is a dicotyledonous pseudocereal herbaceous plant belongs to the family Amaranthaceae which first originated in the Andean region of northwestern South America. It is pronounced as KEEN-Wah. It is a grain crop and it has been cultivated in the Andean region for centuries to consume the seeds and leaves (Jacobsen, 2017). Bolivia, Peru, Ecuador, Argentina, Chile and Colombia are the top producers of quinoa grains and quinoa cultivation is now spreading in other countries (about 123) including France, England, Sweden, Denmark, Holland, Italy, Kenya, India, Morocco, China, Thailand, Australia, Canada and United States (Alandia *et al*., 2020). More than 6000 different types of quinoa are grown by farmers worldwide (Wilfredo *et al*., 2015).

However, during the past three decades, quinoa cultivation and consumption have gained popularity on a global scale (Wu *et al*., 2017). For a very long time, it has been known that quinoa offers greater nutritional content than regular cereals (White *et al*., 1955). The percentages of protein, crude fat, carbohydrates, ash, and raw fiber in quinoa seeds range from 10 to 18%, 4.5 to 8.5%, 54.1% to 64.2%, and 2.1% to 2.4%, respectively (Jancurová *et al*., 2009). Quinoa is complete protein that contains all essential amino acids including lysine, isoleucine, methionine, histidine, cystine and glycine which are rare and often a limiting factor in cereals and legumes (Repo-Carrasco *et al*., 2003). Quinoa is a gluten-free protein which is helpful for celiac disease patients (Gordillo-Bastidas *et al*., 2016). The ash has been found to primarily consist of potassium and phosphorus (65% of total) and also containing high amount of calcium, iron, zinc, copper and manganese. Compared to rice, maize, wheat, or oats, quinoa has much greater levels of calcium and iron (White *et al*., 1955). Quinoa also has phytohormones, which make it superior to other plant diets in terms of human nutrition (Vega-Gálvez *et al*., 2010).

Quinoa seeds have a lower glycemic index (53) than white rice (73) which benefits those with diabetes and obesity (Atkinson *et al*., 2008). The digest ability of quinoa protein is more than 80%. Quinoa provides a variety of antioxidant phytonutrients including ferulic, coumaric, hydroxybenzoic and vanillic acid. Antioxidant flavonoids including quercetin and kaempferol are also plentiful in quinoa. Quinoa also contain natural antioxidants like α-tocopheral, γ-tocopheral and phytoestrogens that prevent chronic diseases such as osteoporosis, breast cancer, heart diseases and other feminine problems caused by lack of oestrogen during menopause. Hence, FAO (UN General Assembly) declared 2013 as 'International year of Quinoa' (Bhargava *et al*., 2006).

Although quinoa is typically produced for its seeds, certain studies have highlighted the nutritional value of its leaves. Quinoa leaves are a potent source of nutrients, including protein (27-30 g kg^{-1}), sodium (289 mg 100 g^{-1}), ash (3.3%), fiber (1.9%), nitrates (0.4%), and other bioactive substances (vitamin E (2.9 mg-TE 100 g^{-1}) and vitamin C (1.2-2.3 g kg^{-1}). Quinoa leaves can be eaten like spinach or in salads (Bhargava *et al*., 2006). It has been demonstrated that quinoa leaves have larger levels of proteins and essential amino acids than amaranth and spinach leaves, while having lower levels of carbohydrates (Pathan *et al*., 2019). An important aspect regarding the nutritional value of quinoa leaves is that the content of anti-nutritional factors such as phytic acid, oxalates, saponins, the trypsin inhibitor or α-amylase is low (0.03–0.06 g 100 g^{-1} fw; 0.11–0.25 g 100 g^{-1} fw; 0.07–0.15 g 100 g^{-1} fw; 0.34–0.62 TUI mg^{-1} fw; and 0.13–0.31 g·100 g^{-1} fw, respectively) (Stoleru *et al*., 2022).

Quinoa (*Chenopodium quinoa* Willd.) is adapted to a variety of agroecological conditions globally and resistant to abiotic stresses like drought, cold, and salt

(Ruiz *et al.*, 2014). Quinoa could survive 4000 m above the sea level and in temperatures -8 and 38^0c and able to cope with high salinity levels (approximately 50 ds/m).

Despite this large ecological range, substantial yield variations are seen depending on the variety, soil, water, climate, and agronomic practices (Scanlin and Lewis, 2017). For instance, a considerable diminution in yield occurs when temperatures are high during the flowering and grain filling phases (Hinojosa *et al.*, 2018). In actuality, grain production is decreased by 23% to 31% during the flowering phase when nighttime temperatures are between 20 and 22 °C (Lesjak and Calderini, 2017).

The sowing technique is a crucial agronomic strategy for a novel crop, like quinoa, to achieve a targeted high yield under field conditions. The first stage is to determine the best time to plant, which serves as a foundation for the development of the suitable manufacturing technology, particularly for a novel crop in a particular region (Sajjad *et al.*, 2014). Because the emergence of seedlings affects plant density and final output, finding the best time to sow is one of the most crucial tasks in quinoa farming. Seeds are sown depending on location, variety, soil moisture and sowing depth and climate variables like temperature, photoperiod, solar radiation, and other biotic elements, as well as the sowing date, all have a significant impact on the growth and productivity of the quinoa crop (Hirich *et al.*, 2014). The sowing density is the most significant agricultural practice that influences crop performance. Each cultivation method has a plant density that allows for the achievement of the optimum output while maximizing the consumption of the resources that are available (such as water, fertilizers, and daylight). Quinoa yields increase at low densities, with branch system alterations compensating for the smaller plant spacing and higher yields were reported per unit area under high density treatment (200,000 plants ha^{-1}) (Dao *et al.*, 2020). Quinoa development can be slowed down or obstructed by dense plant populations.Quinoa is now very popular as a ‘‘superfood’’ for its wide adaptability and nutritional quality. With its nutritional demand kept in mind, cultivation of quinoa in Bangladesh will be the great contribute to our agriculture sector.

National Seed Board (NSB) has registered ‘‘SAU Quinoa-1’’ to disseminate the crop throughout Bangladesh. Quinoa may be grown throughout the rabi season even though it is a cold-weather crop. The month of November is ideal for quinoa farming in Bangladesh (Biswas and Tanni, 2020).

As the winter is very short in Bangladesh, it is of immense need to find out the suitable plant density and sowing date having narrow gap to sustain the food as well as nutritional security of the country. Considering these facts, the study has been designed with the following objectives:

i. To find out the optimum plant density of quinoa.
ii. To identify the suitable sowing date for maximum yield of quinoa, and
iii. To find out the best combination of population density and sowing date for quinoa cultivation in Bangladesh.

CHAPTER II

REVIEW OF LITERATURE

Quinoa has a high monetary worth and superior nutritional qualities. Its composition has caught the attention of the scientific community for its excellent nutritional value, being rich in proteins, fats, fibers, vitamins, and minerals, with an extraordinary balance of essential amino acids. Additionally, it is gluten-free, making it suitable for usage by celiac disease patients and it has low glycemic index (GI) which is helpful for diabetic patients. Despite all of these qualities, there aren't enough studies done on this pseudo-cereal because people don't know enough about its advantages. This chapter aims to review the relevant research on the impact of plant density and sowing date on growth, yield characteristics, and quinoa yield that is relevant to the current study under the following heads.

2.1 Influence of plant density on growth and yield of quinoa

2.1.1 Growth

An experiment was carried out by Ghosh (2021) in Sher-e-Bangla Agricultural University, Dhaka, Bangladesh and found the highest number of leaves plant^{-1} from wider plant spacing (P_4: 30 cm).

Minh *et al*. (2020) conducted an experiment in the rainy and dry seasons of 2018/2019 using four quinoa genotypes and four plant densities (13.3, 10.0, 8.0 and 6.6 plants m^{-2}). The findings demonstrated that polynomial trends on panicle length, panicle number plant^{-1}, seed number panicle^{-1}, 1000-seed weight, seed yield, protein content, and ash content were strongly influenced by plant density. According to the research, 8.0 plants per square meter seems to be the ideal plant density for quinoa.

An appropriate seeding rate allows to development of strong, well-branched plants. Gesinski (2018) by using a planting rate of 3 kg ha^{-1} instead of 2 kg ha^{-1}, quinoa yield was increased.

Jacobsen (2017) emphasizes how quinoa can fill up any residual gaps between plants by altering the agro-morphological structure of its branches. The results of this study demonstrate that plants are more productive per unit area at high density rates (D_1: 200,000 plants ha^{-1}), such as in Titicaca, but not in terms of gross annual yield (GYP), which is highest at low density rates. Titicaca showed a clear correlation between production per unit area and density rate.

Pourfarid *et al*. (2014) evaluated two genotypes of amaranth, Amar and Anna, grown at four densities (17, 35,70, and 140 plants m^{-2}), by hand thinning at a 30-cm row spacing, and discovered that plant density levels in Tehran had no appreciable impact on plant height.

Rojas and Pinto (2013) indicate how the branching system has a normally branch to second third panicle as a result of the large distance between plants (20 and 25 cm). In general, a common response of plants is to grow new branches in existing gaps. This occurs as a result of nearby plants reflecting canopy gaps and variations in the red/far-red light ratio. As a result, it influences branch direction in addition to increasing stem elongation properties. These findings are consistent with those made public by Risi and Galwey (1991), who found that the number of branches increased for Amarilla de Marangani, Blanca de Junin, and Baer at low density rates.

Lower plant density resulted in increased plant branching and roughly 50–60% of the total seed yield coming from secondary panicles, while higher plant density increased seed yield per area by primarily contributing to reduce branching and produce a higher proportion of seed yield from main panicles (Ebrahim *et al*., 2018).

According to Spehar and Rocha (2009), several research in tropical conditions demonstrate that plant height decreases as plant density rises (from 100,000 to

600,000 plants per hectare) and that branching systems expand at low seeding densities.

2.1.2 Yield

An experiment was conducted by Wali *et al*. (2022) in Egypt and results revealed that increased plant density from 20,000 to 36,000 plants fed^{-1} significantly increased the biological yield, seed yield.

Zulkadir (2021) carried out research to determine the best row spacing and sowing time for quinoa in Karamanmaras under Mediterranean climate conditions. Between March 15 and May, there are four sowing dates with a 15-day gap and row spacings of 20, 40, and 60 cm. The results showed that the maximum grain and plant production was achieved at a 20 cm spacing for sowing in early or late April.

A field experiment was conducted by Ghosh (2021) to find out the best row spacing and plant spacing for quinoa cultivation and found higher seed yield of quinoa (2.15 t ha^{-1}) maintaining 50 cm x 20 cm spacing.

Hammad *et al*. (2021) conducted a field experiment at the faculty of agriculture and natural resources' experimental farm during the 2018–19 and 2019–20 growing seasons and found that seed yield increased by 39.83 and 50.38% with increase of plant density from 56,000 to 84,000 plant fed^{-1} in the 1st and 2nd seasons, respectively.

Wang *et al*. (2020) conducted a study and the results revealed that the yield under 20 plants m^{-2} reached 39.5 g plant^{-1}, which was 13.5 g plant^{-1} higher than 40 plants m^{-2}.

A study was conducted by Dao *et al*. (2020) to know the effectiveness of various genotypes (Titicaca, Puno, Pasankalla, and Negra Collana) to various planting methods (ridges, dibbling, broadcasting, transplanting, traditional-pits, and flat sowing) and sowing density rates (from 80,000 to 200,000 plants ha^{-1}) in two separate experiments in Burkina Faso. The result showed higher yields at low densities, with branch system alterations compensating for reductions in plant spacing. However, under high density treatments (200,000 plants ha^{-1}), greater yields per unit area were recorded (Titicaca with 98.8 g m^{-2}). On conclusion, it was advised to employ short cycle varieties (Puno and Titicaca) sown in ridges at high density rates.

According to Erazzu *et al*. (2016) increasing plant density from 70,000 to 460,000 ha^{-1} resulted in a reduction in grain yield from 5,389 to 3,049 kg ha^{-1}. In addition, they discovered that at low planting densities, seeds' protein and ash concentrations rose while their carbohydrate concentration fell.

Sief *et al*. (2015) conducted field experiments at the Ismailia Agriculture Research Station, Agriculture Research Center, Ismailia, Egypt, for two consecutive winter seasons in 2012–2013 and 2013–2014 to determine the best planting procedures, which included three interrow spacings (20, 30 and 40 cm) and three intra plant spacings (10, 15 and 20 cm) and their combination. The results showed that the narrowest row spacing (20 cm) and plant spacing (20 cm) with a significant interaction effect in each of the two seasons provided the best grain yield of quinoa. This outcome was acceptable because of the plants' well-balanced dispersal, which lessened competition for all of the plants' enormously important current needs, including germination, seed emergence, growth, and development, which had an impact on output and quality.

By increasing the intra spacing between plants, i.e., 10,15 and 20 cm, a substantial loss in grain production was obtained. However, at wider plant interspaces of 30 and 40 cm, increases in intra spaces of 10, 15 and 20 cm between plants induce sub stand increases in grain output in the first and second seasons, with notable variances in the first seasons. This may be attributed to the proper plant distribution, which reduces plant competition and enables it to make the most of the environment around it.

According to Olofintoye *et al*. (2015), in a sandy loam soil at the National Horticultural Research Institute of Nigeria, the seed yield of amaranth was significantly higher at a planting density of 60000 plants ha^{-1} (3330 kg ha^{-1}) than it was at planting densities of 100000 plants ha^{-1} (2799 kg ha^{-1}) and 40000 plants ha^{-1} (3211kg ha^{-1}) and dry matter production (g $plant^{-1}$) was found to be significantly higher with planting density of 40000 plants ha^{-1} (157.01g $plant^{-1}$) than planting density of 100000 plants ha^{-1} (139.11 g $plant^{-1}$) and 60000 plants ha^{-1} (153.94 g $plant^{-1}$).

At the National Horticultural Research Institute in Nigeria, researchers studied two varieties of amaranth, TE81/28 and CEN18/97, planted at three different planting densities (100000, 60000 and 40000 plants ha^{-1}). They discovered that planting density had no discernible impact on the biological yield of the amaranth crop (Olofintoye *et al*., 2015).

According to Pourfarid *et al*. (2014), at Tehran University, the total dry matter output of amaranth was significantly larger at a planting density of 140 plants m^{-2} (2.41 kg) than it was at 17 plants m^{-2} (0.33 kg), 35 plants m^{-2} (0.62 kg), and 70 plants m^{-2} (1.13 kg), respectively and the grain production was significantly higher at planting density of 140 plants m^{-2} (1.04 kg ha^{-1}), compared to planting density of 17 (0.18 kg ha^{-1}), 35 (0.29 kg ha^{-1}), and 70 (0.73 kg ha^{-1}) when the Amar and Anna types of amaranths are examined. They examined two amaranth genotypes, Amar and Anna, at four densities (17, 35,70 and 140 plants m^{-2}), by hand thinning at a 30-cm row spacing, and discovered that 140 plants m^{-2} in Tehran produced the highest yield.

With one quinoa cultivar and two planting densities of 56.000 plants per hectare (low) and 167.000 plants per hectare (high), two field tests were carried out during two consecutive growing seasons in a marginal land at the El-Fayoum oasis in Egypt in 2015 and 2016. The result showed that plant density increased from 56.000 to 167.000 plants per hectare, increased seed yield by 34.7% (Eisa *et al*., 2018).

In their 2009 study, Spher and Rocha (2009) examined the effects of increasing plant densities (100,000–600,000 plants ha^{-1}) on quinoa genotype 4.5 in Brazilian Savannah conditions. They discovered that while low plant densities increased 1000-seed weight, increasing plant densities had no significant effects on these variables.

The maximum quinoa seed output was reported to be 6,960 kg ha^{-1} with a row spacing of 20 cm and a sowing density of 20 kg seed ha^{-1} (Risi and Galwey, 1991).

2.2 Performance of quinoa at different dates of sowing

2.2.1 Growth

A field experiment was carried out by Taaime *et al*. (2022) in the Rehamna region in 2020-2021 to examine the impact of the sowing date on quinoa growth, development, and yield. Two cultivars, ICBA-Q5 and Titicaca, and five sowing dates from 15 November to 15 March were evaluated. Results revealed that because of heavy precipitation, ideal temperatures, and a short photoperiod, seeding in December increased plant height, total leaf area, and the number and dry weight of branches, leaves, and panicles. For both cultivars, late sowing slowed down development and shortened the time for panicle emergence, blooming, and maturity. Early sowing of ICBA-Q5 is recommended to increase quinoa yield in arid regions of Morocco.

An experiment was conducted Biswas *et al*. (2021) at Sher-e-Bangla Agricultural University, Dhaka during rabi season and reported highest number of leaves $plant^{-1}$ (84.67) of quinoa in Bangladesh with November 20 sowing maintaining 30 cm x

10 cm spacing.

Hammad *et al*. (2021) conducted a field experiment at the faculty of agriculture and natural resources' experimental farm during the 2018–19 and 2019–20 growing seasons to determine the best planting time and plant density for quinoa cv. Regalona grown in sandy soil with drip irrigation where planting dates (P_1: 10^{th} October, P_2: 25^{th} October and P_3: 10^{th} November) were occupied main plots and plant density (D_1:56.000, D_2:70.000 and D_3:84.000 plant fed^{-1}. The results showed that planting quinoa on October 10 produced the highest plant heights, inflorescence plant counts, and chemical compositions in both seasons.

Biswas and Tanni (2020) carried out a field experiment at experimental farm, department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka during November, 2017 to July, 2018. to identify the suitable planting date on growth, yield and its quality of quinoa and identified that Titicaca produced the highest plant height at harvest (72.83 cm), branches plant^{-1}(25.20) when it was seeded in November -10.

In order to achieve the best agricultural transactions under the circumstances of Central Egypt, Nagib *et al*. (2020) conducted a field experiment at the nursery of ornamental plants, Faculty of Agriculture, Minia University during the 2018/2019 and 2019/2020 seasons to examine the effect of three planting dates (November 1st, November 15th, and December 1st) on growth, yield, and chemical composition of quinoa plants in order to achieve the best agricultural transactions under the circumstances of Central Egypt. The results advised to cultivate the quinoa on November 15th under Central Egypt conditions because it gave the best results for economic qualities.

According to Hinojosa *et al*. (2018) quinoa has a strong flexibility in response to high temperature, although pollen viability and pollen wall structure were impacted by high temperatures in the anthesis stage and heat stress reduced the pollen viability between 30% and 70%.

A field experiment was conducted at college farm, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad during rabi 2015-16 to test three dates of sowing (D_1:15th October, D_2:1st November and D_3:16th November). The date of sowing, October15, yielded higher crop growth rates (Devi *et al*., 2017).

In Bornova-Izmir, Turkey, under Mediterranean ecological conditions, Geren *et al*., (2020) studied six sowing dates: 1st March, 15th March, 1st April, 15th April, 1st May, and 15th May. They discovered that plant height at 1st April (111.7 cm) and at 15th April were comparable to one another and propagated significantly taller than 1st March date of sowing.

