GROWTH AND YIELD OF QUINOA (*Chenopodium quinoa* Willd.) AS AFFECTED BY DIFFERENT SOWING METHODS AND FERTILIZER MANAGEMENT

GAIOTRI SUTTRADHAR

DEPARTMENT OF AGRONOMY

SHER-E-BANGLA AGRICULTURAL UNIVERSITY

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BY

GAIOTRI SUTTRADHAR

REGISTRATION NO. 15-06669

Email:gaiotrisuttradhar@gmail.com

Mobile No: 01727227091

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Approved by:

Prof. Dr. Parimal Kanti Biswas **Supervisor**	**Prof. Dr. Md. Shahidul Islam** **Co-supervisor**

Prof. Dr. Md. Abdullahil Baque
Chairman
Examination Committee

DEPARTMENT OF AGRONOMY
Sher-e-Bangla Agricultural University
Sher-e-Bangla Nagar, Dhaka-1207
Phone: 44814043

CERTIFICATE

This is to certify that the thesis entitled "**GROWTH AND YIELD OF QUINOA (*Chenopodium quinoa* Willd.) AS AFFECTED BY DIFFERENT SOWING METHODS AND FERTILIZER MANAGEMENT**" 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 (MS) in AGRONOMY, embodies the results of a piece of bona fide research work carried out by GAIOTRI SUTTRADHAR, Registration No. 15-06669 under my supervision and guidance. No part of this 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 the course of this investigation has duly been acknowledged.

Dated:

Dhaka, Bangladesh

Prof. Dr. Parimal Kanti Biswas

Supervisor

DEDICATED

TO

MY BELOVED

PARENTS,

THE REASON OF

WHAT I HAVE

BECOME

TODAY

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GROWTH AND YIELD OF QUINOA (*Chenopodium quinoa* Willd.) AS AFFECTED BY DIFFERENT SOWING METHODS AND FERTILIZER MANAGEMENT

ABSTRACT

A field experiment was conducted at the Sher-e-Bangla Agricultural University, Dhaka, during November 2021 to February 2022 in Rabi season to examine the effect of different sowing methods and fertilizer management on growth and yield of quinoa. The experiment consisted of three sowing methods (*viz*. M_1- Broadcast sowing method, M_2- Line sowing method and M_3- Bed sowing method) and five fertilizer management level (*viz.* F_1- No fertilizer (control), F_2- 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B (RFD) ha^{-1}, F_3- 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B (RFD) ha^{-1}+ 10 t cowdung ha^{-1} and F_4- 150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1} and F_5- 150-100-100 kg N, P_2O_5, K_2O). The experiment was laid out in split-plot design with three replications. Sowing methods were allocated in main plots and fertilizer management in sub-plots. Results revealed that different growth characters, yield and yield contributing characters of quinoa were significantly influenced by sowing methods, fertilizer management and their interactions. Among different sowing methods, bed sowing method resulted in maximum plant height (45.66 cm), dry weight (7.04 g $plant^{-1}$), seed yield (3.23 g $plant^{-1}$),seed yield (2.52 t ha^{-1}), straw yield (1.20 t ha^{-1}), biological yield (3.71 t ha^{-1}) and harvest index (68.369 %). The highest number of leaves $plant^{-1}$, number of branches $plant^{-1}$, SPAD values, seed yield (3.68 g $plant^{-1}$), seed yield (3.02 t ha^{-1}), biological yield (4.39 t ha^{-1}) and harvest index (68.79%) were recorded in F_3 fertilizer management at different growth stages and at harvest. Interaction between bed sowing method and F_3 fertilizer level resulted in highest seed yield (3.09 t ha^{-1}) and biological yield (4.51 t ha^{-1}) at harvest. From the above results it was appeared that bed sowing method and F_3 fertilizer level resulted in highest values in most of the yield attributing characters and their interaction provided the best seed yield (3.09 t ha^{-1}) and biological yield value (4.51 t ha^{-1}).

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LIST OF ACRONYMS

AEZ	Agro-Ecological Zone
Anon.	Anonymous
B	Boron
BBS	Bangladesh Bureau of Statistics
BV	Biological Value
BS	Bed Sowing
°C	Degree Centigrade
cm	Centimeter
CV %	Percent Coefficient of Variance
CP	Crude Protein
CWP	Crop Water Productivity
DAS	Days After Sowing
dS/m	Deci Siemens per meter
EC	Electrical Conductivity
et al.	And others
e.g.	*exempli gratia* (L), for example
etc.	etcetera
FAO	Food and Agriculture Organization
FLS	Flat Line Sowing
g	Gram
GY	Grain Yield
ha^{-1}	Per hectare
HI	Harvest Index
i.e.	*id est* (L), that is
kg	Kilogram (s)

LIST OF ACRONYMS (Contd.)

K_2O	Potassium oxide
LAI	Leaf Area Index
LSD	Least Significant Difference
MoP	Muriate of Potash
m^2	Meter squares
MPW	Main Panicle Weight
M.S.	Master of Science
N	Nitrogen
No.	Number
NPK	Nitrogen, Phosphorus and Potassium
NS	Non-significant
P_2O_5	Phosphorus pentoxide
$Plant^{-1}$	Per Plant
PNPP	Panicle Number Per Plant
RS	Ridge Sowing
S	Sulfur
SAU	Sher-e-Bangla Agricultural University
SPAD	Soil Plant Analytical Development
SSW	Sowing in Standing Water
$t\ ha^{-1}$	Ton per hectare
TDM	Total Dry Matter
TGW	Thousand Grain Weight

LIST OF ACRONYMS (Contd.)

TSP	Triple Super Phosphate
Viz.	Videlicet (namely)
Zn	Zinc
%	Percentage

CHAPTER I

INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd.) is an annual, herbaceous, dicotyledonous plant under Amaranthaceae family. It is termed as pseudo-cereal (Pedrali *et al.*, 2023; Nirmala and Sinha, 2022; Awadalla and Morsy, 2017) and mostly a short day plant (Wu *et al.*, 2023). Rabi season is the most preferable time for quinoa cultivation in Bangladesh (Biswas and Tanni, 2020). Quinoa was originated and has been cultivated in Andean region since five thousand years (Biswas and Tanni, 2020) and was known as "mother grains" to the Incas (Oustani *et al.*, 2023). It is one of the main food crops in the Andean mountains and due to its good nutritional qualities and adaptability in wide range of conditions quinoa has gained a great attention globally (Curti *et al.*, 2012). Presently quinoa is being cultivated in 123 countries worldwide (Alandia *et al.*, 2020) and the leading quinoa producing countries are Bolivia and Peru. The edible parts involve leaves and grains (Bhathal *et al.*, 2017; Lamothe *et al.*, 2015) but grown primarily for its edible seeds. Whole quinoa plant can also be used as nutritious livestock fodder (Voronov *et al.*, 2023; Afzal *et al.*, 2022; Asher *et al.*, 2020). Keep in view the importance of quinoa, the Food and Agriculture Organization (FAO) selected it as most imperative crop to offer the food security in the 21st century (FAO, 2013a). Quinoa is a halophyte with a high tolerance to salinity (Gandla *et al.*, 2022) and FAO suggests growing it in poor and barren lands. It can be cultivated up to 30 dS m^{-1} level of salinity in Bangladesh (Narjis, 2018). It is capable to withstand in drought, cold, salinity, hail and requires low input, which leaves no doubt as to why it has been called the "golden grain" (Sghaier *et al.*, 2023; Nirmala and Sinha, 2022; Angeli *et al.*, 2020).

Quinoa is referred to as a "complete food" due to its abundance of good-quality protein (Villacrés *et al.*, 2022; Coţovanu *et al.*, 2021). Quinoa seeds have high quality proteins (7.47 to 22.08%) (Biswas and Tanni, 2020; Bhargava *et al*., 2006) and its protein is comparable with milk protein (Nirmala and Sinha, 2022; Jancurova *et al*., 2009). It is the only vegetable food that provides all nine essential amino acids fundamental to human life (Pandey *et al*., 2023; FAOSTAT, 2013b) and to fulfill our daily protein requirement in the most favorable quantities (Vega-Gálvez *et al*., 2010). The biological value (BV) of a protein, which links nitrogen consumption to nitrogen excretion, serves as a measure of protein intake for both human and animal nutrition. The proteins in whole eggs (93.7%) and cow milk (84.50%) have the highest BV values (Friedman, 1996). Quinoa's protein has a BV of 83%, greater than the proteins found in fish (76%), beef (74.3%), soybeans (72.8%), wheat (64%) and rice (64%) as well as corn (60%). The protein of quinoa contains acceptable quantities of phenylalanine, tyrosine, histidine, isoleucine, threonine, and valine in accordance with the FAO/WHO dietary needs for children between the ages of 10 and 12 (Abugoch, 2009). More than 80 % of quinoa protein is digestible.

Quinoa also provides higher level of energy, calcium, phosphorus, iron, fibre and vitamin B than barley, oats, rice, corn or other wheat (Koziol, 1991) and can be used as nutritional ingredient in food products (Gonzalez *et al.*, 2012). It is gluten-free (Pathan and Siddiqui, 2022) and it contains high amount of essential fatty acid, minerals, fibre, vitamins, carbohydrate, phytohormones and antioxidant that can make a strong contribution to human nutrition, particularly to protect cell membrane and with proven good results in brain neuronal function(Antonio *et al.,* 2010). Quinoa seed is richer in lipids than most cereal grains including wheat, rice, barley, maize, oat, and rye. Lipid content of quinoa typically ranges from 5.0 to 7.20% and is a good source of essential fatty acids (Vega-Gálvez *et al*., 2010). Because of these exceptional nutritional characteristics and health benefits quinoa is occasionally called a "superfood" (Wu *et al*., 2023; Pathan and Siddiqui, 2022).

Quinoa is the grain crop with the highest nutrients per 100 calories, according to FAO. It has no cholesterol and does not cause allergies. Because of these unique nutritional qualities, NASA has selected ‘‘superfood quinoa’’ to feed astronauts on long space missions. Being high in various important nutrients, it is considered as world’s one of the most popular health foods. Quinoa is celebrated for its excellent nutritional quality and potential to improve national and global food security and malnutrition (Wu *et al*., 2017; Noratto *et al*., 2019).

For a new crop like quinoa, the sowing technique is an important agronomic practice to obtain a targeted high yield under field conditions. Because an effective sowing method not only makes the crop able to utilize the resources efficiently but also reduces the surface runoff and stores moisture in the soil under water stress conditions (Awadalla and Morsy, 2017; Belachew and Abera, 2010). Furthermore, a suitable sowing method creates a favorable root zone and reduces the chances of lodging. Various management practices can result in different responses with respect to canopy development, time to physiological maturity and grain yield among cultivars of quinoa (González *et al*., 2012). Dao *et al*. (2020) reported higher yield of quinoa sown in ridges (sowing depth: 3 cm; ridge height and width: 15 cm and 17 cm) under high density rates as the most optimal agronomic technique in terms of yield. Ali *et al.* (2020) showed that bed sowing method improved the morphological attributes *viz.* stem thickness, main panicle, thousand grain weight, grain yield, and harvest index of quinoa as compared to sowing in standing water.