Because the plant life cycle is constrained by temperature and photoperiod, Parvin *et al*. (2013) showed that delaying sowing lowered plant height, number of inflorescence plant^{-1}, leaf area plant^{-1}, shoot dry weight, and grain yield plant^{-1}and showed how Amaranth plant height fluctuated depending on when it was sown and discovered that plant height at 10 April (83.5 cm) was much taller than 26 March (52.6 cm) and 25 April (52.5 cm) at 40 days after sowing.

Fernando *et al*. (2012) evaluated the quinoa crop at Campo Mourao, Brazil, on six different dates (18 March, 2 April, 17 April, 2 May, and 10 June) in 2008. They discovered that the plant height at 18 March (77.5 cm) and at 17 April were comparable to one another and significantly taller than the 2 May date of sowing in the off-season.

Troiani *et al*. (2004) studied with *Amaranthus cruentus* L. in the semi-arid Argentine Pampa to determine the ideal sowing window for grain production and discovered that plant height was higher when seeding was completed from the second part of November to the end of December.

2.2.2 Yield

A field experiment was carried out Taaime *et al*. (2022) in the Rehamna region in 2020–2021 to examine the impact of the sowing date on quinoa growth, development, and yield. Two cultivars, ICBA-Q5 and Titicaca, and five sowing dates from 15 November to 15 March were evaluated. The results showed that because of the high precipitation, ideal temperatures, and short photoperiod, seeding in December increased plant productivity. The highest grain yield (0.84 t ha^{-1}) was obtained with ICBA-Q5 and late sowing decreased the yield. To increase quinoa productivity in Morocco's arid regions, early ICBA-Q5 sowing is advised. Grain yield is more influenced by the environment and the genotype–environment interaction (Thiam *et al*., 2021) and showed that Titicaca presented the best harvest index (69.00%) as well as the best 1000-grain weigh (3.4 g).Higher harvest index (87.00%) of quinoa was reported by Rojas (2003).

Hamza *et al*. (2021) carried out an experiment in Gomal University, D.I Khan Pakistan to investigate the best planting date, the most prolific quinoa genotype, and the ideal sowing technique between 2018 and 2020. The dates for sowing were 15 October, 30 October, 14 November, and 29 November. A split split-plot design replicated three times was used to examine two sowing techniques (ridge vs. flat sowing), three farmer varieties (RBDC-I, RBDC-II, and RBDC-III), and one approved quinoa line (Q7). The results showed that, as compared to other sowing dates, quinoa sown on November 14 generated significantly higher panicle length (19.2 cm), 1000-grain weight (2.9 g), and grain yield (2063 kg ha^{-1}). G × SM interaction revealed that RBDC-II sown on ridge produced higher main panicle length (25.4 cm), 1000-grains weight (3.3 g) and grain yield (3171 kg ha^{-1}) compared with other G × SM interaction. The results suggested that RBDC II was the most productive quinoa genotype and sowing on 14 November produced 5–11% and 37.5% more yield compared with earlier and later sown quinoa, respectively.

Hammad *et al*. (2021) conducted a field experiment at the faculty of agriculture and natural resources' experimental farm during the 2018–19 and 2019–20 growing seasons to determine the best planting time and plant density for quinoa cv. Regalona grown in sandy soil with drip irrigation where planting dates (P_1: 10th October, P_2: 25th October and P_3: 10th November) were occupied main plots and plant density (D_1:56,000, D_2:70,000 and D_3:84,000 plant fed^{-1}. The results showed that the highest seed yield obtained in the 1st date (10-October) 753.60 and 767.93 kg fed^{-1} in both seasons, respectively.

The field experiment was conducted Ram *et al*. (2021) during rabi (winter) season at Agricultural Research Station, Mandor, Jodhpur and aimed at identifying the optimum sowing time with suitable crop geometry and identified that quinoa crop sown between 15th November and 25th November with plant geometry of 30 cm x 30 cm for higher seed yield in western Rajasthan.

Biswas and Tanni (2020) carried out a field experiment at experimental farm, department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka during November, 2017 to July, 2018 to identify the suitable planting date on growth, yield and its quality of quinoa and results revealed that Titicaca produced the highest 1000-seed weight (2.58 g), seed yield (1.16 t ha^{-1}), and straw yield (1.33 t ha^{-1}) when it was seeded in November -10.

A study was conducted in Igdir University , faculty of Agriculture, department of field crops, Igdir, Turkey to examine the effects of different sowing (middle of March, end of March, beginning of April and middle of April) and harvesting (the end of vegetative stage, beginning of the flowering and the full flowering) periods on herbage yield and quality performance of quinoa and found that higher plant height, dry matter and crude protein yields were obtained from plants sown at the end of March and harvested at full flowering (Temel and Yolcu, 2020).

A research was carried out by Casini (2019), aimed at identifying the suitable sowing date of quinoa in Central Italy and identified that anticipated photoperiod and radiation were important determinants of plant growth and yield. Hirich *et al*. (2014) conducted a field study in the south of Morocco to investigate the effects of sowing date on quinoa performance in a series of experiments and found the highest seed yield and dry matter yield of quinoa in November and early December sowing.

According to Shams and Galal (2014) sown quinoa on December 15 under Egyptian climate conditions, and resulted the highest plant height, main head weight, grain yield plant^{-1}, and weight of 1000 grains. Quinoa test weights on March 1 (3.4 g) and May 15 (3.2 g) in Bornova-Izmir, Turkey, under Mediterranean ecological conditions, did not differ significantly from one another but 1st April (217.9 kg ha^{-1}) and 15th April (216.6 kg ha^{-1}) produced significantly higher seed yield of quinoa than 1st March (150.6 kg ha^{-1}) (Geren *et al*., 2020).

Sajjad *et al*. (2014) conducted a study at University of Faisalabad, Pakistan and found that 15th December (285.93 kg ha^{-1}) produced significantly higher grain yield than 15th January (215.18 kg ha^{-1}) date of sowing and higher stalk yield of quinoa (6994 kg ha^{-1}) in 15th December than 15th January (6519 kg ha^{-1}) date of sowing and test weight of 15th December (2.70 g) date of sowing was significantly higher than 15th January (2.60 g) date of sowing.

According to Chaudhari *et al*. (2009) grain amaranths had considerably longer panicles on their 1st November (44.6 cm) and 15th November (39.4 cm) planting dates than on their 15th December (32.7 cm) sowing date and grain yield of amaranths in 1st November (1232 kg ha^{-1}) and 15th November (1171 kg ha^{-1}) date of sowing were at par with each other and significantly higher than 15th December date of sowing and also found that 1st November (0.60 g) and 15th November (0.56 g) obtained significantly higher test weight of grain amaranthus than 15th

December (0.49 g) date of sowing. At Navsari, Gujarat, Chaudhari *et al*. (2009) discovered that amaranth seeds sown on November 1 produced a much higher B: C ratio (2.61) than seeds sown on December 15.

Numerous authors have highlighted that the ideal planting date and plant spacing have positive effects on the development, yield, and chemical makeup of various plant species. Bhargava *et al*. (2007) and Sief *et al*. (2015) discovered that the best quino growth and yield were obtained due to 25 cm spacing and 15 November sowing date, while late sowing date (during December1) caused the lowest yield regardless of plant spacings (10, 20 and 25 cm).

At Amity University, Lucknow, India, Bhargava *et al*. (2007) tested the effects of three sowing dates (November 15, 30 and December 15) on the protein content of quinoa leaves and discovered that the 30th November's (3.88%) leaf protein content was significantly higher than the 15th December's (3.50%).

Amaranthus cruentus L. field trials were conducted in the semi-arid Pampa region of Argentina to determine the best sowing date. It was discovered that sowing done from the second half of November to the end of December recorded a significantly higher harvest index as compared to the other sowing dates (Troiani *et al*., 2004).

CHAPTER III

MATERIALS AND METHODS

The present investigation entitled "Influence of plant density and sowing date on growth and yield of Quinoa (*Chenopodium quinoa* Willd.)" was carried out during Rabi season at the Agronomy field of Sher-e-Bangla Agricultural University, Dhaka-1207. The materials and methods for this experiment include a brief explanation of the experiment's location, the soil conditions, the climate in the area, the materials utilized, the design of the experiment, data collecting, and data analysis procedures. Under the following topics, a detailed summary of the materials and methods used for this experiment is provided below.

3.1 Description of the experimental site

3.1.1 Experimental period

The experiment was conducted during the month of October, 2021 to March, 2022.

3.1.2 Experimental location

The experiment was done at the Research Farm of Sher-e-Bangla Agricultural University (SAU), Dhaka and it was located in 23° 77' N latitude and 90^{o} 33' E longitude and altitude of 8.2 m above the sea level. The experimental site was shown in Appendix I.

3.1.3 Characteristics of soil

The experimental field's predominant soil type was Deep Red Brown Terrace soil, which was a part of the Tejgaon series under the Agro-ecological Zone, Madhupur Tract (AEZ-28). 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 experimental site was level, had a drainage and irrigation system, and was above flood level. The selected plot was a medium-high piece of land. The characteristics of soil was described in Appendix III.

3.1.4 Climatic condition

The experimental site's climate was subtropical, with three different seasons: Rabi from November to February, Kharif-I, the hot pre-monsoon season, from March to April, and Kharif-II monsoon season, from May to October. The combined monthly averages for temperature, relative humidity, and rainfall during the crop-growing season was conducted from the Bangladesh Meteorological Department's Weather Yard and presented in Appendix IV.

3.2 Experimental details

3.2.1 Treatments of the experiment

The experiment comprised of two factors

Factor A: Planting density

i) 25 plants m^{-2} – P_1
ii) 50 plants m^{-2} – P_2
iii) 75 plants m^{-2} – P_3

Factor B: Sowing date

i) October 30 – D_1
ii) November 15 – D_2
iii) November 30 – D_3
iv) December 15 – D_4
v) December 30 – D_5
vi) January 15 – D_6

3.2.2 Planting material

The Agronomy department of Sher-e-Bangla Agricultural University provided the seeds of quinoa variety “SAU Quinoa-1”. The seed's ability to germinate was examined before planting.

3.2.3 Germination test

Before planting the seeds in the field, a germination test was conducted. Petri dishes were covered with filter paper, which had been moistened with water. Randomly selected 50 seeds were placed in each petri dish for germination. After 24 hours, the seed began to emerge, and by 48 hours, it was fully developed. The variety's germination rate was reported to be greater than 80%.

3.2.4 Experimental design and layout

The experiment was laid out in a split-plot design having three plant density and six sowing date with three replications. An area of 15.25 m × 14.5 m was divided into three blocks. Different plant densities were assigned in the main plot and sowing dates in sub-plot. The size of each unit plot was 2 m × 1.25 m. The space between two blocks and two plots were 0.50 m and 0.50 m, respectively. Experimental design and layout was shown in Appendix II.

3.2.5 Land preparation

The experimental field was ploughed on 24 October 2021 with the help of a tractor drawn disc plough, later 27 October 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 29 October 2021 according to experimental specification.

3.2.6 Fertilizer application

The 150-100-100-55-5 kg ha^{-1} of N-P_2O_5-K_2O-S-Zn in the form of Urea, TSP, MoP, gypsum and Zn respectively were used for this experiment. One third urea and the entire amounts of other fertilizers and cowdung (5 t ha^{-1}) were 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).

3.3 Growing of crops

3.3.1 Sowing of seeds in the field

The seeds of Quinoa were sown as per treatment in solid rows in the furrows having a depth of 2-3 cm and maintaining row to row distance of 25 cm.

3.3.2 Intercultural operations

3.3.2.1 Mulching

The top soil was broken down and a natural mulch was maintained at 15 DAS.

3.3.2.2 Thinning

Four days after being sown (DAS), seeds began to germinate. To maintain the best plant population in each plot, thinning was done twice: once at 15 DAS and again at 25 DAS.

3.3.2.3 Irrigation, drainage and weeding

In order to maximize the vegetative growth of Quinoa for all experimental plots equally, irrigation was given as and when necessary. The crop field needed to be weed free and hence two weeding were done manually for all treatments at 15 and 30 DAS.

3.3.2.4 Plant protection measures

At stage of seed sowing Sevin powder with seed before sowing was mixed to prevent ant attack. Plants were infested with aphid to some extent which was successfully controlled by applying Imitaf 20SL.

3.4 Crop sampling and data collection

Five plants from each plot were randomly selected and marked with sample card. Plant height, number of branches plant^{-1}, number of leaves plant^{-1}, number of inflorescence plant^{-1}, inflorescence diameter, fresh weight of biomass plant^{-1}, dry weight of biomass plant^{-1}, dry matter content of seed, seed weight were recorded at different DAS and at harvest.

3.5 Harvest and postharvest operations

The experimental crop was considered to be mature when 80% of the flower turned reddish yellow. The crops were harvested, sun-dried, threshed, and weighed to a certain moisture content. To get a safe moisture level in the seeds, they were separated, cleaned, and dried in the sun for 3 to 5 days.

3.5.1 Threshing

The crop was spread out on the open threshing floor for three days to be sun dried. Hand threshing was used to separate the seeds from the plant.

3.5.2 Drying, cleaning and weighing

The seeds were then dried in the sun to maintain a constant level of moisture in the seeds. Both the straw and the dried seeds were cleaned and weighed.

3.6 Data collection

Throughout the experiment, data were collected on the following parameters.

A. Crop growth characters

a) Plant height at different days
b) Number of leaves plant^{-1} at different days
c) Number of branches plant^{-1} at different days
d) Dry weight plant^{-1} at different days

B. Yield and other crop characters

a) Effective branches plant^{-1}
b) Ineffective branches plant^{-1}
c) Seed weight plant^{-1}
d) Straw weight plant^{-1}
e) 1000- seed weight
f) Seed yield
g) Straw yield
h) Biological yield
i) Harvest index

3.7 Procedure of data collection

3.7.1 Crop growth characters

a) Plant height

The height of plant was recorded in centimeter (cm) at 25, 45, 65 DAS and harvest. Five randomly chosen plants from each plot were used to gather data, and average plant height was recorded for each treatment. The height was calculated from the ground up to the main shoot's leaf's tip.

b) Number of leaves plant^{-1}

Five tagged plants' total leaves were counted from each plot at 25, 45, 65 DAS, and harvest; the average was noted as number of leaves plant^{-1}.

c) Number of branches plant^{-1}

Five tagged plants' total branches were counted from each plot at 25, 45, 65 DAS and harvest. Number of branches plant^{-1} was the average figure recorded.

d) Dry weight plant^{-1}

Five randomly chosen plants from each plot were weighed at 30, 60, and harvest using their dry weights. The average dry weight plant^{-1} was noted.

3.7.2 Yield and other crop characters

a) Effective branches plant^{-1}

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

b) Ineffective branches plant^{-1}

Ineffective branches 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}.

c) Seed weight plant^{-1}

The seeds of five different plants' were weighed, averaged, and reported as seed weight plant^{-1} and expressed as gram (g).

d) Straw weight plant^{-1}

The combined husk weight of five plants' was measured, averaged, and reported as husk weight plant^{-1} and expressed as gram (g).

e) 1000- seed weight

The seed sample, 1000 cleaned and dried seeds from each plot were manually counted and weighed with an electrical balance. After that, a balance with an electrical charge weighed the seeds. The data were recorded in gram.

f) Seed weight

Based on the entire harvested area plot^{-1} (1 m^{2}) departing the boundary lines, the total seed yield was weighed, recorded, and expressed as t ha^{-1} basis.

g) Straw yield

The amount of straw harvested from each plot was sun dried, and the weight of the straw was taken to convert the yield to a ha^{-1} basis.

h) 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**.**

i)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.

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

3.8 Data analysis technique

The collected data were compiled and analyzed statistically using the analysis of variance (ANOVA) technique with the help of a computer package program CropStat and the mean differences were adjudged by Least Significance Difference (LSD) test at 5% level of significance.

CHAPTER IV

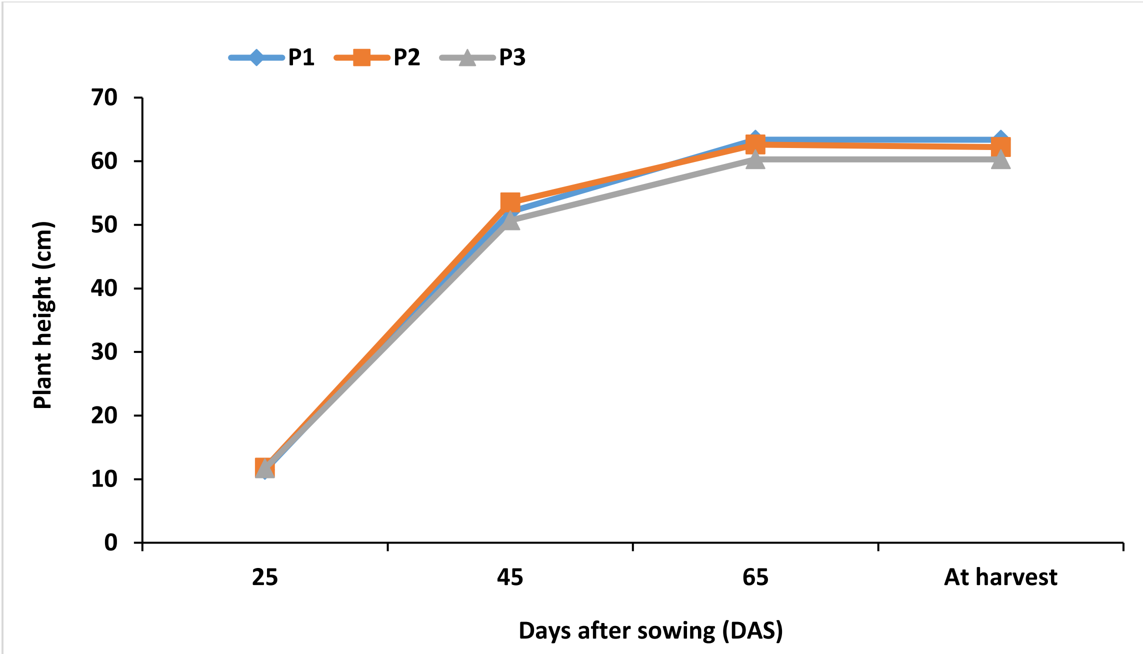
RESULTS AND DISCUSSION

An experiment was carried out to ascertain how plant density and sowing date affected quinoa's growth and yield. The appendices also included the results of the analyses of variance (ANOVA) performed on the data for various parameters. Under the following headings, the results have been presented, discussed, and potential interpretations have been given:

4.1 Plant height

4.1.1 Effect of plant density

Plant height at 25 DAS showed significant variation for different plant densities and at 45 DAS, 65 DAS and at harvest showed non-significant variation (Figure 1 and Appendix V). The result revealed that at 25 DAS, the highest plant height (11.77 cm) was recorded from medium plant density (P_2) which was statistically similar with the plant height of P_3 (11.69 cm) and the lowest plant height (11.42 cm) was recorded from low plant density P_1, which was also statistically similar with the plant height of P_3. At 45 DAS, no significant variations of plant height observed among the treatment though numerically the highest plant height (53.49 cm) recorded from medium plant density (P_2) and the lowest plant height (50.70 cm) recorder from high plant density (P_3). For other analyzed durations (65 DAS and at harvest), a same tendency was also seen. These results were similar with the findings of Pourfraid *et al*. (2014) who reported that plant density levels had no appreciable impact on plant height.

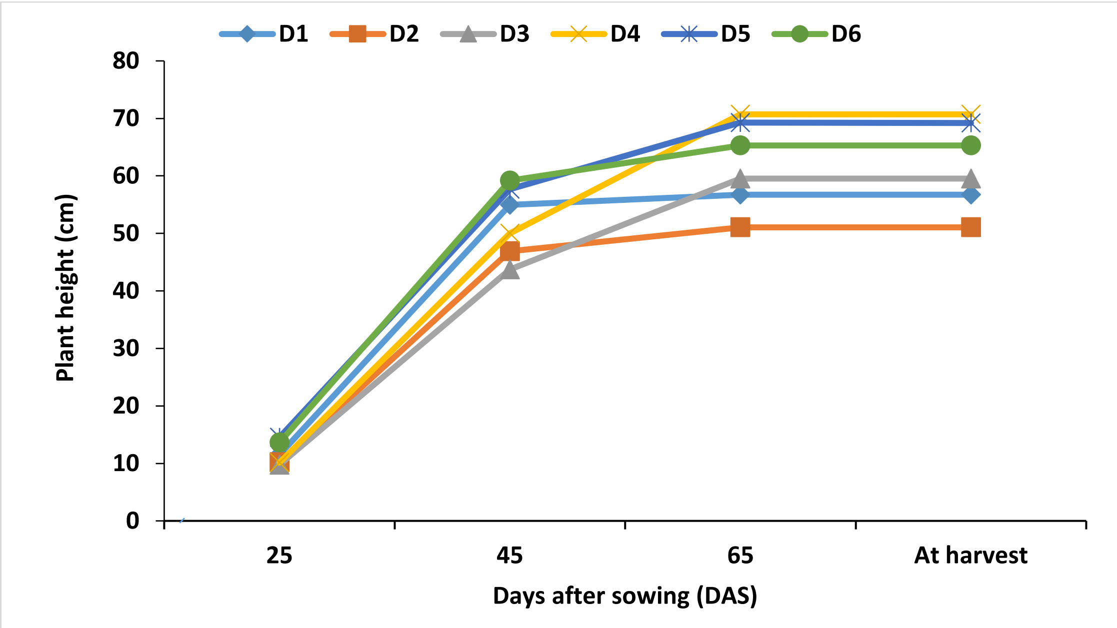


P_1=25 plants m^{-2}, P_2=50 plants m^{-2}, P_3=75 plants m^{-2}

Figure 1. Effect of plant density on plant height of quinoa at different growth stages ($LSD_{(0.05)}$ = 0.32 at 25 DAS and NS at 45, 65 DAS and harvest, respectively).

4.1.2 Effect of sowing date

The results showed that plant height was significantly influenced by different dates of sowing (Figure 2 and Appendix V). At 25 DAS, the highest plant height (14.53 cm) was recorded from 30 December sowing (D_5) and the lowest plant height (9.77 cm) recorded from 30 November sowing (D_3), which was statistically similar with the plant height of 15 November sowing (D_2) (10.18 cm) and D_4 sowing (10.13 cm). At 45 DAS, the highest plant height (59.21 cm) was recorded from 15 January sowing (D_6), which was statistically similar with 30 October sowing (D_1) plant height (54.95 cm) and 30 December sowing (D_5) (57.69 cm) and the lowest plant height (43.74 cm) was recorded from 30 November sowing (D_3), which is statistically similar with 15 November sowing (D_2) (46.91 cm). At 65 DAS, the highest plant height (70.71 cm) was recorded from 15 December sowing date (D_4), which was statistically similar with D_5 plant height (69.27 cm) and the lowest plant height (51.05 cm) was recorded from 15 November (D_2) sowing date. Similar results were recorded at harvest. These results are similar with the findings of Taaimee *et al*. (2022) who observed that because of ideal temperatures and a short photoperiod, seeding in December increased plant height.



D_1= 30 October, D_2= 15 November, D_3= 30 November, D_4= 15 December, D_5= 30 December, D_6= 15 January

Figure 2. Effect of sowing date on plant height of quinoa at different growth stages ($LSD_{(0.05)}$ = 0.544, 4.422, 5.296, 5.282 at 25, 45, 65 DAS and harvest, respectively).

4.1.3 Interaction effect

Interaction effect of plant density and sowing date showed statistically significant variation on plant height at different growth stage (Table 1 and Appendix V). At 25 DAS, the highest plant height (15.07 cm) was recorded from P_2D_5, which was statistically similar with P_3D_5 (14.48 cm) and the lowest plant height (9.72 cm) was recorded from P_1D_3, which was statistically similar with P_1D_2 (10.12 cm),

P_1D_4 (9.96 cm), P_2D_2 (10.29 cm), P_2D_3 (9.88 cm), P_2D_4 (10.13 cm), P_3D_2 (10.14 cm), P_3D_3 (9.73 cm), and P_3D_4 (10.31 cm).

Table 1. Interaction effect of plant density and sowing date on plant height of quinoa at different growth stage

Treatments	Plant height (cm) at			
	25 DAS	45 DAS	65 DAS	Harvest
P_1D_1	11.50 d	58.33 abc	61.09 c-f	61.09 c-f
P_1D_2	10.12 e	46.93 f	50.17 h	50.17 h
P_1D_3	9.72 e	39.02 g	56.29 e-h	56.29 e-h
P_1D_4	9.96 e	48.91 e	73.02 a	73.02 a
P_1D_5	14.04 bc	58.66 abc	70.75 ab	70.75 ab
P_1D_6	13.20 c	60.56 ab	69.01 abc	69.01 abc
P_2D_1	11.53 d	54.77 b-e	55.91 e-h	55.91 e-h
P_2D_2	10.29 e	47.20 ef	52.09 fgh	52.09 fgh
P_2D_3	9.88 e	46.69 f	56.14 e-h	56.14 e-h
P_2D_4	10.13 e	49.27 def	70.51 ab	70.51 ab
P_2D_5	15.07 a	62.69 a	73.83 a	73.83 a
P_2D_6	13.74 bc	60.29 ab	67.16 a-d	67.16 a-d
P_3D_1	11.54 d	57.77 c-f	53.18 fgh	53.18 fgh
P_3D_2	10.14 e	46.59 fg	50.89 gh	50.89 gh
P_3D_3	9.73 e	45.49 fg	66.15 a-d	66.15 a-d
P_3D_4	10.31e	51.84 c-f	68.61 a-d	68.61 a-d
P_3D_5	14.48 ab	51.72 c-f	63.23 b-e	63.23 b-e
P_3D_6	13.95bc	56.79 a-d	59.70 d-g	59.70 efg
$LSD_{(0.05)}$	0.942	7.659	9.172	9.148
CV (%)	4.86	8.82	8.86	8.83

P_1=25 plants m^{-2}, P_2=50 plants m^{-2}, P_3=75 plants m^{-2}, D_1=30 October, D_2=15 November, D_3=30 November, D_4= 15 December, D_5=30 December, D_6= 15 January

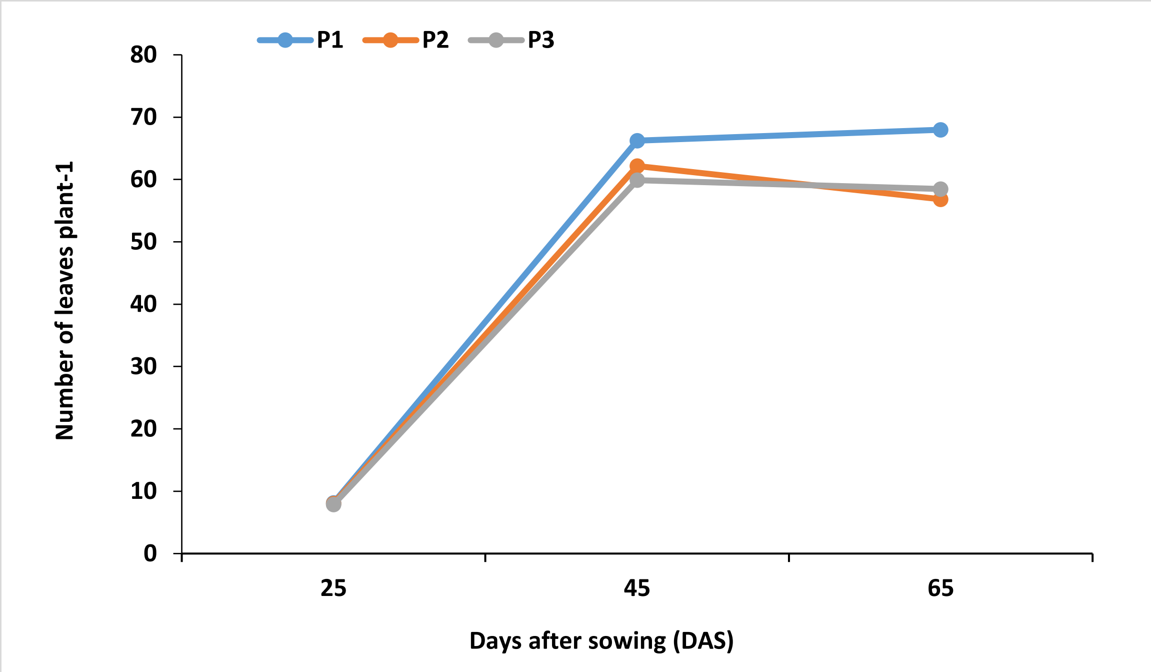
At 45 DAS, the highest plant height (62.69 cm) was recorded from P_2D_5, which was statistically similar with P_1D_1 (58.33 cm), P1D5 (58.66 cm), P_1D_6 (60.56 cm),

P_2D_6 (60.29 cm), P_3D_6 (56.79 cm) and the lowest plant height (39.02 cm) was recorded from P_1D_3, which was statistically similar with P_3D_2 (46.59 cm) and P_3D_3 (45.49 cm). At 65 DAS, the highest plant height (73.83 cm) was recorded from P_2D_5, which was statistically similar with P_1D_4 (73.02 cm), P_1D_5 (70.75 cm), P_1D_6 (69.0 cm), P_2D_4 (70.51 cm), P_2D_6 (67.16 cm), P_3D_4 (68.61 cm) and the lowest plant height (50.17 cm) was recorded from P_1D_2, which was statistically similar with P_1D_3 (56.29 cm), P_2D_1 (55.91 cm), P_2D_2 (52.09 cm), P_2D_3 (56.14 cm), P_3D_1 (53.18 cm), P_3D_2 (50.89 cm), and P_3D_6 (59.7 cm). At harvest, identical result with 65 DAS were observed. This might be due to the minimum interval between the two durations. The highest plant height at harvest by P_2D_5 combination was 47.16% high compared to that of the lowest plant height of P_1D_1. Risi and Galwey (1991) and Biswas and Tanni (2020) also reported the variation of quinoa plant height for different sowing dates and plant densities.

4.2 Number of leaves plant $^{-1}$

4.2.1 Effect of plant density

There were no significant variations observed on number of leaves plant^{-1} at different growth stages (25 DAS and 45 DAS) except at 65 DAS (Figure 3 and Appendix VI). At 25 DAS, numerically the highest leaves number plant^{-1}(8.14) was obtained from low plant density (P_1) and the lowest leaves number plant^{-1} (7.87) was obtained from high plant density (P_3). At 45 DAS, numerically the highest leaves number plant^{-1} (66.23) was obtained from low plant density (P_1) and the lowest leaves number plant^{-1} (59.89) was obtained from high plant density (P_3). At 65 DAS, there was significant variation observed and the highest leaves number plant^{-1} (67.98) was obtained from low plant density (P_1) and the lowest leaves number plant^{-1} (56.84) was obtained from medium plant density (P_2), which was statistically similar with P_3 (58.49). The lowest plant density (P_1) showed 15.63% higher number of leaves plant^{-1} at 65 DAS compared to that of P_3. Similar variation of leaves number plant^{-1} due to plant density was also reported by Ghosh (2021).

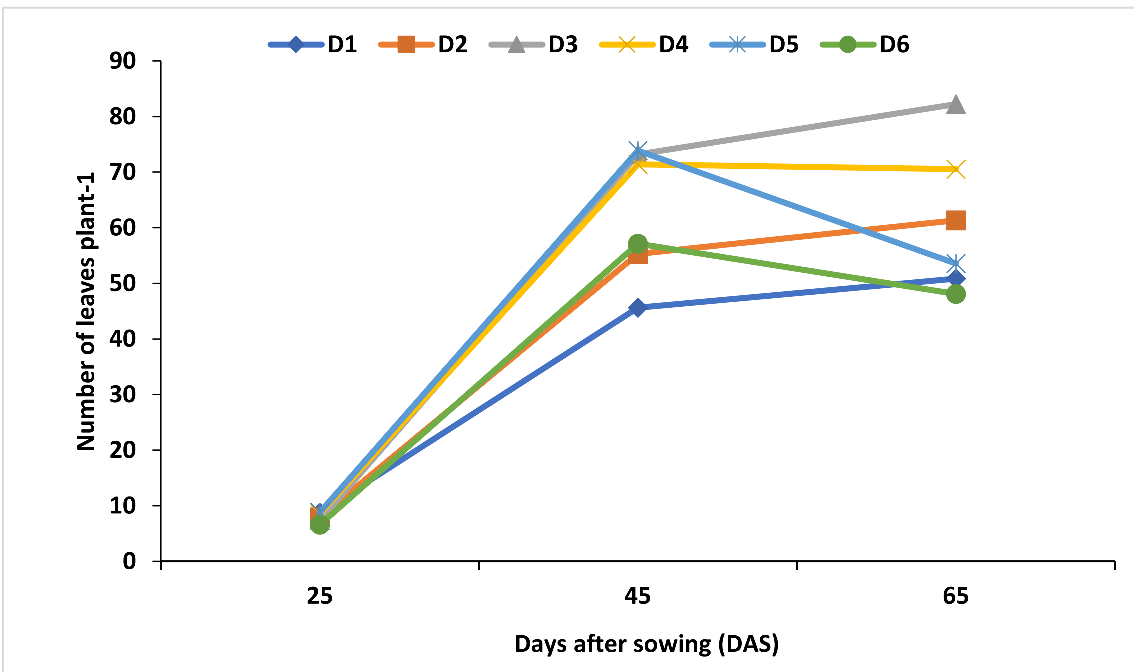


P_1=25 plants m^{-2}, P_2=50 plants m^{-2}, P_3=75 plants m^{-2}

Figure 3. Effect of plant density on number of leaves plant^{-1} of quinoa different growth stages (LSD$_{(0.05)}$ = 8.022 at 65 DAS and NS at 25 and 45 DAS, respectively).

4.2.2 Effect of sowing date

Number of leaves plant^{-1} of quinoa at different growth stages had significant variation on different date of sowing (Figure 4 and Appendix VI). At 25 DAS, the highest number of leaves plant^{-1} (8.82) was obtained from 30 December sowing (D_5), which was statistically similar with 30 October sowing (D_1) (8.79), 15 December sowing (D_4) (8.54) and the lowest number of leaves plant^{-1} (6.59) was obtained from 15 January sowing (D_6). At 45 DAS, the highest number of leaves plant^{-1} (73.87) was obtained from 30 December sowing (D_5), which was statistically similar with 30 November sowing (D_3) (73.19) and 15 December sowing (D_4) (73.87) and the lowest number of leaves plant^{-1}(45.64) was obtained from 30 October sowing (D_1), which was similar with 15 November sowing (D_2) (55.31). At 65 DAS, the highest number of leaves plant^{-1} (82.23) was obtained from 30 November sowing (D_3) and the lowest number of leaves plant^{-1} (48.11) was obtained from 15 January sowing (D_6), which was statistically similar with 30 October sowing (D1) (53.84) and 30 December sowing (D_5) (53.58). The results revealed from the study were similar with the findings of Taaimee *et al*. (2022) found that because of ideal temperatures and a short photoperiod, increased number of leaves plant^{-1} of December sowing.



D_1= 30 October, D_2= 15 November, D_3= 30 November, D_5= 30 December, D_6= 15 January D_4= 15 December,

Figure 4. Effect of sowing date on number of leaves plant^{-1} of quinoa at different growth stages ($LSD_{(0.05)}$ = 6.12, 9.752, 8.756 at 25, 45, 65 DAS respectively).

4.2.3 Interaction effect

Number of leaves plant^{-1} was significantly influenced by interaction of plant density and sowing at different growth stage (25 DAS, 45 DAS and 65 DAS) (Table 2 and Appendix VI). At 25 DAS, the highest number of leaves plant^{-1} (9.17) was obtained from P_2D_5, which was similar with P_1D_1, P_1D_4, P_1D_5, P_2D_1, P_2D_4, P_3D_1, P_3D_4 (9.13, 8.67,9.03, 8.43, 8.53, 8.80, 8.43 respectively) and lowest number of leaves plant^{-1} (6.37) was obtained from P_1D_6, which was statistically similar with P_2D_6, P_3D_3, P_3D_6 (6.63, 7.10, 6.77 respectively). At 45 DAS, the highest number of leaves plant^{-1} (83.93) was P_1D_5, which was similar with P_1D_4, P_2D_3, P_2D_4, P_2D_5, P_3D_3, P_3D_4 (72.73, 69.00, 71.60, 74.67, 79.47, 69.87 respectively) and the lowest number of leaves plant^{-1} (40.87) was obtained from P_3D_1, which was statistically similar with P_1D_1, P_1D_2, P_2D_1, P_2D_6, P_3D_2 and P_3D_6 (50.33, 55.60, 45.73, 54.73, 57.20, 55.60 and 50.53). At 65 DAS, the highest number of leaves plant^{-1} (89.33) was obtained from P_1D_3, which was statistically similar with P_1D_4 (78.07), P_3D_3 (87.30) and the lowest number of leaves plant^{-1} (43.60) was obtained from P_2D_1, which was statistically similar with P_1D_6, P_2D_5, P_2D_6, P_3D_1, P_3D_2, P_3D_5, P_3D_6 (52.67, 54.20, 46.53, 46.07, 57.53, 47.40, 45.13 respectively). Wider spacing of quinoa sown in November 30 (P_1D_3) showed 104.89% higher number of leaves plant^{-1} at 65 DAS compared to that of P_2D_1. Biswas *et al*. (2021) also reported 84.67 leaves plant^{-1} of quinoa in Bangladesh with November 20 sowing maintaining 30 cm X 10 cm spacing. This might be due to well-balanced dispersal of the plants which lessened competition that reported by Sief *et al*. (2015).