The balanced nutrient supply and uptake by a growing plant is one of the most important factors that improves the ability of plant to perform its physiological functions during its various development stages (Mengel and Kirby, 2001; Havlin *et al*., 2005). Risi and Galwey (1984) and Schulte *et al*. (2005) evaluated the response of quinoa yield to N fertilization rates and NUE and found a strong response of the grain yield to N fertilization. Although, some studies have been conducted to identify fertilizer requirements by quinoa plant but to the date a little is reported on the sowing techniques. There is a need for further studies on the relationship of quinoa plant with different sowing method and fertilizer under Bangladesh condition. Considering these facts the study has been designed with the following objectives:

(i) To select the best performing sowing method

(ii) To determine the suitable combination of fertilizer

(iii) To find out the best interaction of sowing method and fertilizer management for quinoa cultivation in Bangladesh.

CHAPTER II

REVIEW OF LITERATURE

Being a low Glycemic Index (GI) food and having good nutritional qualities and adaptability in wide range of conditions, quinoa gained a great attention globally (Lu *et al*, 2023; Curti *et al.*, 2012; Shams, 2012). It is highly tolerant to drought and soil salinity (Razzaghi *et al*., 2011). Quinoa is superior to other cereals with respect to the high content of proteins, lipids as well as nutraceutical compounds (Islam *et al.,* 2021). Because of its great nutritional value and its exceptional balance of key amino acids, its composition has caught the attention of the scientific community and posse's high commercial value. Besides that, it is gluten-free, allowing celiac patients to consume it (Pedrali *et al*., 2023; Afzal *et al*., 2022; Asher *et al*., 2020). Though numerous studies on the effects of various fertilizer levels on quinoa have been conducted abroad and in Bangladesh thus far, there have been relatively few studies on the ideal sowing methods for quinoa not only in Bangladesh but also globally. Some research related to the effects of different fertilizer levels and sowing methods of quinoa have been reviewed in this chapter under the following heads. When ample information on quinoa related to different fertilizers and sowing methods were not available, relevant literatures were also cited.

2.1 Performance of quinoa under different fertilizer levels

According to Minh *et al*. (2022) the interaction between nitrogen at 120 and 150 kg N ha^{-1} rate with 105 kg K_2O ha^{-1} resulted in better yield component values of quinoa. They also reported that applying 90 kg K_2O ha^{-1} combined with 120 and 150 kg N ha^{-1} showed better growth performance of quinoa.

According to Alvar-Beltrán *et al.* (2021) 12.7, 1.6 and 35.5 kg ha^{-1} of N, P, and K must be given to the soil in order to produce one ton of quinoa biomass (containing seeds, stems, and leaves). P is needed in lesser amounts while N and K are needed in medium to high concentrations. Therefore, potassium nitrate (KNO_3) fertilizers are more suited than those with higher phosphorus concentrations, such as phosphate (PO_4^{3-}).

An experiment was conducted by Afrin (2018) at the Agronomy research field, Sher-e-Bangla Agricultural University, Dhaka from November, 2017 to January, 2018 to study the performance of two different varieties of quinoa as influenced by seven fertilizer levels, F_1 (no fertilizer), F_2 (120 kg N ha^{-1}), F_3 (50 kg P ha^{-1}), F_4 (50 kg K ha^{-1}), F_5 (120-50 kg NP ha^{-1}), F_6 (120-50 kg NK ha^{-1}), F_7 (120-50-50 kg NPK ha^{-1}) and suggested that Vikinga and Titicaca with 120-50-50 NPK kg ha^{-1} or 120-50 kg NK ha^{-1} is the most compatible in respect of yield advantage and economic gain. Out of the different fertilizer levels 120-50 kg NK ha^{-1} showed maximum growth and yield in Quinoa.

Bascuñan-Godoy *et al*. (2018) reported that during drought-influenced senescence, nitrogen supply controls photoprotection of the photosynthetic apparatus of quinoa plants. Ramesh *et al*. (2019) found that 100 kg N, 50 kg P_2O_5, 50 kg K_2O ha^{-1} recorded the higher growth, yield and yield attributes of quinoa. It is known that quinoa yield and metabolism respond strongly to nitrogen fertilization (Almadini *et al*., 2019; Kakabouki *et al*., 2014; Basra *et al*., 2014; Bilalis *et al*., 2012; Schulte *et al*., 2005 and Berti *et al*., 2000).

Kakabouki*et al.* (2018) conducted a three year experiment and found that the nitrogen uptake and utilization efficiency were only influenced by fertilization. The higher biomass nitrogen content (4.08-4.33%), biomass nitrogen yield (371-386 kg N ha^{-1}), seed nitrogen content (2.59-2.78%), seed nitrogen yield (62.58-

65.42 kg N ha^{-1}) and total plant nitrogen uptake (437.20-454.93 kg N ha^{-1}) were found in 200 kg N ha^{-1} .