Table 2. Interaction effect of plant density and sowing date on number of leaves plant^{-1} of quinoa at different growth stages

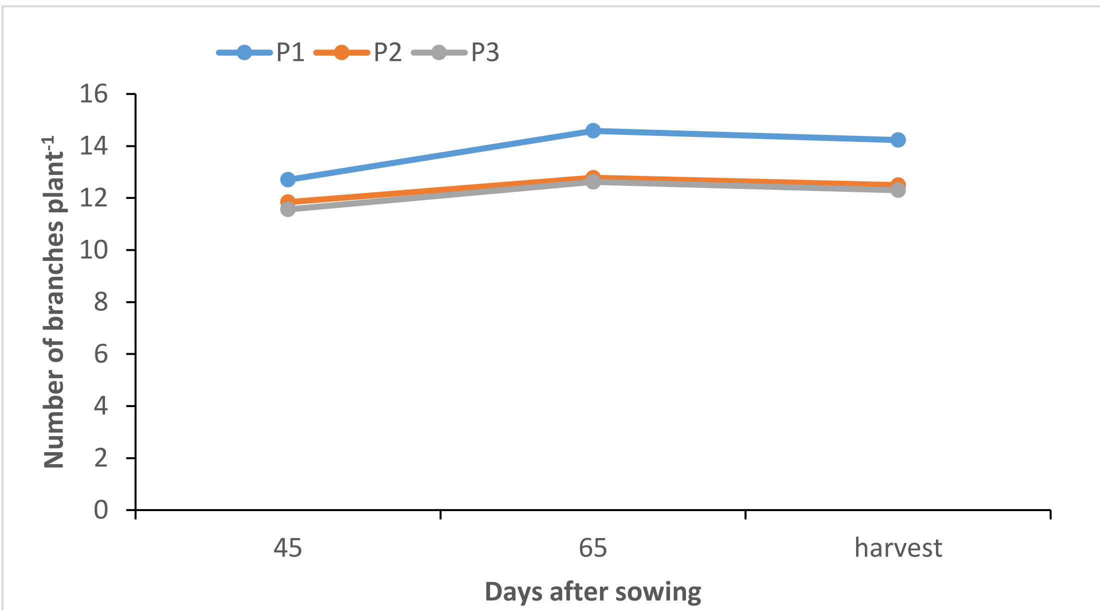
Treatments	Leaves plant^{-1} (No.) at		
	25 DAS	**45 DAS**	**65 DAS**
P_1D_1	9.13 a	50.33 ef	62.87 cde
P_1D_2	8.20 c-f	55.60 def	65.47 b-e
P_1D_3	7.43 fgh	71.10 bcd	89.33 a
P_1D_4	8.67 abc	72.73 abc	78.07 ab
P_1D_5	9.03 ab	83.93 a	59.47 c-g
P_1D_6	6.37 i	63.67 b-e	52.67 e-h
P_2D_1	8.43 a-e	45.73 f	43.60 h
P_2D_2	7.77 d-g	54.73 def	61.00 c-f
P_2D_3	7.70 efg	69.00 a-d	70.07 bc
P_2D_4	8.53 a-d	71.60 a-d	65.67 b-e
P_2D_5	9.17 a	74.67 ab	54.20 d-h
P_2D_6	6.63 hi	57.20 c-f	46.53 fgh
P_3D_1	8.80 abc	40.87 f	46.07 fgh
P_3D_2	7.83 d-g	55.60 def	57.53 c-h
P_3D_3	7.10 ghi	79.47 ab	87.30 a
P_3D_4	8.43 a-e	69.87 a-d	67.87 bcd
P_3D_5	8.27 b-e	63.00 b-e	47.07 fgh
P_3D_6	6.77 hi	50.53 ef	45.13 gh
$LSD_{(0.05)}$	0.818	16.891	15.166
CV (%)	6.12	16.14	14.88

P_1=25 plants m^{-2}, P_2=50 plants m^{-2}, P_3=75 plants m^{-2}, D_1=30 October, D_2=15 November, D_3=30 November, D_4= 15 December, D_5=30 December, D_6= 15 January

4.3 Number of branches plant^{-1}

4.3.1 Effect of plant density

Number of branches plant^{-1} of quinoa significantly influenced by different plant density at different growth stages (45 DAS, 65 DAS) except at harvest (Figure 5 and Appendix VII). At 45 DAS, the maximum number of branches plant $^{-1}$ (12.7) was recorded from low plant density (P_1), which was statistically similar with P2 (11.84) and the lowest number of branches plant^{-1} (11.56) was recorded from highest plant density (P3), which was statistically similar with P_2 (11.84).



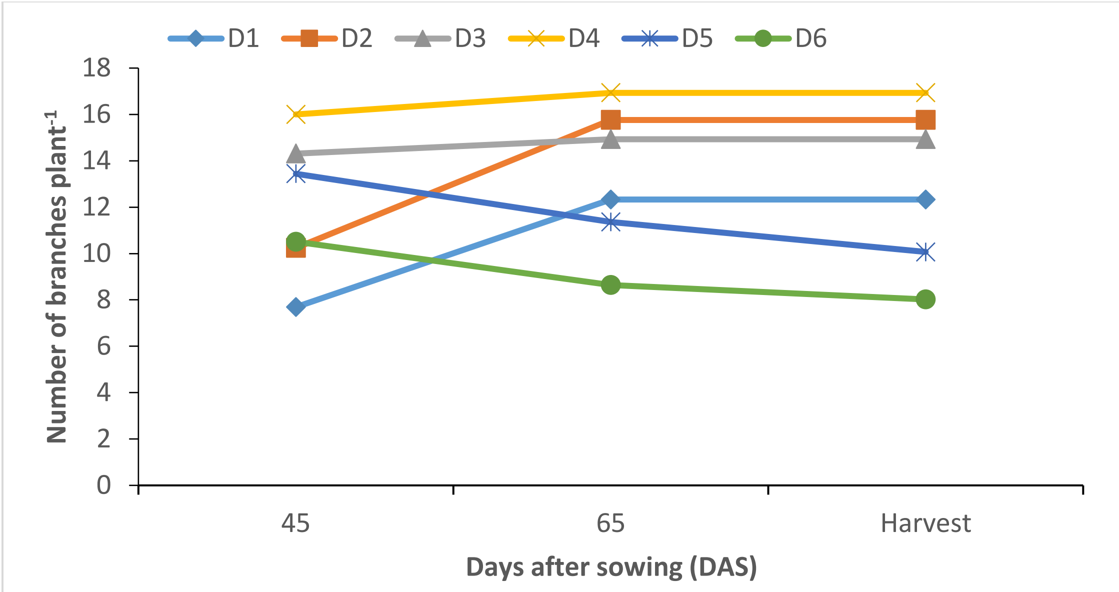
P_1=25 plants m^{-2}, P_2=50 plants m^{-2}, P_3=75 plants m^{-2}

Figure 5. Effect of plant density on number of branches plant^{-1} of quinoa at different growth stages (LSD$_{(0.05)}$ =1.085, 1.897, 1.932 at 45, 65 DAS, respectively and NS at harvest).

At 65 DAS, the maximum number of branches plant^{-1} (14.58) was recorded from low plant density (P_1), which was statistically similar P_2 (12.78) and the lowest number of branches plant^{-1} (12.62) was recorded from high plant density (P_3), which was statistically similar with P_2 (12.78). At harvest, there was no significant variation observed among the three plant densities, however numerically the maximum number of branches plant^{-1} (14.23) was recorded from low plant density (P_1) and the lowest number of branches plant^{-1} (12.30) was recorded from high plant density (P_3). These findings were consistent with those reported by Risi and Galwey (1991), who found that the number of branches increased for Amarilla de Marangani, Blanca de Junin, and Baer at low density rates. Spaher and Rocha (2009), demonstrated that the branching system expand at low seeding density.

4.3.2 Effect of sowing date

There were significant variations in number of branches plant^{-1} of quinoa recorded at different growth stages (45 DAS, 65 DAS and at harvest) for different sowing date (Figure 6 and Appendix VII). At 45 DAS, the maximum number of branches (16) was recorded from 15 December sowing (D_4) and the lowest number of branches (10.24) was recorded from 15 November sowing (D_2), which was statistically similar with 15 January sowing (D_6) (10.51). At 65 DAS, the maximum number of branches plant^{-1} (16.93) was recorded from 15 December sowing (D_4), which was statistically similar with 15 November sowing (D_2) (15.76) and the lowest number of branches plant^{-1} (8.64) was recorded from 15 January sowing (D_6). At harvest, the maximum number of branches plant^{-1} (16.93) was recorded from 15 December sowing (D_4), which was statistically similar with 15 November sowing (D_2) (15.76) and the lowest number of branches plant^{-1} (8.02) was recorded from 15 January sowing (D_6). These results were similar with the findings of Biswas and Tanni (2020), who identified that Titicaca produced the highest branches plant^{-1}(25.20) when it was seeded in November -10.



D_1= 30 October, D_2= 15 November, D_3= 30 November, D_4= 15 December, D_5= 30 December, D_6= 15 January

Figure 6. Effect of sowing date on number branches plant^{-1} of quinoa at different growth stages ($LSD_{(0.05)}$ =1.47, 1.621, 1.635 at 45, 65 DAS and harvest respectively).

4.3.3 Interaction effect

Number of branches plant^{-1} of quinoa was significantly influenced by different plant density and different sowing date at different growth stages (Table 3 and Appendix VII). At 45 DAS, the maximum number of branches plant^{-1} (16.40) was recorded from P_3D_4, which was statistically similar with P_1D_3, P_1D_4, P_1D_5, P_2D_4, P_3D_3 (14.33, 15.87, 15.13, 15.73, 15.20 respectively) and the lowest number of branches plant^{-1} (6.53) was recorded from P_3D_1, which was statistically similar with P_1D_1 (8.73), P_2D_1 (7.80). At 65 DAS, the maximum number of branches plant^{-1} (17.07) was recorded from P_1D_4, P_3D_4, which was statistically similar with P_1D_1, P_1D_2, P_1D_3, P_2D_2, P_2D_4, P_3D_4 (15.40, 16.8, 15.73,16.33,16.67,15.93 respectively) and the lowest number of branches plant^{-1} (7.80) was recorded from

P_3D_6, which was statistically similar with P_1D_6, P_2D6, P_3D_1, P_3D_5 (9.80, 8.33, 10.53,10.27 respectively). At harvest, similar results were recorded.

Table 3. Interaction effect of plant density and sowing date on number of branches plant^{-1} of quinoa at different growth stage

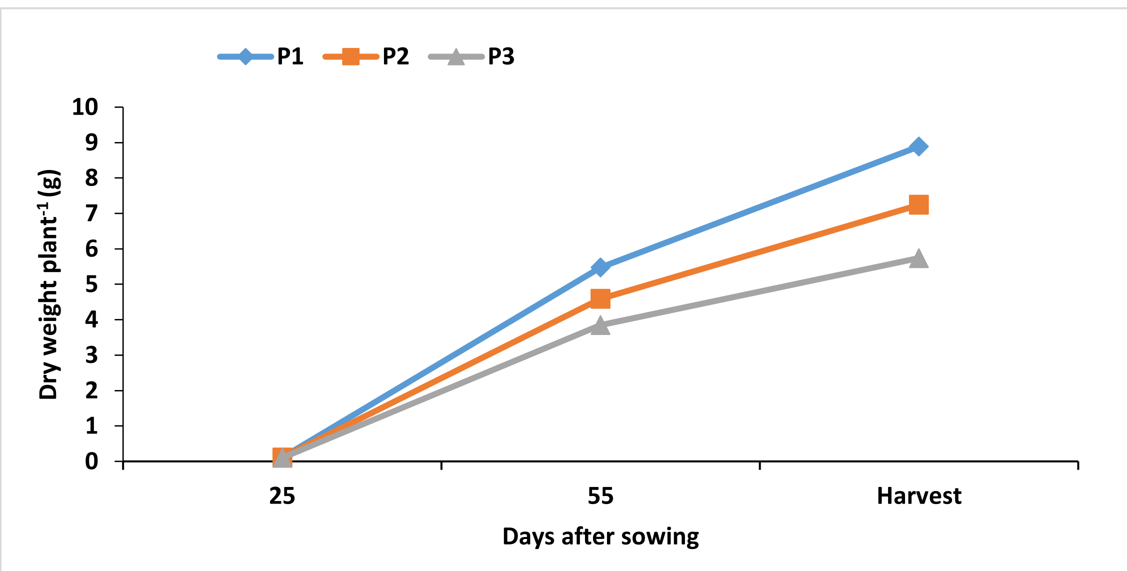
Treatments	Branches plant^{-1} (No.) at		
	45 DAS	65 DAS	Harvest
P_1D_1	8.73 efg	15.40 a-d	15.40 abc
P_1D_2	10.80 de	16.80 ab	16.80 ab
P_1D_3	14.33 ab	15.73 abc	15.73 abc
P_1D_4	15.87 ab	17.07 a	17.07 a
P_1D_5	15.13 ab	12.67 def	11.33 def
P_1D_6	11.33 cd	9.80 gh	9.07 fgh
P_2D_1	7.80 fg	11.07 efg	11.07 ef
P_2D_2	9.93 def	16.33 ab	16.33 ab
P_2D_3	13.40 bc	13.13 cde	13.13 cde
P_2D_4	15.73 ab	16.67 ab	16.67 ab
P_2D_5	13.67 bc	11.13 efg	9.93 fgh
P_2D_6	10.53 de	8.33 gh	7.80 gh
P_3D_1	6.53 g	10.53 e-h	10.53 efg
P_3D_2	10.00 def	14.13 bcd	14.13 bcd
P_3D_3	15.20 ab	15.93 ab	15.93 abc
P_3D_4	16.40 a	17.07 a	17.07 a
P_3D_5	11.53cd	10.27 fgh	8.93 fgh
P_3D_6	9.67 def	7.80 h	7.20 h
$LSD_{(0.05)}$	2.555	2.808	2.83
CV (%)	12.73	12.64	13.06

P_1=25 plants m^{-2}, P_2=50 plants m^{-2}, P_3=75 plants m^{-2}, D_1=30 October, D_2=15 November, D_3=30 November, D_4= 15 December, D_5=30 December, D_6= 15 January

4.4 Dry weight plant^{-1}

4.4.1 Effect of plant density

Dry weight plant^{-1} of quinoa at 25 DAS had no significant variation on different plant density but at 55 DAS and at harvest showed significant variation on different plant density (Figure 7 and Appendix VIII). At 25 DAS, numerically the highest dry weight plant^{-1} (0.11 g) was recorded from low and medium density (P_1, P_2 respectively) and the lowest dry weight plant^{-1} (0.10) was recorded from high plant density (P_3). At 55 DAS, the highest dry weight plant^{-1} (5.47 g) was recorded from low plant density (P_1) and the lowest dry weight plant^{-1} (3.85 g) was recorded from high plant density (P_3). At harvest, the highest dry weight plant^{-1} (8.89 g) was recorded from low plant density (P_1) and the lowest dry weight plant^{-1} (5.74 g) was recorded from high plant density(P_3). Olofintoye *et al*. (2015) also found higher dry matter production with lower population densities.

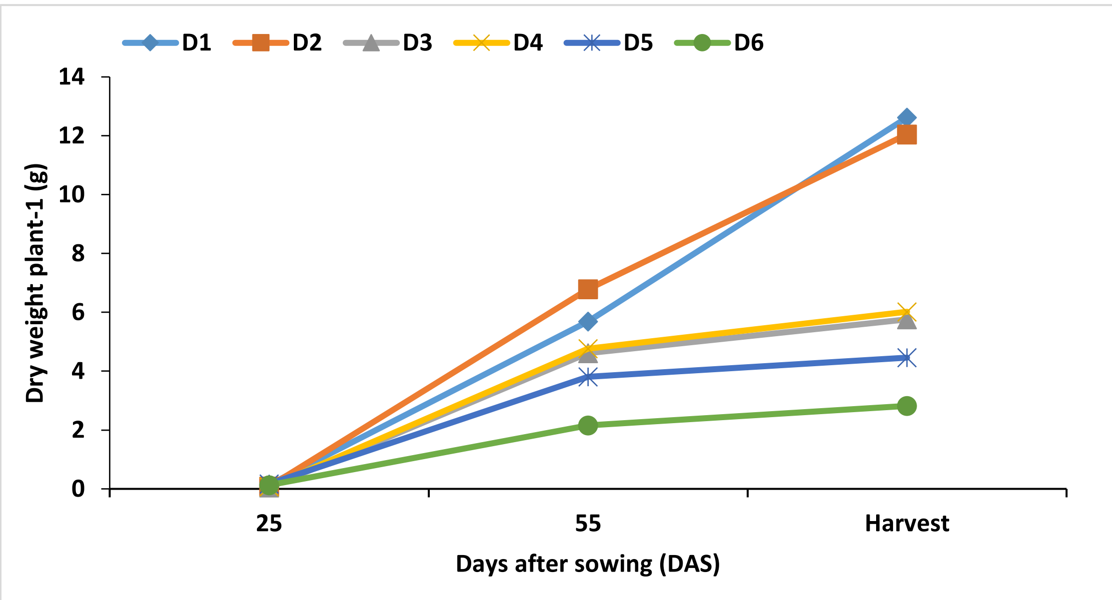


P_1=25 plants m^{-2}, P_2=50 plants m^{-2}, P_3=75 plants m^{-2}

Figure 7. Effect of plant density on dry weight plant^{-1} at different growth stages ($LSD_{(0.05)}$ = 13.30 and 13.15 at 55 DAS and at harvest respectively).

4.4.2 Effect of sowing date

Dry weight plant^{-1} of quinoa was significantly influenced by different sowing date at different growth stages (Figure 8 and Appendix VIII). At 25 DAS, the maximum dry weight plant^{-1} (0.17 g) was recorded from 30 December sowing (D_5) and the lowest dry weight plant^{-1} (0.05 g) was recorded from 30 November sowing (D_3). At 55 DAS, the maximum dry weight plant^{-1} (6.79 g) was recorded from 15 November sowing (D_2) and the lowest dry weight plant^{-1} (2.16 g) was recorded from 15 January sowing (D_6), which was statistically similar with 30 December sowing (D_5) (3.81 g).



D_1= 30 October, D_2= 15 November, D_3= 30 November, D_4= 15 December, D_5= 30 December, D_6= 15 January

Figure 8. Effect of sowing date on dry weight plant^{-1} at different growth stage ($LSD_{(0.05)}$ =0.017, 0.642, 1.208 at 25, 55 DAS and at harvest respectively).

At harvest, the maximum dry weight plant^{-1} (12.62 g) was recorded from 30 October sowing (D_1), which was statistically similar with 15 November sowing (D_2) (12.05 g) and the lowest dry weight plant^{-1} (2.82 g) was recorded from 15

January sowing (D_6). Taaime *et al*. (2022) and Parvin *et al*. (2013) and Biswas and Tanni (2020) also reported lower dry matter production due to delayed planting of quinoa due to slowed down of development that shortened the time of panicle emergence, blooming and maturity.

4.4.3 Interaction effect

Dry weight plant^{-1} of quinoa was significantly influenced by different plant density and different sowing date at different growth stages (Table 4 and Appendix VIII). At 25 DAS, the maximum dry weight plant^{-1} (0.18 g) was recorded from P_1D_5, which was statistically similar with P_1D_1, P_2D_5, P_3D_5 (0.17g, 0.15g and 0.17 g respectively) and the lowest dry weight plant^{-1} (0.05 g) was recorded from P_3D_3, P_1D_3, which was statistically similar with P_1D_2, P_1D_4, P_2D_2, P_2D_3, P_2D_4, P_3D_2, P_3D_5 (0.08 g, 0.06 g, 0.08 g, 0.06 g, 0.08 g and 0.07g respectively). At 55 DAS, the maximum dry weight plant^{-1} (7.53 g) was recorded from P_1D_2, which was statistically similar with P_1D_1 (7.20 g), P_2D_2 (6.51 g) and the lowest dry weight plant^{-1} (1.68 g) was recorded from P_3D_6, which was statistically similar with P_1D_6, P_2D_6, P_3D_5 (2.67 g, 2.13 g and 2.66 g respectively). At harvest, the maximum dry weight plant^{-1} (17.96 g) was recorded from P_1D_1 and the lowest dry weight plant^{-1} (2.18 g) was recorded from P_3D_6, which was statistically similar with P_1D_6, P_2D_6, P_3D_5 (3.47 g, 2.80 g and 3.45 g respectively). Earlier sowing with lower plant population resulted better performance of quinoa as reported by Risi and Galwey (1991).

Table 4. Interaction effect of plant density and sowing date on dry weight plant^{-1} of quinoa

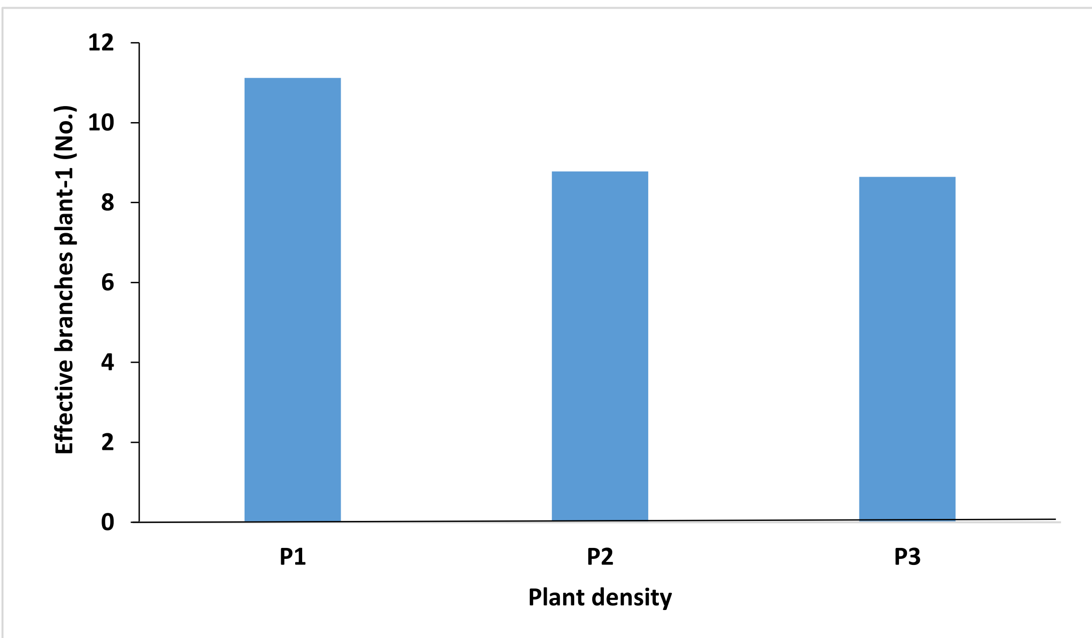
Treatments	Dry weight plant^{-1} (g) at		
	25 DAS	55 DAS	Harvest
P_1D_1	0.17 ab	7.20 ab	17.96 a
P_1D_2	0.08 d	7.53 a	12.78 bc
P_1D_3	0.05 d	4.87 d-g	6.75 d
P_1D_4	0.06 d	5.59 cd	6.82 d
P_1D_5	0.18 a	4.97 def	5.54 def
P_1D_6	0.13 c	2.67 hi	3.47 fgh
P_2D_1	0.12 c	5.49 cde	10.69 cd
P_2D_2	0.08 d	6.51 abc	13.59 b
P_2D_3	0.06 d	4.95 def	5.76 de
P_2D_4	0.08 d	4.68 d-g	6.22 de
P_2D_5	0.17 a	3.79 gh	4.41 efg
P_2D_6	0.14 bc	2.13 i	2.80 gh
P_3D_1	0.14 bc	4.38 efg	9.80 d
P_3D_2	0.08 d	6.33 bc	9.79 d
P_3D_3	0.05 d	4.01 fg	4.77 d-g
P_3D_4	0.07 d	4.02 fg	5.02 def
P_3D_5	0.15 abc	2.66 i	3.45 fgh
P_3D_6	0.13 c	1.68i	2.18 h
$LSD_{(0.05)}$	16.50	1.112	2.09
CV (%)	0.029	14.38	17.22

P_1=25 plants m^{-2}, P_2=50 plants m^{-2}, P_3=75 plants m^{-2}, D_1=30 October, D_2=15 November, D_3=30 November, D_4= 15 December, D_5=30 December, D_6= 15 January

4.5 Effective branches plant^{-1}

4.5.1 Effect of plant density

Effective branches plant^{-1} of quinoa had significant variation for different plant densities at harvest (Figure 9 and Appendix IX). The maximum number of effective branches plant^{-1} (11.12) was obtained from low plant density (P_1) and the lowest number of effective branches plant^{-1} (8.64) at high plant density (P_3), which was statistically similar with P_2 (8.78). Sowing quinoa maintaining 25 plants m^{-2} resulted 28.70% higher number of branches plant^{-1} compared to that of 75 plants m^{-2}. Risi and Galwey (1991) and Spehar and Rocha (2009) also reported higher number of branches in quinoa with lower population density.

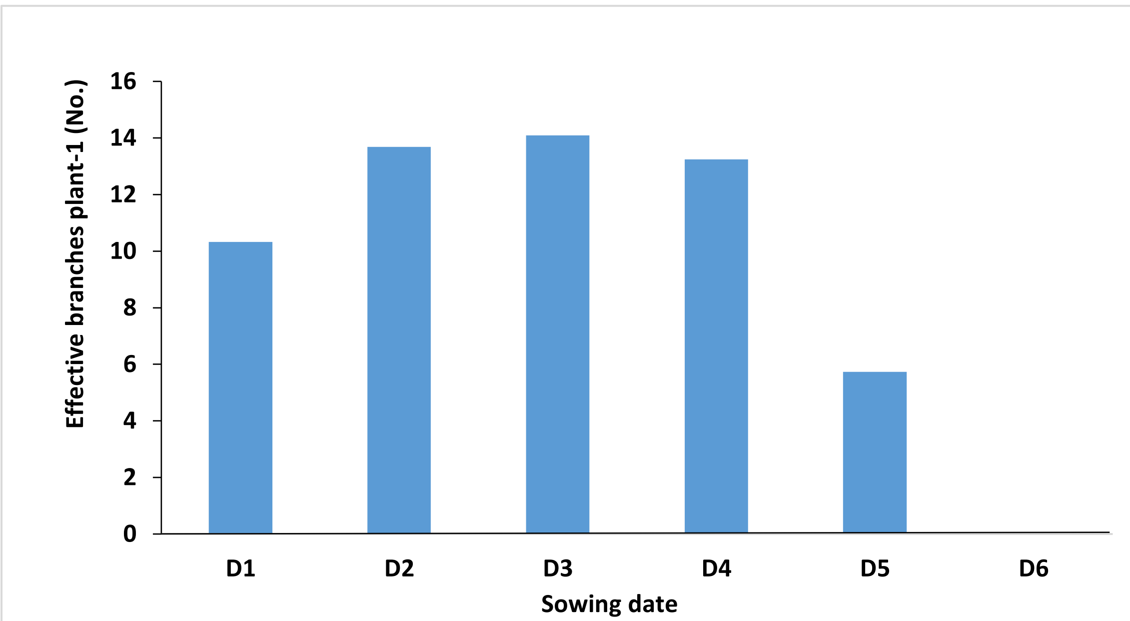


P_1=25 plants m^{-2}, P_2=50 plants m^{-2}, P_3=75 plants m^{-2}

Figure 9. Effect of plant density on number of effective branches of quinoa plant^{-1} at harvest ($LSD_{(0.05)}$ = 1.763).

4.5.1 Effect of sowing date

Effective branches plant^{-1} of quinoa was significantly influenced by different sowing date at harvest (Figure 10 and Appendix IX). The maximum number of effective branches plant^{-1} (14.09) was obtained from 30 November sowing (D_3), which was statistically similar with 15 November sowing (D_2) and 15 December (D_4) sowing (13.69, 13.24 respectively) and the lowest number of effective branches plant^{-1} (0) was obtained from 15 January sowing (D_6). No effective branches plant^{-1} in January sowing might be due to higher temperature during flowering to grain development period as Hinojosa et al. (2018) reported 30-70% reduction of pollen viability of quinoa.



D_1= 30 October, D_2= 15 November, D_3= 30 November, D_4= 15 December, D_5= 30 December, D_6= 15 January

Figure 10. Effect of sowing date on number of effective branches of quinoa plant^{-1} at harvest ($LSD_{(0.05)}$ = 1.619).

4.5.3 Interaction effect

Effective branches plant^{-1} of quinoa was significantly influenced by interaction effect of different plant densities and different sowing date at harvest (Table 5 and Appendix IX). The maximum number of effective branches plant^{-1} (15.78) was obtained from P_1D_2, that statistically similar with P_1D_1, P_1D_3, P_2D_2, P_3D_3, P_3D_4 (14.20, 15.53, 13.73, 15.07, 13.27 respectively) and the lowest number of effective branches plant^{-1} (4.07) was obtained from P_3D_5, that statistically similar with P_2D_5 and that plants under the combination of P_1D_6, P_2D_6, P_3D_6 were well developed and branched but there was no effective branch that might be due to environmental interruption (high temperature).

Table 5. Interaction effect of plant density and sowing date on number of effective and ineffective branches plant^{-1} of quinoa

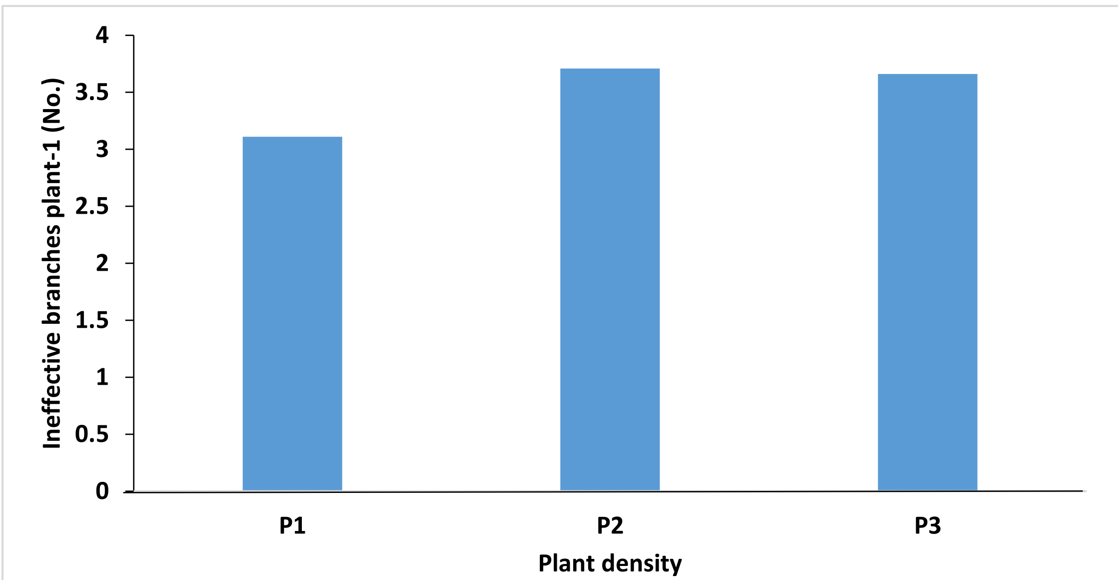
Treatments	Effective branches plant^{-1} (No.)	Ineffective branches plant^{-1} (No.)
P_1D_1	14.20 abc	1.20 hij
P_1D_2	15.87 a	0.93 ij
P_1D_3	15.53 ab	0.20 j
P_1D_4	13.73 abc	3.33 def
P_1D_5	7.40 ef	3.93 cd
P_1D_6	0.00 h	9.07 a
P_2D_1	8.80 de	2.27 fgh
P_2D_2	13.73 abc	2.60 efg
P_2D_3	11.67 c	1.47 ghi
P_2D_4	12.73 bc	3.93 cd
P_2D_5	5.73 fg	4.20 cd
P_2D_6	0.00 h	7.80 b
P_3D_1	8.00 ef	2.53 fg
P_3D_2	11.47 cd	2.67 efg
P_3D_3	15.07 ab	0.87 ij
P_3D_4	13.27 abc	3.80 cde
P_3D_5	4.07 g	4.87 c
P_3D_6	0.00 h	7.20 b
$LSD_{(0.05)}$	2.804	1.250
CV (%)	17.67	21.47

P_1=25 plants m^{-2}, P_2=50 plants m^{-2}, P_3=75 plants m^{-2}, D_1=30 October, D_2=15 November, D_3=30 November, D_4= 15 December, D_5=30 December, D_6= 15 January

4.6 Ineffective branches plant^{-1}

4.6.1 Effect of plant density

There was significant variation observed on ineffective branches plant^{-1} by different plant densities (Figure 11 and Appendix IX). The maximum number of ineffective branches plant^{-1} (3.71) was recorded from medium plant density (P_2), which was statistically similar with high plant density (P_3) and the lowest number of ineffective branches plant^{-1} (3.11) was recorded from low plant density (P_1).

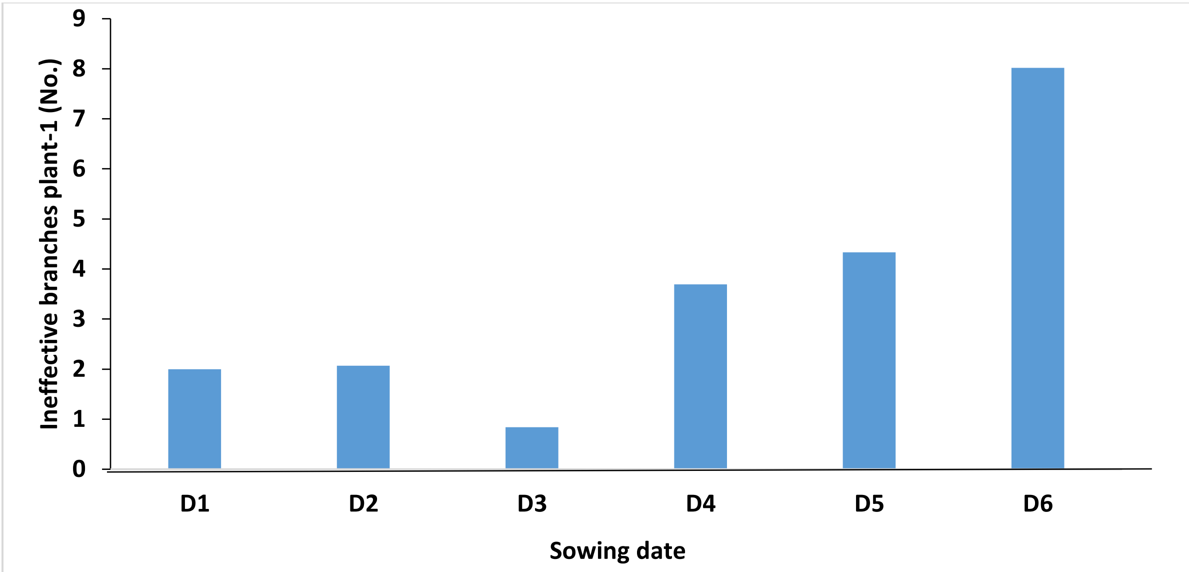


P_1=25 plants m^{-2}, P_2=50 plants m^{-2}, P_3=75 plants m^{-2}

Figure 11. Effect of plant density on number of ineffective branches plant^{-1} of quinoa at harvest ($LSD_{(0.05)}$ =0.426).

4.6.2 Effect of sowing date

Considerable variation was observed on ineffective branches plant^{-1} by different sowing date (Figure 12 and Appendix IX). The maximum number of ineffective branches plant^{-1} (8.02) was recorded from 15 January sowing (D_6) and the lowest number of branches plant^{-1} (0.84) was recorded from 30 November sowing (D_3).



D_1= 30 October, D_2= 15 November, D_3= 30 November, D_4= 15 December, D_5= 30 December, D_6= 15 January

Figure 12. Effect of sowing date on number of ineffective branches plant^{-1} of quinoa at harvest ($LSD_{(0.05)}$ =0.722).

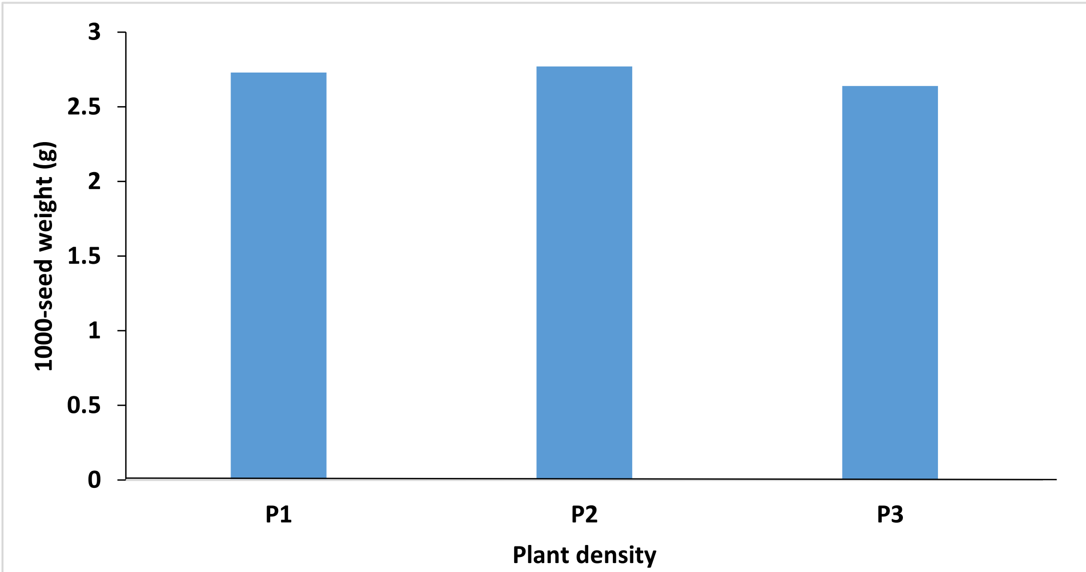
4.6.3 Interaction effect

Ineffective branches plant^{-1} was significantly influenced by interaction of different plant density and sowing date at harvest (Table 5 and Appendix IX). The maximum number of branches plant^{-1} (9.07) was recorded from P_1D_6, which was statistically dissimilar from all other treatments and the lowest number of branches plant^{-1} (0.20) was recorded from P_1D_3, which was statistically similar with P_1D_1, P_1D_2 and P_3D_3 (1.20, 0.93 and 0.87 respectively).

4.7 1000-seed weight

4.7.1 Effect of plant density

There was significant variation observed on 1000-seed weight of quinoa for different plant densities (Figure 13 and Appendix X). The maximum 1000-seed weight (2.77 g) was obtained from medium plant density (P_2), which was statistically similar with low plant density (P_1) (2.73 g) and minimum 1000-seed weight (2.64 g) was obtained from high plant density (P_3), which was statistically similar with P_2.