In studies conducted by Gomaa (2013) in Egypt where quinoa plants were fertilized with ammonium nitrate (34% N) at 0, 120, 238, 357 kg ha^{-1} in combination with nitrobin (biofertilizer) or calcium super phosphate (15.50% P_2O_5) at 0, 120, 238, 357 kg ha^{-1} in combination of phosphor in (biofertilizer). The plants performed the best in the treatment receiving 238 kg $ha^{-1}$of ammonium nitrate in combination with nitrobin.

Darwinkel and Stølen (1997) reported the requirements of 70 kg P_2O_5 ha^{-1} for quinoa prior to seed filling and noted that existing levels of 29 kg phosphorus in many agricultural soils are likely sufficient. They also noted a fairly large requirement for potassium, with uptake of 400 kg K ha^{-1}, and recommend application of 100-200 kg K_2O ha^{-1}.

Almadini *et al*. (2019) reported that at 0, 80 and 160 kg ha^{-1} N fertilizer treatment, the NUE of quinoa was 0.00, 5.52 and 4.31 respectively. They found that at 80 kg N ha^{-1} the NUE of quinoa was maximum and then decreased with increased rate of N fertilizer application.

Awadalla and Morsy (2017) conducted two field experiments at South Valley Farm Research Station, Toshka Region, (ARC), Egypt during 2014/2015 and 2015/2016 seasons with four N-levels (*i.e.* 0.0, 50, 100, 150 kg N/fad). They reported that in both season, the maximum nitrogen use efficiency (NUE) values were observed when quinoa received only 50 kg N/fad. The NUE of quinoa was averaged as 22.2 kg ha^{-1} and did not decrease with increasing N rates that reported by Fawy *et al.* (2017).

Shams (2012) stated that there was significant decrease in NUE with increasing rate of fertilizer. He reported that nitrogen use efficiency (NUE) values of 5.367 Kg Kg^{-1} N and 3.417 Kg Kg^{-1} N were obtained when quinoa received only 90 kg N ha^{-1} in first and second season, respectively. These results were hold true in both seasons and supported by several investigators as Pospisil *et al*. (2006), Schulte *et al*. (2005), Meyers (1998), El-Behri *et al.* (1993) and Finck (1982).

2.1.1 Growth parameters

2.1.1.1 Plant height

An experiment conducted by Biswas *et al*. (2021) on Rabi season 2018-2019 in Dhaka at Sher-e-Bangla Agricultural University and it was found that among eight nitrogen doses the highest plant height (56.81 cm) was recorded in 220 kg N ha^{-1} and the lowest plant height (47.55 cm) by 0 kg N ha^{-1}.

Naik *et al.* (2020) conducted an experiment with quinoa, following factorial randomised block design in Bengaluru during Rabi 2018 and reported that 150:75:75 kg NPK ha^{-1} recorded the highest growth parameters like plant height at 30 DAS (25.91 cm), 60 DAS (119 cm) and at harvest (122.28 cm). According to Wang *et al.* (2020) applying 240 kg N ha^{-1} resulted in higher plant height of quinoa than applying 80 kg N ha^{-1}.

A field experiment was conducted by Almadini *et al*. (2019) to evaluate the response of the quinoa yield to nitrogen (N) fertilization. Three levels of N fertilizer (*i.e.,* 0, 80 and 160 kg N ha^{-1}) were used and laid out in a randomized complete block design with four replicates to evaluate the response of the quinoa yield to nitrogen (N) fertilization. They reported that fertilizing quinoa with 160 kg N ha^{-1} resulted in maximum plant height of 75.9 cm.

According to Afrin (2018) at 30 DAS the highest plant height was observed (15.22 cm) in F_7 (120-50-50 kg NPK ha^{-1}). At 45, 60 DAS and at harvest plant height was highest (29.49, 23.40 and 28.65 cm, respectively) in F_6 (120-50 kg NK ha^{-1}) and lower in 30, 45, 60 DAS (8.59, 17.9 and 20.21 cm, respectively) in F_3 (50 kg P ha^{-1}) and at harvest the lowest plant height (16.65) was observed from F_1 (no fertilizer).

Fawy *et al*. (2017) reported that 240 kg N ha^{-1}, 37 kg P ha^{-1} and 150 kg K ha^{-1} (P as ordinary superphosphate of 68 g P kg^{-1} and K as potassium sulfate of 420 g K kg^{-1}) fertilizers as soil application increases about 33% for plant height (cm) he also found that the combination of 48 mg organic manure ha^{-1} + 240 kg N ha^{-1} with spraying with humic acid solution of 600 mg L^{-1} + ascorbic acid solution of 1000 mg L^{-1} gave the highest positive response of plant height (cm) of 118. They also stated that soil application of organic manure in comparison with those without application gave 9.0% greater plant height (cm) of quinoa.

Geren (2015) found that the highest plant height (101.10 cm) was obtained from 175 kg N ha^{-1} application in 2014, whereas the lowest was 43.80 cm for 0 kg N ha^{-1} application in 2013. Year effect was also significant and average quinoa height of second year (76.20 cm) was higher than the first year (66.10 cm) due to the total precipitation of the second year which was clearly higher than first year. He also informed that the plant height of quinoa increased noticeably by increasing nitrogen fertilizer rate up to 175 kg N ha^{-1} in both seasons. Many researchers informed that the plant height of quinoa increases with the increasing nitrogen level are mainly due to the role of nitrogen in stimulating metabolic activity which contribute to the increase in metabolites amount and consequently lead to internodes elongation and increase plant height with the increasing nitrogen rate (Shams, 2012; Erley *et al.,* 2005 and Jacobsen *et al*., 1994). Weisany *et al.* (2013) reported that soil application of nitrogen resulted in 33% higher plant height of quinoa than in control.