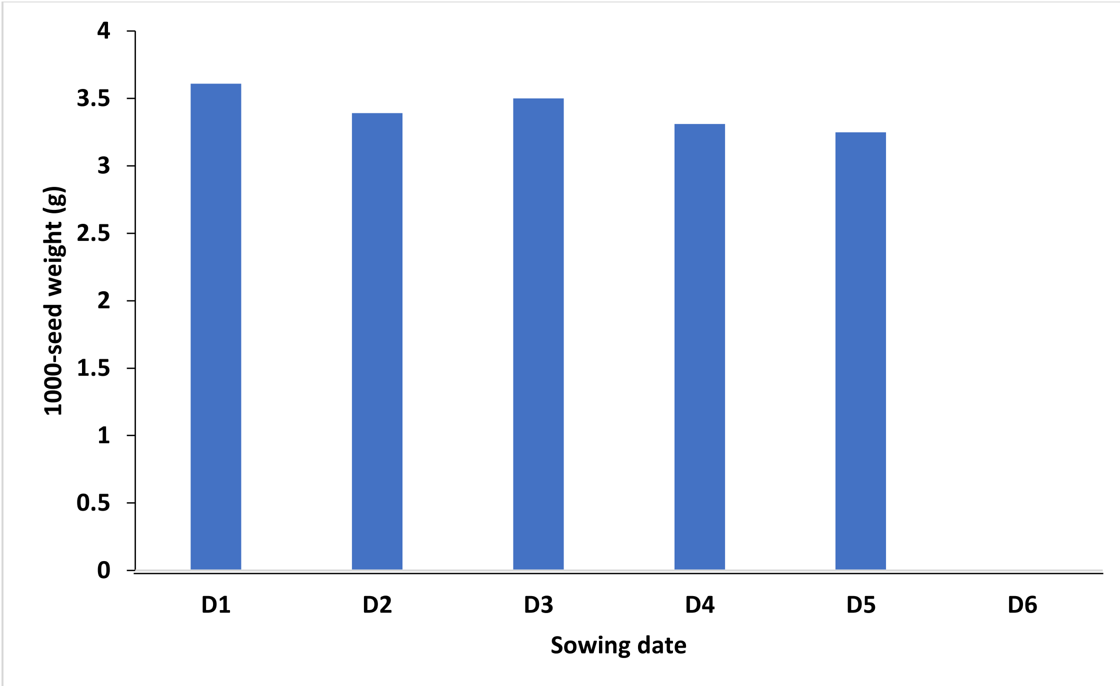


P_1=25 plants m^{-2}, P_2=50 plants m^{-2}, P_3=75 plants m^{-2}

Figure 13. Effect of plant density on 1000-seed weight of quinoa ($LSD_{(0.05)}$ =0.092).

4.7.2 Effect of sowing date

1000-seed weight of quinoa was significantly influenced by different sowing date (Figure 14 and Appendix X). The maximum 1000-seed weight (3.61 g) was obtained from 30 October sowing (D_1), which was statistically similar with 30 November sowing (D_3) (3.50 g) and minimum 1000-seed weight (2.65 g) was obtained from 30 December sowing (D_5). At 15 January sowing (D_6), plants were developed and branched but no seed produced from that sowing, it was might be environmental interruption (High temperature) as reported by Hinojosa *et al*. (2018).



D_1= 30 October, D_2= 15 November, D_3= 30 November, D_4= 15 December, D_5= 30 December, D_6= 15 January

Figure 14. Effect of sowing date on 1000-seed weight of quinoa (LSD $_{(0.05)}$ =0.109).

4.7.3 Interaction effect

The 1000-seed weight was significantly influenced by different plant densities and sowing dates (Table 6 and Appendix X). The maximum 1000-seed weight (3.74 g) was recorded from P_2D_1, which was statistically similar with P_1D_1 (3.70 g), P_1D_3 (3.56 g), P_2D_3 (3.59 g) and the lowest 1000-seed weight (2.61 g) was obtained from P_1D_5, which was statistically similar with P_2D_5 (2.68 g), P_3D_3 (2.65 g). At P_1D_6 P_2D_6, P_3D_6 combination, phenological growth of plants were occurred but there was no effective branch and no seed produced, it might be due to environmental interruption (High temperature).

Table 6. Interaction effect of plant density and sowing date on 1000-seed Weight, seed yield straw yield, biological yield and harvest index

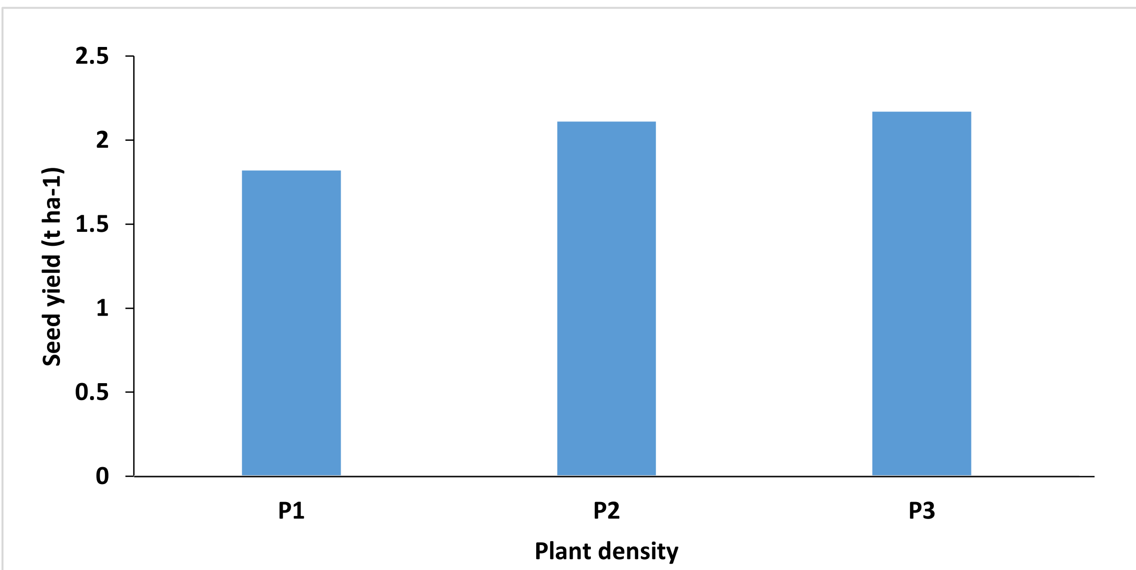
Treatments	1000-seed weight (g)	Seed yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
P_1D_1	3.70 a	2.72 cde	0.88 i	3.60 fgh	75.56 a
P_1D_2	3.39 cde	2.43 def	0.95 hi	3.38 fgh	71.98 abc
P_1D_3	3.56 abc	2.86 bcd	1.64 de	4.51 c	63.52 cd
P_1D_4	3.11 f	2.03 f	1.72 d	3.75 efg	53.36 e
P_1D_5	2.61 g	0.86 h	1.49 ef	2.35 i	36.60 f
P_1D_6	0.00 h	0.00 i	1.39 f	1.39 j	0.00 g
P_2D_1	3.74 a	2.45 def	0.95 hi	3.41 fgh	72.02 abc
P_2D_2	3.40 bcd	3.10 bc	1.15 gh	4.25 cde	73.49 ab
P_2D_3	3.59 ab	3.27 ab	1.94 bc	5.22 ab	62.75 d
P_2D_4	3.20 ef	2.44 def	2.13b	4.57 c	53.26 e
P_2D_5	2.68 g	1.38 g	1.78 cd	3.16 h	46.28 e
P_2D_6	0.00 h	0.00 i	1.72 d	1.72 j	0.00 g
P_3D_1	3.37cde	2.74 cde	1.14 gh	3.89 def	74.72 ab
P_3D_2	3.40 bcd	3.20 ab	1.23 g	4.43 cd	72.12 abc
P_3D_3	3.35 de	3.56 a	2.11 b	5.67 a	67.40 abcd
P_3D_4	3.09 f	2.32 ef	2.38 a	4.70 bc	49.20 e
P_3D_5	2.65 g	1.19 gh	1.98 bc	3.17 gh	37.38 f
P_3D_6	0.00 h	0.00 i	1.84 cd	1.84 ij	0.00 g
$LSD_{(0.05)}$	0.190	0.440	0.204	0.579	8.797
CV (%)	4.20	13.00	7.75	9.61	10.39

P_1=25 plants m^{-2}, P_2=50 plants m^{-2}, P_3=75 plants m^{-2}, D_1=30 October, D_2=15 November, D_3=30 November, D_4= 15 December, D_5=30 December, D_6= 15 January

4.8 Seed yield

4.8.1 Effect of pant density

Seed yield of quinoa showed significant variation on different plant densities (Figure 15 and Appendix XI). The highest seed yield (2.17 t ha^{-1}) was obtained from high plant density (P_3), which was statistically similar with P_2 (2.11 t ha^{-1}) and the lowest yield (1.82 t ha^{-1}) was obtained from low plant density (P_1). Wali *et al*. (2022) also reported variation of quinoa seed yield for varied plant densities and increasing plant density from 20,000 to 36,000 plant $feddan^{-1}$ significantly increased seed yield. Ghosh (2021) also found higher seed yield of quinoa (2.15 t ha^{-1}) maintaining 50 cm X 20 cm spacing.



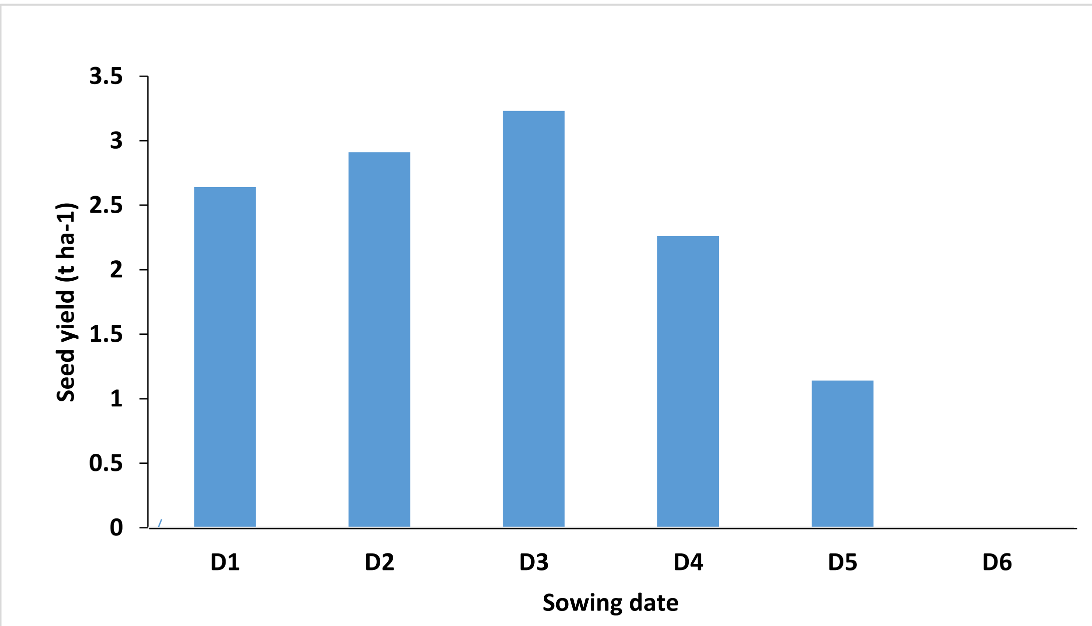
P_1=25 plants m^{-2}, P_2=50 plants m^{-2}, P_3=75 plants m^{-2}

Figure 15. Effect of plant density on seed yield of quinoa ($LSD_{(0.05)}$ =0.119).

4.8.2 Effect of sowing date

Seed yield of quinoa was significantly affected by different sowing date (Figure 16 and Appendix XI). The highest seed yield (3.23 t ha^{-1}) was obtained from 30 November sowing (D_3) and lowest yield (1.14 t ha^{-1}) was obtained from 30

December sowing (D_5). At 15 January sowing (D_6), phenological development was occurred and plants were well developed and well branched but no seed produced in that sowing, it might be due environmental interruption (High temperature) as reported by Hinojosa *et al*. (2018), Bhargava *et al*. (2007). Similar results were also found by Casini (2019), where higher temperature of late sowing decreased the number of days that able emergence to panicle appearance and flowering. Late sowing also decreased the vegetative development of quinoa and resulted stunted growth and loss yield (Hirich *et al*., 2014).



D_1= 30 October, D_2= 15 November, D_3= 30 November, D_4= 15 December, D_5= 30 December, D_6= 15 January

Figure 16. Effect of sowing date on seed yield of quinoa ($LSD_{(0.05)}$ = 0.254).

4.8.3 Interaction effect

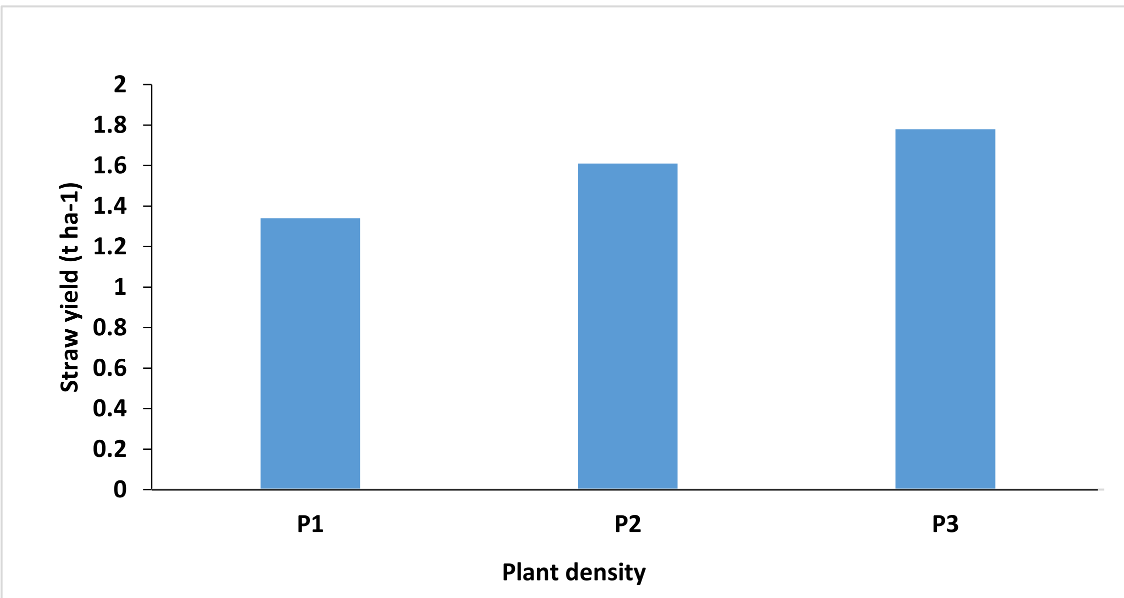
Different plant densities and sowing date showed significant variation on seed yield of quinoa (Table 6 and Appendix XI). The highest seed yield (3.56 t ha^{-1}) was obtained from P_3D_3, which was statistically similar with P_2D_3 (3.27 t ha^{-1}), P_3D_2 (3.20 t ha^{-1}) and the lowest yield was obtained from P_1D_5 (0.86 t ha^{-1}), P_3D_5

(1.19 t ha^{-1}). At P_1D_6, P_2D_6, P_3D_6 combination, plants were developed and well branched but there were no yield found that might be due to environmental interruption (High temperature). Ram *et al*. (2021) also found yield variation of quinoa with sowing dates and plant geometry in semi arid region of India.

4.9 Straw yield

4.9.1 Effect of plant density

Statistically significant variation was observed on straw yield of quinoa for different plant densities (Figure 17 and Appendix XI). The highest straw yield (1.78 t ha^{-1}) was obtained from high plant density (P_3) and the lowest straw yield (0.1.34 t ha^{-1}) was obtained from low plant density (P_1).

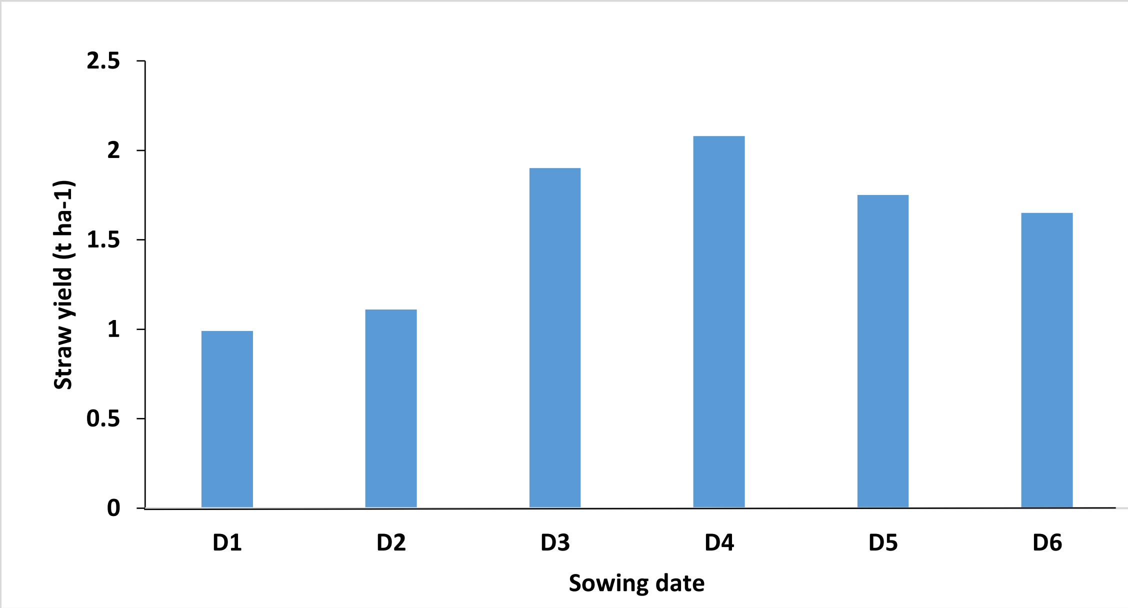


P_1=25 plants m^{-2}, P_2=50 plants m^{-2}, P_3=75 plants m^{-2}

Figure 17. Effect of plant density on straw yield of quinoa (LSD$_{(0.05)}$ =0.086).

4.9.2 Effect of sowing date

There was significant variation observed on straw yield of quinoa for different sowing dates (Figure 18 and Appendix XI). The highest straw yield (2.08 t/ha) was obtained from 15 December sowing (D_4) and lowest straw yield (0.99 t/ha) was obtained from 30 October sowing (D_1), which was statistically similar with 15 November sowing (D_2).



D_1= 30 October, D_2= 15 November, D_3= 30 November, D_4= 15 December, D_5= 30 December, D_6= 15 January

Figure 18. Effect of sowing date on straw yield of quinoa ($LSD_{(0.05)}$ =0.118).