A two years experiment was conducted with N rates of 0, 90, 180, 270 and 360 kg N ha^{-1} by Shams (2012) to find out the effect of nitrogenous fertilization on quinoa under sandy soil conditions. He clearly found that plant height in quinoa increased gradually with increasing nitrogen levels up to 360 kg N ha^{-1} and reported that fertilizing quinoa with 360 Kg N ha^{-1} resulted in maximum plant height of 52.73 cm and 51.78 cm. The increases plant height of quinoa with increasing N level are mainly due to role of N in stimulating metabolic activity which contributed to the increase in metabolites amount and consequently lead to internodes elongation and increase plant height with increasing nitrogen rate. These results were in agreement with these obtained by El-Behri *et al.* (1993) and Posipisil *et al.* (2006). Jacobsen *et al.* (1994) expressed that plant height of quinoa increased with increasing N fertilization rate from 40 to 160 kg N ha^{-1}.

2.1.1.2. Leaf area and leaf number

An experiment was conducted by Abdolahpour *et al*. (2021) following a randomized complete block design at Shahid Bahonar University of Kerman in 2019 to find out the response of quinoa towards N: P: K fertilizer combinations (30:25:20, 60:50:40, 90:75:60, 120:100:80, 150:125:100, 180:150:120 kg ha^{-1}). According to them, the highest LAI value of quinoa was recorded in 120: 100: 80 kg ha^{-1} N: P: K combination.

At 35 DAS/P, the highest number of leaves $plant^{-1}$ (77.53) was found in 150 kg N ha^{-1} and the lowest number of leaves $plant^{-1}$ in control plants by Biswas *et al.* (2021). According to Wang *et al.* (2020) applying 240 kg N ha^{-1} resulted in greater LAI of quinoa than applying 160 and 80 kg N ha^{-1}.

According to Almadini *et al*. (2019) among three levels of N fertilizer ha^{-1} (*i.e.,* 0, 80 and 160 kg N ha^{-1}) 160 Kg N ha^{-1} resulted in greater leaf area (22.12 cm^2) and leaves $plant^{-1}$ (43).

Afrin (2018) stated that for different fertilizer levels, at 30 DAS leaf number was highest (22.59) in F_7 (120-50-50 kg NPK ha^{-1}), and in 45 and 60 DAS the highest leaf number was (48.53 and 30.44) in F_6 (120-50 kg NK ha^{-1}).

2.1.1.3. Number of branches plant^{-1}

Biswas *et al.* (2021) stated that application of 100 kg N ha^{-1} gave the highest number of branches plant^{-1} (17.07) and the lowest number of branches plant^{-1} (11.53) was found in 250 kg N ha^{-1} of quinoa plants. Combination of 120: 100: 80 kg ha^{-1} N: P: K resulted in the highest mean of number of branches of quinoa was stated by Abdolahpour *et al*. (2021).

Naik *et al.* (2020) conducted an experiment with quinoa and followed factorial randomised block design in Bengaluru during Rabi 2018. He reported that application of 150:75:75 kg NPK ha^{-1} made the highest total number of branches plant^{-1} (17.70). Afrin (2018) informed that at harvest, the maximum number of branches plant^{-1} (20.03) was found from F_7 (120-50-50 kg NPK ha^{-1}) and the minimum number of branches plant^{-1} (14.03) was found from F_4 (50 kg K ha^{-1}).

Fawy *et al*. (2017) stated that more quinoa branches (7.30%) were found in soil applied with organic manure. The combination of 48 mg organic manure ha^{-1}+ 240 kg N ha^{-1} with spraying with humic acid solution of 600 mg L^{-1}+ ascorbic acid solution of 1000 mg L^{-1} gave the highest positive response of number of branches plant^{-1} of 26.4. According to Weisany *et al*. (2013) 43% higher numbers of branches in quinoa plants were produced by applying nitrogen in soil than control treatment.

2.1.1.4 Biomass production

Almadini *et al*. (2019) reported that among three levels of N fertilizer (*i.e.,* 0, 80 and 160 kg N ha^{-1}) used in a randomized complete block design with four replications to evaluate the response of the quinoa yield to nitrogen (N) fertilization, fertilizing quinoa with 160 kg N ha^{-1} resulted in maximum fresh weight (66.56 g), dry weight (18.11) g $plant^{-1}$. These results were in consistent with the findings presented in other studies by Jacobsen *et al*. (1994), Sa-Nguansak (2004) and Erley *et al.* (2005).

Afrin (2018) stated that maximum straw weight $plant^{-1}$ at harvest (4.13 g) was produced in F_7 (120-50-50 kg NPK ha^{-1}) and minimum weight (1.63 g) was produced in F_1 (no fertilizer). The maximum straw yield (725.04 kg ha^{-1}) was recorded in F_7 (120-50-50 kg NPK ha^{-1}) and the minimum straw yield (222.29 kg ha^{-1}) was recorded in F_3 (50 kg P ha^{-1}). The higher biological yield (1721.50 kg ha^{-1}) was found in F_7 (120-50-50 kg NPK ha^{-1}) and the minimum biological yield (182.40 kg ha^{-1}) was observed in F_3 (50 kg P ha^{-1}).

Kakabouki *et al*. (2018) found that biomass nitrogen content was significantly affected by different fertilization treatments. Thanapornpoonpong (2004) reported that in a greenhouse study, quinoa has shown a positive reaction to nitrogen and specifically, biomass production was positively correlated with nitrogen fertilization.

2.1.1.5. SPAD value

The SPAD value of the quinoa significantly varied depending on the nitrogen levels. According to Biswas *et al*. (2021) the 200 kg N ha^{-1} plant had the highest value (64.61), while the control plants had the lowest value (38.13 cm). Abdolahpour *et al*. (2021) reported that 120: 100: 80 kg ha^{-1} N: P: K combination resulted in the maximum mean value of Chl a, Chl b, Chl a+b of quinoa.

Almadini *et al.* (2019) reported that the ratio of chlorophyll of quinoa increased with increased nitrogen fertilization rate applied in field. They found that the

SPAD value was 32.1, 48.10 and 70.28 when 0, 80 and 160 kg N ha^{-1} was applied in the field respectively.

2.1.2. Yield parameters

2.1.2.1 Length of inflorescence plant^{-1}

According to Biswas *et al.* (2021) the length of the quinoa inflorescence significantly varied depending on the amount of nitrogen fertilizer applied. In control plots, the lowest inflorescence length (26.53 cm) was found and maximum length (36.02 cm) was produced by 200 kg N ha^{-1}.

According to Abdolahpour *et al*. (2021) the highest mean of quinoa panicle lengths were observed in 120: 100: 80 kg ha^{-1} N: P: K combination which was statistically similar with 90: 75: 60 kg ha^{-1} N: P: K combination. Naik *et al.* (2020) conducted an experiment with quinoa, following factorial randomised block design in Bengaluru during Rabi 2018 and reported that 150:75:75 kg NPK ha^{-1} recorded the highest total number of panicles plant^{-1} (17.63), length of glomerule (16.55 cm).

At harvest, the highest inflorescence length plant^{-1} (18.56) was produced in F_6 (120-50 kg NK ha^{-1}) and lowest (10.03) in F_3 (50 kg P ha^{-1}) as stated by Afrin (2018).

2.1.2.2 1000-seed weight

Ali *et al*. (2023) reported that 1000-seed weight of quinoa increased with potassium application from 90 to 190 kg K_2O ha^{-1}. Biswas *et al.* (2021) stated that the weight of 1000 seeds varied significantly due to different nitrogen fertilizer doses. The highest weight (3.10 g) was found in 250 kg N ha^{-1}, that was similar to 3.09 g, 3.08 g, 3.06 g and 3.06 g resulted in F_6, F_7, F_5 and F_4 respectively. The lowest 1000-seed weight (2.67 g) was observed in control treatment which showed 13.87% lower weight than F_8 treatment.

Owji *et al*. (2021) found that highest 1000-seed weight was obtained by using 180 kg N ha^{-1}. 120: 100: 80 kg ha^{-1} N: P: K combination resulted in the maximum mean value of 1000-seed weight of quinoa was stated by Abdolahpour *et al*. (2021). The highest 1000-seed weight (2.84 g) was found from 120-50-50 kg NPK ha^{-1} and the lowest 1000-seed weight (2.24 g) was recorded by applying 50 kg P ha^{-1} according to Afrin (2018).

Significant changes in the weight of 1000 seeds were observed after applying different amounts of nitrogen fertilizer by Kansomjet *et al*. (2017). The highest weight (3.10 g) was observed in 250 kg N ha^{-1} that statistically similar to 3.09 g, 3.08 g, 3.06 g and 3.06 g 1000-seed weight obtained from applying 200 kg N ha^{-1}, 220 kg N ha^{-1}, 180 kg N ha^{-1} and 150 kg N ha^{-1} respectively . The lowest 1000-seed weight (2.67 g) was found in control treatment that showed 13.87% lower weight than F_8 (250 kg N ha^{-1}) treatment. By applying 187.50 kg N ha^{-1}, greater 1000-seed weight (3.06 g) of quinoa was noted by them.

Fawy *et al*. (2017) stated that yield parameters of quinoa increased with increasing application of N fertilizer. The yields and components of quinoa plants increased with soil application of organic manure in comparison with those without application. The treatments with organic manure gave greater value (8.90%) of weight of 1000-seed (g) than without treatments.

Basra *et al.* (2014) stated that thousand grain weight of quinoa (2.10 g) was not affected by nitrogen fertilization from 0 to 120 kg ha^{-1}. N fertilizer as soil application increased yield parameters of quinoa plant was stated by Weisany *et al*. (2013). It increased 44% 1000- seed weight than control treatment.

Nitrogen fertilizers application with nitrobin increased the average thousand seed weight from 0 (3.30 g) to 119 (4.90 g) kg N ha^{-1} was reported by Gomaa (2013). Thanapornpoonpong (2004) found that thousand seed weight of 1.77 g was the highest after application of 0.80 g N pot^{-1}, with increasing nitrogen level to 1.20 g N per pot it was decreased to 1.58 g.

2.1.2.3 Seed yield $plant^{-1}$

At the Experimental Station of the Environmental Studies and Research Institute, University of Sadat City, Sadat City, Menofia Governorate, Egypt, a research was conducted by Ali *et al*. (2023) for 2016/2017 and 2017/2018 growing seasons in order to find out the influence of applying potassium fertilizer at 90, 140 and 190 kg K_2O ha^{-1} combined with spraying applications of seaweed extract. Seed yield $plant^{-1}$ of quinoa responded positively towards potassium application in both seasons. With increasing potassium level from 90 to 190 kg K_2O ha^{-1}, seed yield $plant^{-1}$ significantly increased. At 190 kg K_2O ha^{-1}, maximum value and at 90 kg K_2O ha^{-1} minimum value of seed yield $plant^{-1}$ was recorded.