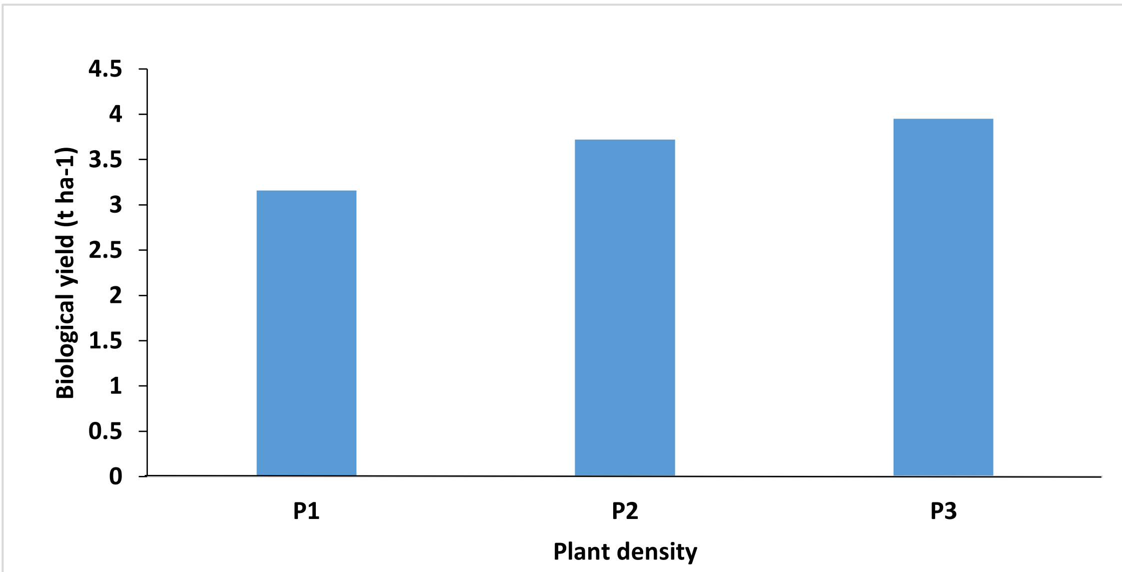
4.9.3 Interaction effect

Straw yield of quinoa was significantly influenced by different plant densities and different sowing dates (Table 6 and Appendix XI). The highest straw yield (2.38 t ha^{-1}) was obtained from P_3D_4, which was statistically dissimilar from all other treatments and lowest straw yield (0.88 t ha^{-1}) was obtained from P_1D_1, which was statistically similar with P_1D_2, P_2D_1 (0.95 t ha^{-1}).

4.10 Biological yield

4.10.1 Effect of plant density

There was significant variation observed on biological yield of quinoa for different plant densities (Figure 19 and Appendix XI). The highest biological yield (3.95 t ha $^{-1}$) was obtained from high plant density (P_3) and the lowest biological yield (3.16 t ha^{-1}) was obtained from lowest plant density (P_1).

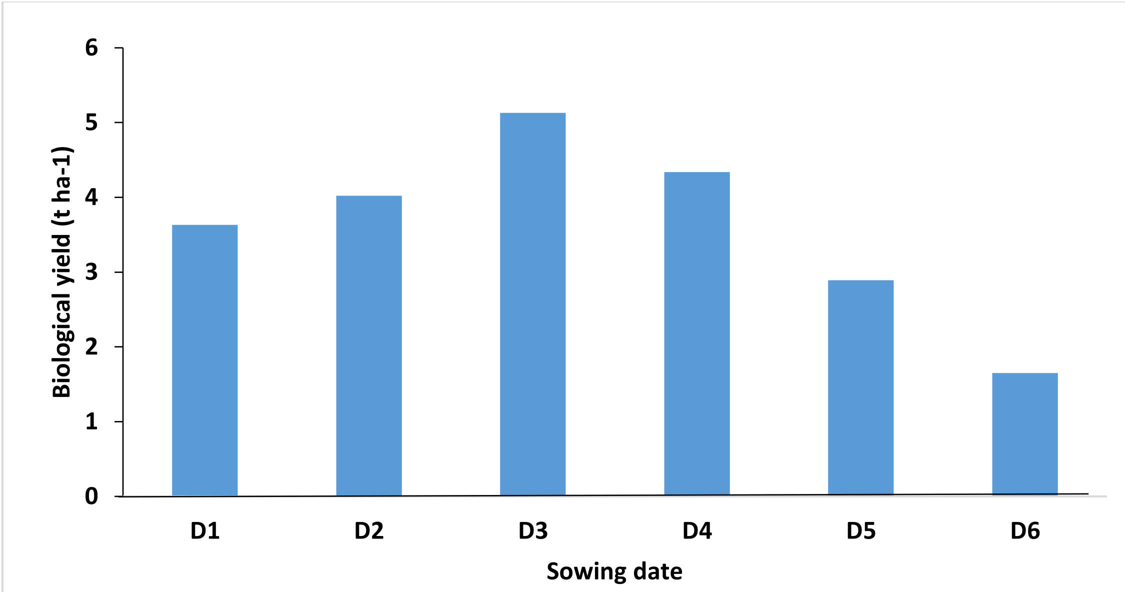


P_1=25 plants m^{-2}, P_2=50 plants m^{-2}, P_3=75 plants m^{-2}

Figure 19. Effect of plant density on biological yield of quinoa ($LSD_{(0.05)}$ =0.199).

4.10.2 Effect of sowing date

Biological yield of quinoa had significant variation for different sowing dates (Figure 20 and Appendix XI). The highest biological yield (5.13 t ha^{-1}) was obtained from 30 November sowing (D_3) and lowest biological yield (2.89 t ha^{-1}) was obtained from 15 January sowing (D_6).



D_1= 30 October, D_2= 15 November, D_3= 30 November, D_4= 15 December, D_5= 30 December, D_6= 15 January

Figure 20. Effect of sowing date on biological yield of quinoa ($LSD_{(0.05)}$ = 0.334).

4.10.3 Interaction effect

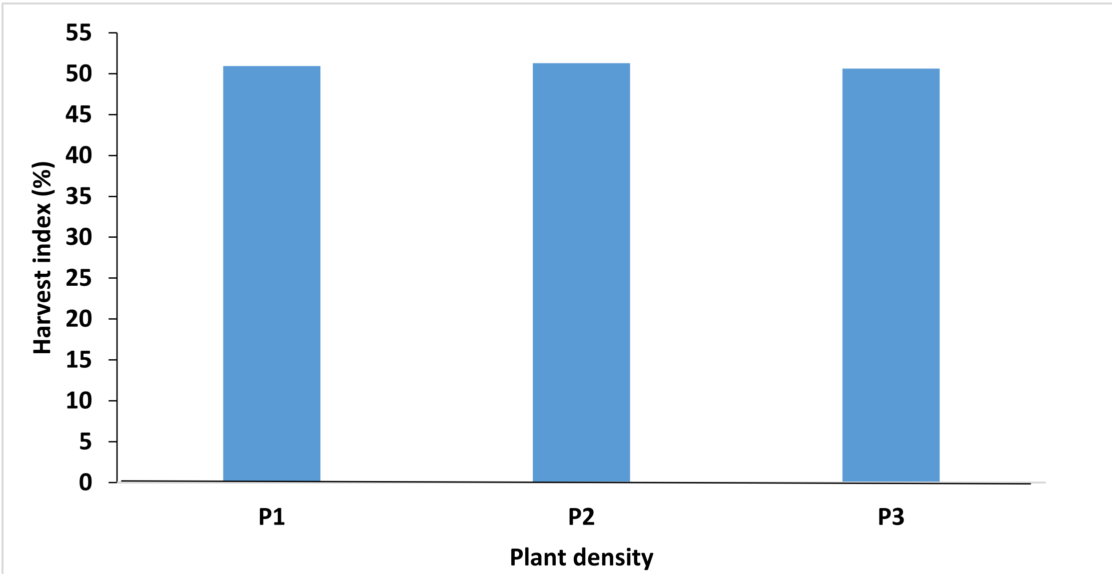
Biological yield of quinoa was significantly influenced by different plant densities and different sowing dates (Table 6 and Appendix XI). The highest biological yield (5.67 t ha^{-1}) was obtained from P_3D_3, which was statistically similar with P_2D_3 (5.22 t ha^{-1}) and lowest biological yield (1.39 t ha^{-1}) was obtained from P_1D_6, which was statistically similar with P_2D_6 (1.72 t ha^{-1}) and P_3D_6 (1.84 t ha^{-1}). November sowing with 75 plants m^{-2} (P_3D_3) gave 208.15% higher biological yield compared to that of January sowing with same population densities.

4.11 Harvest index

4.11.1 Effect of plant density

There was no significant variation observed on harvest index for different plant densities (Figure 21 and Appendix XI). Numerically the highest harvest index

(51.30 %) was recorded from medium plant density (P_2) and the lowest harvest index (50.64%) was recorded from high plant density (P_3).

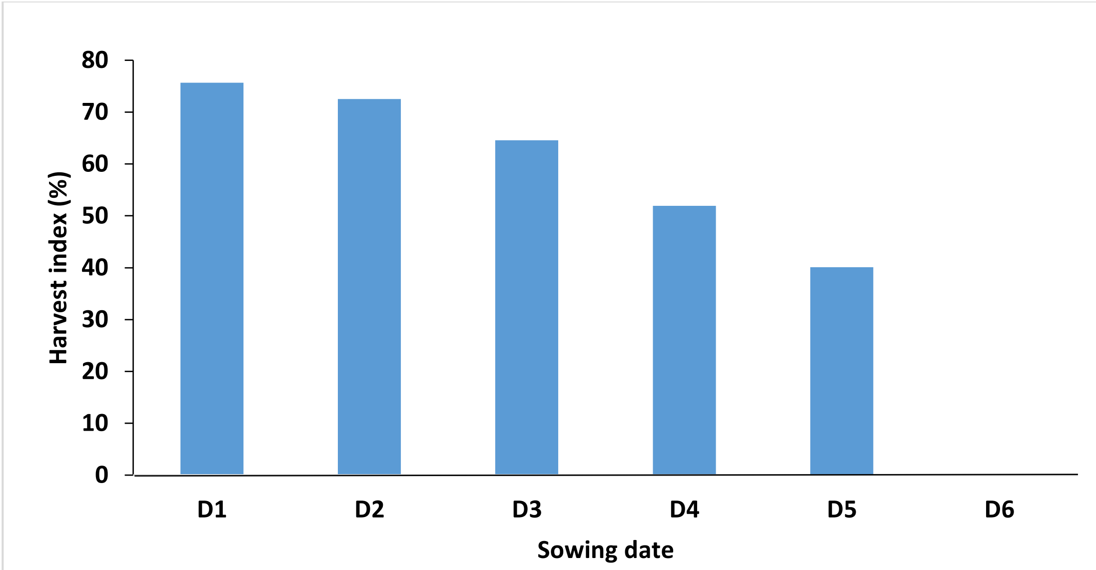


P_1=25 plants/m^2, P_2=50 plants/m^2, P_3=75 plants/m^2

Figure 21. Effect of plant density on harvest index of quinoa ($LSD_{(0.05)}$ = NS).

4.11.2 Effect of sowing date

The harvest index was significantly influenced by different sowing date (Figure 22 and Appendix XI). The highest harvest index (75.66 %) was recorded from 30 October sowing (D_1), which was statistically similar with 15 November sowing (D_2) and lowest harvest index (40.09 %) was recorded from 30 December sowing (D_5). At 15 January sowing (D_6), plants were well developed and branched but there was no effective branch and seed production was zero.



D_1= 30 October, D_2= 15 November, D_3= 30 November, D_4= 15 December, D_5= 30 December, D_6= 15 January

Figure 22. Effect of sowing date on harvest index of quinoa ($LSD_{(0.05)}$ = 5.079).

4.11.3 Interaction effect

Harvest index of quinoa was significantly influenced by interaction of different plant densities and different sowing date (Table 6 and Appendix XI). The highest harvest index (75.56%) was recorded from P_1D_1, which was statistically similar with P_1D_2 (71.98%), P_2D_1 (72.02%), P_2D_2 (73.49%), P_3D_1 (74.72%), P_3D_2 (72.12 %), P_3D_3 (67.40%) and lowest harvest index (36.60 %) was recorded from P_1D_5, which was statistically similar with P_3D_5 (37.38 %). At P_1D_6, P_2D_6, P_3D_6 combination phenological growth was occurred but no seed produced from that combination, it might be environmental interruption (Hight temperature).Similar higher harvest index (87.00%) of quinoa was reported by Rojas (2003) and 69.00% harvest index by Thiam *et al*. (2021).

CHAPTER V

SUMMARY AND CONCLUSION

The field experiment was conducted at the experimental farm of Sher-e-Bangla Agricultural University, Dhaka, during October 2021 to March 2022 to study growth and yield of quinoa (*Chenopodium quinoa* Willd.) as affected by plant density and sowing date under the Agro-ecological Zone, Modhupur Tract (AEZ-28). The treatment of the experiment consists of three plant densities viz. 25 plants m^{-2} (P_1: low plant density), 50 plants m^{-2} (P_2: medium plant density) and 75 plants m^{-2} (P_3: high plant density) and six sowing dates *viz*. 30 October (D_1), 15 November (D_2), 30 November (D_3), 15 December (D_4), 30 December (D_5) and 15 January (D_6). The experiment was laid out in Split-plot design following the principles of randomization with three replications. Plant density was placed in the main plot with different sowing date in the sub plot. Data on different growth stage, yield contributing characters and yield were recorded. Five quinoa plants from each treatment were randomly selected from each plot and marked with red cotton thread for the purpose of data collection. The data on growth parameters *viz.* plant height (cm) at 25 DAS, 45 DAS, 65 DAS and harvest; number of leaves $plant^{-1}$ at 25 DAS, 45 DAS and 65 DAS; number of branches $plant^{-1}$ at 45 DAS, 65 DAS and harvest; dry weight (g) at 25 DAS, 55 DAS and harvest were recorded. And for crop yield and yield attributing characters *viz*. number of inflorescence $plant^{-1}$, straw yield (kg ha^{-1}), seed yield (kg ha^{-1}) and 1000-seed weight (g) data were recorded at harvest. 1000-seed weight was measured from sampled seed. Data were analyzed using CropStat 7.2 package. The mean differences among the treatments were compared by least significant difference test (LSD) at 5% level of significance. Data on different growth parameters, yield attributes and yield were significantly varied for different treatments.

Results revealed that different plant densities had significant effect on different growth parameters except plant height at 45 DAS, 65 DAS and harvest, number of leaves plant^{-1} at 25 DAS and 45 DAS, number of branches plant^{-1} at harvest, dry weight at 25 DAS. In case of plant height, at 25 DAS, highest plant height (11.77 cm) was found from medium plant density (P_2) and lowest plant height (11.42 cm) was found from low plant density (P_1). At 45 DAS, numerically highest plant height (53.49 cm) was found from medium plant density (P_2) and lowest plant height (50.70 cm) was found from high plant density (P_3). At 65 DAS and harvest numerically highest plant height (63.39 cm and 63.36 cm) found from low plant density (P_1) and lowest plant height (60.29 cm) found from high plant density (P_3) respectively. Same as plant height, at 25 DAS and 45 DAS, highest number of leaves plant^{-1} (8.14 and 66.23) was obtained from low plant density (P_1) and lowest number of leaves plant^{-1} (7.87 and 59.89) was obtained from high plant density (P_3) respectively. At 65 DAS, highest number of leaves plant^{-1} (67.98) and lowest number of leaves plant^{-1} (56.84) was obtained from low plant density (P_1) and medium plant density (P_2) respectively. In case of number of branches plant^{-1}, at 45 DAS, 65 DAS and at harvest, low plant density (P_1) shown the maximum value (12.7, 14.58 and 14.23) and high plant density (P_3) shown the minimum value (11.56, 12.62 and 12.30). At 25 DAS, 55 DAS and harvest, highest dry weight plant^{-1} (0.11 g, 5.47 g and 8.89 g) was recorded from low plant density (P_1) and lowest dry weight plant^{-1} (0.10 g, 3.85 g and 5.74 g) was recorded from high plant density (P_3) respectively.

Different plant densities showed statistically significant effect on quinoa plants' yield and yield attributing characters like number of effective branches plant^{-1}, seed yield (t ha^{-1}), straw yield (t ha^{-1}), 1000- seed weight, biological yield (t ha^{-1}) except harvest index (%). Low plant density (P_1) resulted the maximum number of effective branches plant^{-1}(11.12) and minimum number of effective branches plant^{-1} (8.64) at high plant density (P_3). The maximum 1000-seed weight (2.77 g) was obtained from medium plant density (P_2) and minimum 1000-seed weight (2.64 g) was obtained from high plant density (P_3).

The highest seed yield (2.17 t ha^{-1}) was obtained from high plant density (P_3), P_2 (2.11 t ha^{-1}) was statistically similar with P_3 and lowest yield (1.82 t ha^{-1}) was obtained from low plant density (P_1). The highest straw yield (1.78 t ha^{-1}) was obtained from high plant density (P_3) and lowest straw yield (1.34 t ha^{-1}) was obtained from low plant density (P_1). The highest biological yield (3.95 t ha^{-1}) was obtained from high plant density (P_3) and lowest biological yield (3.16 t ha^{-1}) was obtained from lowest plant density (P_1). Numerically highest harvest index (51.30 %) was recorded from medium plant density (P_2) and lowest harvest index (50.64%) was recorded from high plant density (P_3).

Different sowing dates showed significant effect on quinoa plants' different growth characters**.** Higher plant heights at 25 DAS (14.53 cm), at 45 DAS (59.21 cm) and at 65 DAS (70.71 cm) was recorded from D_5 (30 December sowing), D_6 (15 January sowing) and D_4 (15 December sowing) respectively and at 25 DAS, 45 DAS lowest plant height (9.77 cm and 43.74 cm) recorded from D_3 (30 November sowing) and at 65 DAS lowest plant height (51.05 cm) recorded from D_2 (15 November sowing). D_5 (30 December sowing) showed highest number of leaves $plant^{-1}$ (8.82 and 73.87) at 25 DAS and 45 DAS and D_3 (30 November sowing) showed highest number of leaves $plant^{-1}$ (82.23) at 65 DAS. D_6 (15 January sowing) showed lowest number of leaves $plant^{-1}$ (6.59 and 48.11) at 25 DAS and 65 DAS and at 45 DAS, lowest number of leaves $plant^{-1}$ (45.64) was obtained from D_1 (30 October sowing). In case of branches, highest number of branches $plant^{-1}$ (16, 16.93 and 16.93) recorded from D_4 (15 December sowing) at different growth stages (45 DAS, 65 DAS and at harvest) and D_2 (15 November sowing) showed lowest number of branches $plant^{-1}$ (10.24) at 45 DAS and D_6 (15 January sowing) showed lowest number of branches $plant^{-1}$ (8.64 and 8.02) at 65 DAS and harvest. At 25 DAS, D_5 (30 December sowing) resulted maximum dry weight $plant^{-1}$ (0.17 g) and D_3 (30 November sowing) resulted lowest dry weight $plant^{-1}$ (0.05 g). At 55 DAS, maximum dry weight $plant^{-1}$ (6.79 g) was recorded from D_2 (15 November sowing) and lowest dry weight plant^{-1} (2.16 g and3.81 g) was recorded from D_6 (15 January sowing) and D_5 (30 December sowing). At harvest, maximum dry weight plant^{-1} (12.62 g and 12.05 g) was recorded from D_1 (30 October sowing) and D_2 (15 November sowing) and lowest dry weight plant^{-1} (2.82 g) was recorded from D_6 (15 January sowing). The maximum number of effective branches plant^{-1} (14.09) was obtained from D_3 (30 November sowing), which was statistically similar with D_2 (15 November sowing) and D_2 (15 December sowing) (13.69, 13.24 respectively).