A field experiment was conducted by Almadini *et al*. (2019) to evaluate the response of the quinoa yield to nitrogen (N) fertilization. Three levels of N fertilizer (*i.e.,* 0, 80 and 160 kg N ha^{-1}) were used and laid out in a randomized complete block design with four replicates to evaluate the response of the quinoa yield to nitrogen (N) fertilization. They reported that fertilizing quinoa with 160 kg N ha^{-1} resulted in maximum grain yield (18.08 g $plant^{-1}$), number of grains $plant^{-1}$ (5207.30). Adding organic manure into the soil resulted in 9.4% increase in weight of seeds $plant^{-1}$ (g), was stated by Fawy *et al*. (2017).

Geren (2015) did a two year field experiment on quinoa in Turkey and found that the nitrogen × year interaction was highly significant on the seed yield $plant^{-1}$. The highest seed yield (11.20 g $plant^{-1}$) was obtained from 150 kg N ha^{-1} level in the second year, whereas the lowest yield (2.40 g $plant^{-1}$) was recorded in control plots in the first year. Year effect was also significant and average seed yield $plant^{-1}$ of second year (7.60 g) was higher than the first year (6.80 g) most probably due to the average monthly temperatures in the study site which was consistent with the 20-year average, providing better humidity and precipitation for the maturation of crops in 2014 compared to 2013.

Application of nitrogenous fertilizer in soil caused 50% increment in seed yield $plant^{-1}$ than in control treatment was stated by Weisany *et al*. (2013). Shams (2012) reported that fertilizing quinoa with 360 kg N ha^{-1} resulted in maximum seed yield ($plant^{-1}$) of 10.070 g.

2.1.2.4 Seed yield ha^{-1}

An experiment was conducted by Ali *et al*. (2023) at the Experimental Station of the Environmental Studies and Research Institute, University of Sadat City, Sadat City, Menofia Governorate, Egypt, for 2016/2017 and 2017/2018 growing seasons in order to find out the influence of applying potassium fertilizer at 90, 140 and 190 kg K_2O ha^{-1} combined with spraying applications of seaweed extract. They stated that seed yield ha^{-1} of quinoa responded positively towards potassium application in both seasons. With increasing potassium level from 90 to 190 kg K_2O ha^{-1}, seed yield ha^{-1} significantly increased. At 190 kg K_2O ha^{-1}, maximum value and at 90 kg K_2O ha^{-1} minimum value of seed yield ha^{-1} was recorded.

Minh *et al*. (2022) reported that highest seed yield (22.90 t ha^{-1}) of quinoa was recorded in 105 kg K_2O ha^{-1}.

In the summers of 2017 and 2018 in the Kharameh region, Owji *et al*. (2021) conducted a two-year factorial experiment based on randomized full block design, which was carried out to examine the impact of seed rate and nitrogen fertilizer management on quinoa trait. The experimental factors were nitrogen at six levels of 120, 150, and 180 kg ha^{-1} nitrogen divided into 2 (two leaf, budding), and 3 times (two leaf, budding, and pollination initiation), respectively. Seed rate was tested at five levels of 6, 7, 8, 9 and 10 kg ha^{-1}. The seed yield increased by 17.20% and 17.10%, respectively, in the 2 and 3-time split treatments, when nitrogen was added from 120 to 180 kg ha^{-1}.

According to Biswas *et al.* (2021) application of different nitrogen fertilizer doses caused considerable changes in quinoa seed output. The maximum yield (1170.64 kg ha^{-1}) was found in F_4 (150 kg N ha^{-1}) and was followed by the value 1033.37 kg ha^{-1} and 1097.77 kg ha^{-1} found in F_6 and F_5 respectively. In the control treatment, the lowest seed yield (538.19 kg ha^{-1}) was discovered. Whereas no nitrogen (control) as well as greater nitrogen doses negatively influenced yield and other features, the nitrogen dose significantly influenced all the examined parameters. A 150 kg N ha^{-1} (F_4) application produced a yield that was 117.51% higher than the control (no nitrogenous fertilizer application).

A field experiment was conducted by Salim *et al*. (2019) in the fields of College of Agriculture, University of Baghdad in Abu Ghraib (25 km west of Baghdad) during the spring season 2017, to find out the effect of irrigation scheduling and four levels of potassium fertilization (0, 60, 120 and 180 kg K_2O ha^{-1}). They reported that seed yield of quinoa increased when 120 kg ha^{-1} K_2O was used and application of 180 kg K_2O ha^{-1} decreased quinoa seed yield.

The maximum seed yield (553.38 kg ha^{-1}) was recorded by F_6 (120-50 kg NK ha^{-1}) and the minimum seed yield (144.40 kg ha^{-1}) was recorded by F_3 (50 kg P ha^{-1}). These results were found by Afrin (2018).

By applying 93.75 kg N ha^{-1} to quinoa, Kansomjet *et al*. (2017) found a higher seed yield (2641.70 kg ha^{-1}) and that its escalation decreased seed yield (Lavini *et al*., 2014).

Quinoa yielded between 1790 and 3495 kg grain ha^{-1} and responded strongly to N fertilization was reported by Fawy *et al.* (2017). According to Jacobsen and Christiansen (2016), applying nitrogen up to 180 kg N ha^{-1} boosted quinoa output remarkably.