Different sowing dates showed statistically significant effect on quinoa plants' yield and yield attributing characters. At harvest, maximum 1000-seed weight value (3.61 g and 3.50 g) was found in D_1 (30 October sowing) and D_3 (30 November sowing) and highest seed yield (3.23 t ha^{-1}) and highest biological yield (3.95 t ha^{-1}) was obtained from D_3 (30 November sowing) and highest straw yield (2.08 t ha^{-1}) was obtained from D_4 (15 December sowing) and the highest harvest index (75.66 %) was recorded from D_1 (30 October sowing). At harvest, lowest 1000-seed weight value (2.65 g) and lowest seed yield (1.14 t ha^{-1}) was found from D_5 (30 December sowing) and D_1 (30 October sowing) showed lowest straw yield (0.99 t ha^{-1}) and D_6 (15 December sowing) showed lowest biological yield (2.89 t ha^{-1}) and lowest harvest index (40.09 %) was recorded from D_5 (30 November sowing).

Interaction effect of different planting densities and sowing dates also significantly affected growth, yield and yield contributing characters of quinoa. The highest plant heights at 25 DAS, 45 DAS, 65 DAS (15.07 cm, 62.69 cm and 73.83 cm) were recorded in P_2D_5 and lowest plant heights at 25 DAS (9.72 cm) in P_1D_3; at 45 DAS (39.02 cm) in P_1D_3 and at 65 DAS (50.17 cm) in P_1D_2 were recorded. At harvest, identical results with 65 DAS were observed. At 25 DAS (9.17) in P_2D_5; at 45 DAS (83.93) in P_1D_5 and at 65 DAS (89.33) in P_1D_3 the highest number of leaves plant^{-1} were recorded. The lowest number of leaves plant^{-1} at 25 DAS (6.37) in P_1D_6; at 45 DAS (45.73) in P_2D_1 and at 65 DAS (43.60) in P_2D_1 were recorded. The highest number of branches plant^{-1} at 45 DAS (16.40) in P_3D_4; at 65 DAS (17.07) in P_1D_4, P_3D_5 and lowest number of branches plant^{-1} at 45 DAS (6.53) P_3D_2; at 65 DAS (7.80) in P_3D_6 were obtained. At harvest, identical results with 65 DAS were observed. In case of dry weight, the highest dry weight value (0.18 g) in P_1D_5 at 25 DAS; at 55 DAS (7.53 g) in P_1D_2; at harvest (17.96 g) in P_1D_1 were recorded and the lowest dry weight value at 25 DAS (0.05 g) in P_3D_3, P_1D_3; at 55 DAS (1.68 g) in P_3D_6; at harvest (2.18 g) in P_3D_6 were recorded. The maximum 1000-seed weight (3.74 g) was recorded from P_2D_1 and lowest 1000-seed weight (2.61 g) was obtained from P_1D_5. The highest seed yield (3.56 t ha^{-1}) in P_3D_3; straw yield (2.38 t ha^{-1}) in P_3D_4; biological yield (5.67 t ha^{-1}) in P_3D_3 and harvest index (80.25%) in P_1D_1 were observed. And the lowest seed yield (0.86 t ha^{-1}) in P_1D_5; straw yield (0.88 t ha^{-1}) P_1D_1; biological yield (1.39 t ha^{-1}) in P_1D_6 and harvest index (36.60%) in P_1D_5 were recorded.

Considering the findings of the present experiment, following conclusions may be drawn:

- ❖ The highest plant height was recorded from medium plant density (50 plant m^{-2}). However, the lowest plant density (25 plants m^{-2}) resulted in highest number of leaves (25 DAS, 45 DAS and 65 DAS), highest number of branches (45 DAS, 65DAS and at harvest), highest dry weight (25 DAS, 55 DAS and at harvest) and effective branches (at harvest). Though at harvest, the highest seed yield (2.17 t ha^{-1}) observed from high plant density (75 plants m^{-2}) and second highest yield (2.11 t ha^{-1}) found from medium plant density (50 plants m^{-2}), they were statistically similar and highest straw yield, biological yield were observed from P_3 and highest 1000-seed weight recorded from P_2. In all the growth, yield and yield attributing characters, lowest values were observed in low plant density (25 plants m^{-2}) at all studied plant densities.

- ❖ D_5 (30 December sowing) resulted highest plant height at 25 DAS; D_6 resulted highest plant height at 45 DAS and plant height D_4 resulted highest at 65 DAS and at harvest. D_5 resulted highest number of leaves $plant^{-1}$ (at 25 DAS and 45 DAS); D_3 at 65 DAS. And D_4 showed highest number of branches $plant^{-1}$ (at 45 DAS, 65 DAS and at harvest). But at harvest, D_3 (30 November sowing) resulted highest seed (3.23 t ha^{-1}) and biological yield (5.13 t ha^{-1}) and D_2 (15 November sowing) resulted second highest seed yield (2.91 t ha^{-1}).
- ❖ Interaction of high plant density (75 plant m^{-2}) with 30 November sowing (D_3) resulted highest seed (3.56 t ha^{-1}) and biological yield (5.67 t ha^{-1}). Besides, medium plant density (50 plant m^{-2}) with 30 November sowing (D_3) and also high plant density (P_3) with 15 November sowing (D_2) ensured higher seed yield (3.27 t ha^{-1} and 3.20 t ha^{-1} respectively).

Before recommendation of plant density and sowing date to optimize Quinoa production further study is suggested in different Agro-ecological zones of Bangladesh for regional adaptability.

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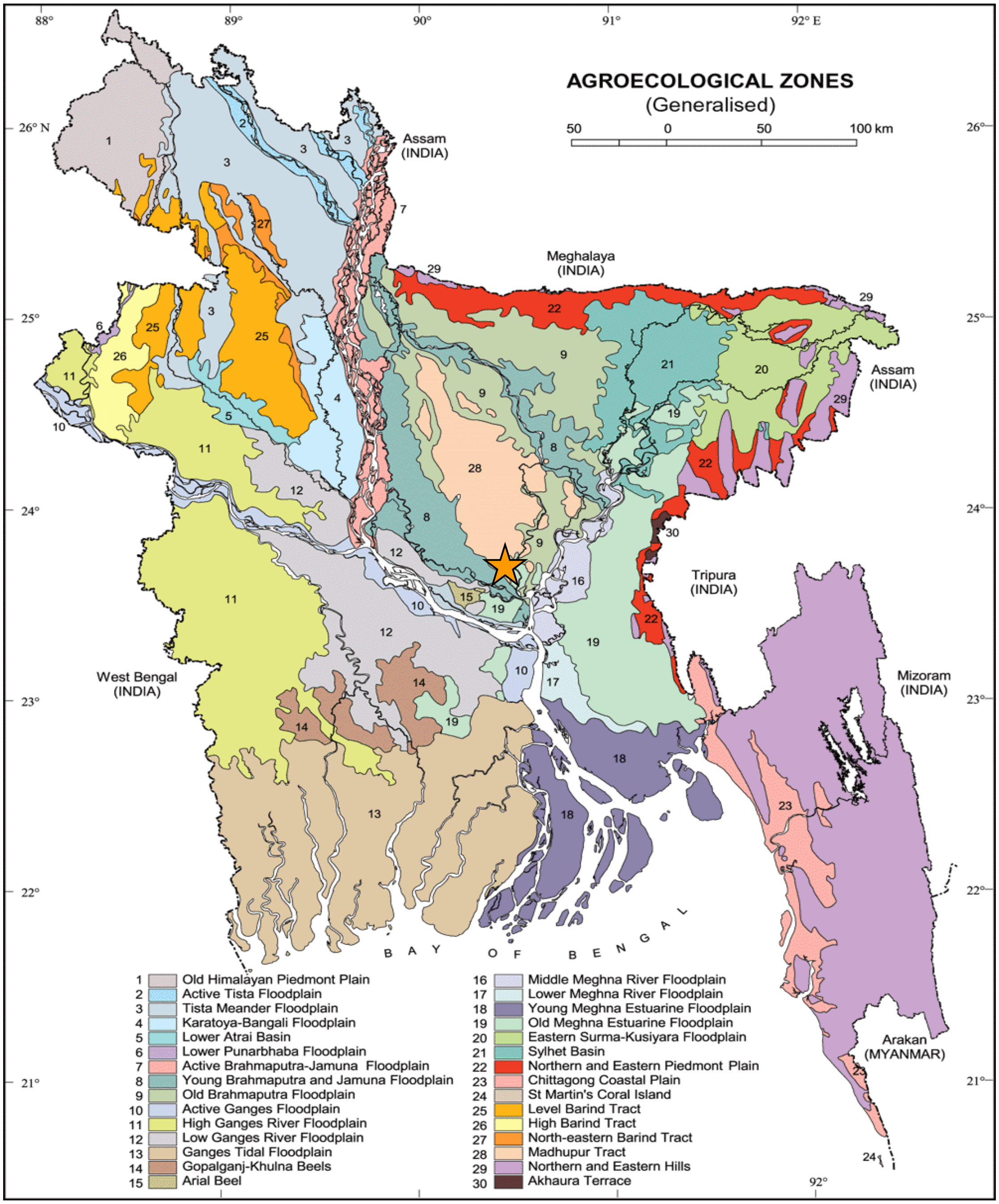
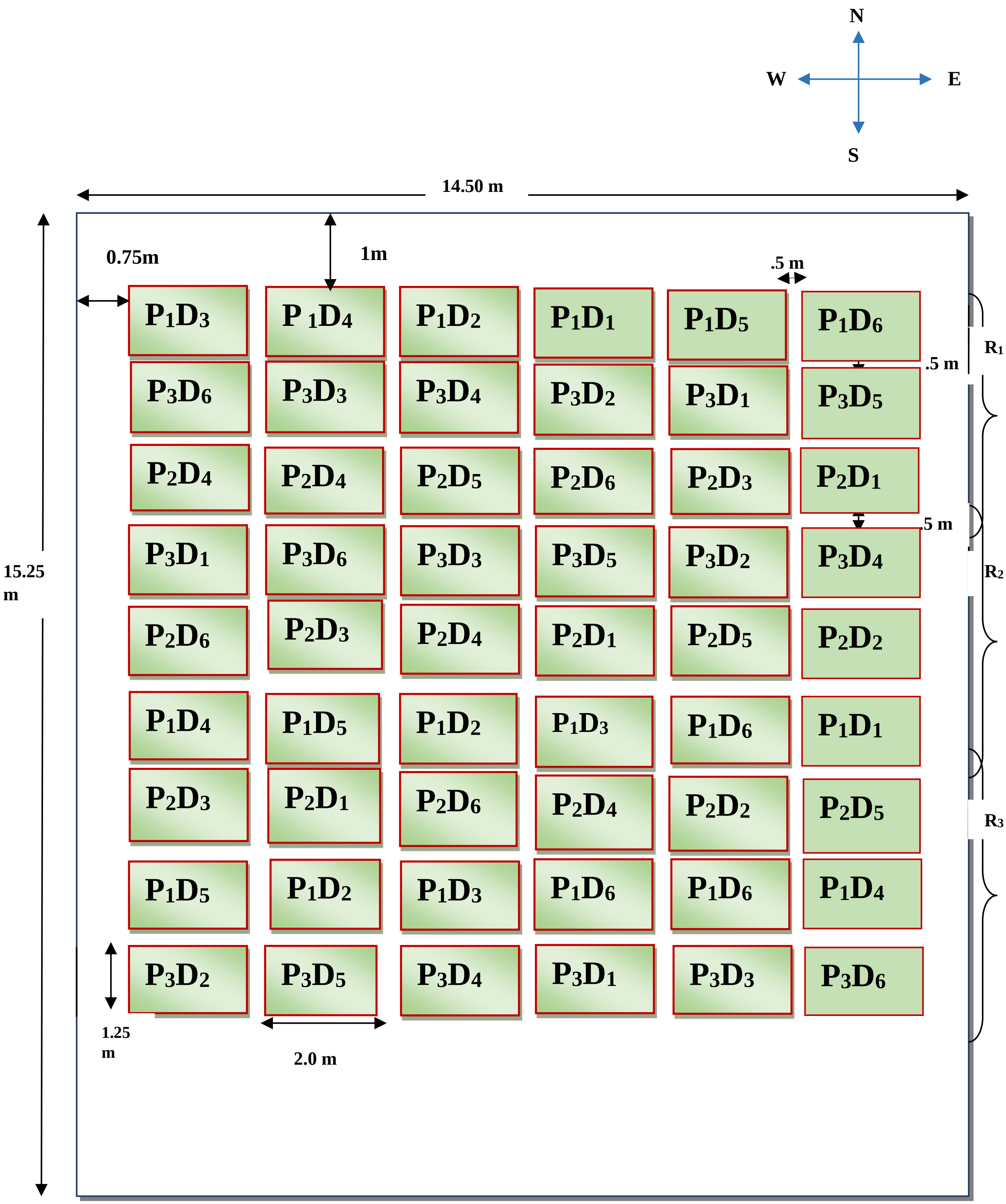
APPENDICES

Appendix I. Map showing the experimental sites under study



★ **The experimental site under study**

Appendix II. Layout of the experimental field



Appendix III. Characteristics of soil of experimental field

A. Morphological characteristics of the experimental field

Morphological features	**Characteristics**
Location	Sher-e-Bangla Agricultural University Research Farm, Dhaka-1207
AEZ	AEZ-28, Madhupur Tract
General soil type	Deep Red Brown Terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled

B. The initial physical and chemical characteristics of soil of the experimental site (0 - 15 cm depth)

Physical characteristic	
Constituents	**Percentage (%)**
Sand	26
Silt	45
Clay	29
Textural class	Silty clay

Chemical characteristic	
Characteristics	Value
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total nitrogen (%)	0.03
Available P (ppm)	20.54
Exchangeable K (me/100gm soil)	0.1

Source: Soil Resource and Development Institute (SRDI), Farmgate, Dhaka

Appendix IV. Monthly average air temperature and total rainfall of the experimental site during the period from November, 2021 to March, 2022

Month (2021-2022)	Air temperature (^{0}c)		Total rainfall (mm)	Relative Humidity (%)
	Maximum	Minimum		
November	29.6	19.16	34.4	74.1
December	26.4	18.13	12.8	71.5
January	25.4	12.65	7.7	51.3
February	28.1	15.5	28.9	62.8
March	32.5	22.5	55.8	68.7

Source: Bangladesh Meteorological Department (Climate & weather division) Agargoan, Dhaka-1212

Appendix V. Mean square values of plant height of quinoa as influenced by plant density and sowing date

Source of variation	Degrees of freedom	Mean square value of plant height at			
		25 DAS	45 DAS	65 DAS	Harvest
Replication	2	1.899	118.745	38.7208	39.5605
Plant density (A)	2	0.602541*	34.8654^{NS}	46.6477^{NS}	46.0063^{NS}
Error I	4	0.120149	29.3053	25.3352	25.9154
Sowing date (B)	5	36.3358*	344.352*	528.022*	526.592*
Interaction (A x B)	10	0.157792*	32.4489*	56.0392*	56.0255*
Error II	30	0.318938	21.0904	30.2602	30.0980

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

Appendix VI. Mean square values of leaves plant^{-1} of quinoa as influenced by plant density and sowing date

Source of variation	Degrees of freedom	Means square value of leaves plant^{-1} at		
		25 DAS	45 DAS	65 DAS
Replication	2	0.390185	189.947	79.5650
Plant density (A)	2	0.341296^{NS}	185.707^{NS}	649.822*
Error I	4	0.111296	60.8791	75.1633
Sowing date (B)	5	7.08474*	1236.34*	1559.04*
Interaction (A x B)	10	0.2266852*	87.9953*	71.8470*
Error II	30	0.240926	102.613	82.7257

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

Appendix VII. Mean square values of branches plant^{-1} of quinoa as influenced by plant density and sowing date

Source of variation	Degrees of freedom	Mean square value of branch plant^{-1} at		
		45 DAS	65 DAS	Harvest
Replication	2	5.22666	8.38741	7.11407
Plant density (A)	2	6.37556*	21.2652*	20.4496^{NS}
Error I	4	1.37556	4.20296	4.35741
Sowing date (B)	5	85.1498*	86.9114*	109.132*
Interaction (A x B)	10	2.45000*	4.26430*	4.31452*
Error II	30	2.34815	2.83689	2.88519

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

Appendix VIII. Mean square values of dry weight plant^{-1} of quinoa as influenced by planting density and sowing date

Source of variation	Degrees of freedom	Mean square value of dry weight plant^{-1} at		
		25 DAS	55 DAS	Harvest
Replication	2	0.587630	0.367555	1.13906
Plant density (A)	2	0.28801^{NS}	11.8887*	44.7571*
Error I	4	0.22113	0.380041	0.919018
Sowing date (B)	5	0.19634*	22.6758*	149.350*
Interaction (A x B)	10	0.37304*	0.563703*	8.64251*
Error II	30	0.311007	0.444433	1.57577

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

Appendix IX. Mean square values of effective/ ineffective branches plant^{-1}of quinoa influenced by plant density and sowing date

Source of variation	Degrees of freedom	Mean square value	
		Effective branch	Ineffective branch
Replication	2	3.88074	1.44963
Plant density (A)	2	34.9607*	1.97852*
Error I	4	3.62963	0.211852
Sowing date (B)	5	283.962*	58.5661*
Interaction (A x B)	10	7.22652*	1.46563*
Error II	30	2.82711	0.562222

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

Appendix X. Mean square values of 1000- seed weight of quinoa as influenced by plant density and sowing date

Source of variation	Degrees of freedom	Mean square value
		1000- seed weight
Replication	2	0.2551556
Plant density (A)	2	0.742055*
Error I	4	0.994443
Sowing date (B)	5	16.9675*
Interaction (A x B)	10	0.235589*
Error II	30	0.129970

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

Appendix XI. Mean square values of yield and harvest index of quinoa as influenced by plant density and sowing date

Source of variation	Degrees of freedom	Mean square value			
		Seed yield	Straw yield	Biological yield	Harvest index
Replication	2	0.16200	0.156367	0.336889	17.4056
Plant density (A)	2	0.628170*	0.888412*	2.85951*	6.40977^{NS}
Error I	4	0.164880	0.85302	0.456362	19.6104
Sowing date (B)	5	13.5930*	1.70992*	13.1692*	7157.53*
Interaction (A x B)	10	0.133691*	0.200*	0.165421*	34.1689*
Error II	30	0.696988	0.150113	0.121574	27.8356

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

LIST OF PLATES

Plate 1. Experimental details and view of field

Plate 2. Land preparation

Plate 3. Field view of a plot at 5 DAS

Plate 4. Field view of a plot at 15 DAS

Plate 5. Field view of a plot at 25 DAS

Plate 6. Field view of a plot at 45 DAS

Plate 7. Field view of a plot at 65 DAS

Plate 8. Field view of a plot at 85 DAS

Plate 9. Overview of experimental plot

Plate 10: Field view of a plot at harvest