Geren (2015) found that the highest grain yield (3308 kg ha^{-1}) was found in the second year at 150 kg N ha^{-1} level, whereas the lowest yield (867 kg ha^{-1}) was in the first year at control plot. He reported that the soil application of N at 150 kg ha^{-1} to quinoa plant achieved maximum seeds yield (2.95 t ha^{-1}).

In a pot experiment with two quinoa lines (Quinoa-52 and Quinoa-37) and two commercial varieties (Titicaca and Puno), Lavini *et al*. (2014) studied the effect of five rates of nitrogen application (0, 50, 100,150 and 200 mg kg^{-1} of soil). The results showed that both the lines responded similarly to the application of nitrogen and yield has improved significantly with increased nitrogen rate.

Combining treatments of N fertilizer with organic amendments significantly increased yields, nutrient in straw or seeds or both of them in quinoa. The outcomes were from Lavini *et al*. (2014) and Bilalis *et al*. (2012). Kakabouki *et al*. (2014) reported that nitrogen fertilization increased also the grain yield of quinoa under different tillage system.

Hirich *et al*. (2014) informed that the yield was highest in the 50% of full irrigation treatment with 240 kg ha^{-1} of nitrogen. CWP increased with higher supply of nitrogen and the degree of water stress, the value being highest in the most stressed treatment (25% of full irrigation) and 240 kg $ha^{-1}$of nitrogen and lowest with the full irrigation without nitrogen supply.

Basra *et al.* (2014) stated that the soil application of N at 75 kg N ha^{-1} attained maximum economic harvest of quinoa. Gomaa (2013) reported that the use of inorganic and biofertilizers (nitrobin or phosphorin) could enhance the quinoa plant's growth characteristics, seed yield, and seed quality.

In a field trial conducted in Wadi El - Natroon region, Beheira Governorate, Egypt during 2008/2009 and 2009/2010 winter seasons, Shams (2012) studied different rates of nitrogen fertilization (0, 90, 180, 270 and 360 kg N ha^{-1}) for improvement of growth and yield in sandy soils. The author found clearly that seed yield increased gradually with increasing nitrogen levels up to the highest level. He reported that fertilizing quinoa with 360 kg N ha^{-1} resulted in maximum grain yield (ha^{-1}) of 1203 and 1088 kg. He informed that in the first and second seasons, respectively, the improvements in grain production per hectare with nitrogen fertilizer application increasing from 90 to 360 kg N ha^{-1} over the control treatment were 574.74, 800.00, 989.47, and 1166.32% and 462.92, 737.08, 882.02, and 1122.47%. The increases in grain and biological yields of quinoa with increasing nitrogen rates are mainly due to role of nitrogen in stimulating metabolic activity which contributed to the increase in metabolites amount most of which is used building yield and its components. These results were in agreement with several investigators such Posipisil *et al*. (2006), Schulte *et al*. (2005), Meyer (1998), Risi and Galwey (1984), Jacobsen *et al*. (1994), El-Behri *et al*. (1993) and Johnson and Ward (1993). The general reduction in grain yield in both seasons may be due to irrigation water salinity or delaying planting date till the end of November. This result was supported by Shams (2012).

Razzaghi *et al*. (2011) found that the soil N fertilizer is applied at 120 kg N ha^{-1}, nitrogen uptake by quinoa is 134 kg N ha^{-1} in sandy clay loam and 77 kg N ha^{-1} in sandy soil, leading to differing quinoa seeds yield of 3300 kg ha^{-1} and 2300 kg ha^{-1}, respectively.

Schulte *et al*. (2005) evaluate the response of quinoa to nitrogen fertilizer rates 0, 80 and 120 Kg N ha^{-1} and its NUE; they found clearly that quinoa grain yield responded strongly to nitrogen fertilization up to the heaviest dose. Johnson and Ward (1993), Risi and Galwey (1984) and Pospisil *et al*. (2006) supported these results.

According to Erley *et al.* (2005), the seed yield of quinoa (*cv.* Faro and Cochabamba) almost doubled from 1790 kg ha^{-1} under the unfertilized treatment to 3495 kg ha^{-1} under 120 kg N ha^{-1} .

Jacobsen *et al.* (1994) found that quinoa grain yield increased with increasing nitrogen fertilization rate from 40 to 160 Kg N ha^{-1}. They reported that yield response of quinoa at 40 kg N ha^{-1} was 24.10% lower than at 160 kg N ha^{-1}.

2.1.2.5 Harvest index

At five locations following randomized complete block design, experiments were conducted by Thiam *et al.* (2021) during the 2017–2018 cropping seasons and according to them quinoa's (Titicaca) highest harvest index value was recorded of 69.00%.

According to the research conducted by Afrin (2018) at the Agronomy research field, Sher-e-Bangla Agricultural University, Dhaka from November, 2017 to January, 2018 the higher harvest index (51.0 %) was recorded by F_6 (120-50 kg NK ha^{-1}) and the minimum harvest index (36.85 %) was recorded by F_1 (no fertilizer).

Geren (2015) reported that the harvest index of quinoa increased by increasing nitrogen treatments till 150 kg N ha^{-1} level but later on decreased. He observed that harvest index presented tremendous variability and ranged from 12.30% to 48.50%.

Szilagyiand Jornsgard (2014) revealed that, among four quinoa varieties (Jason Red, Jacobsen 2, Mixed Jacobsen and Jorgen), harvest index of the cultivar Jacobsen 2 (57.03%) recorded significantly higher harvest index than mixed Jacobsen (48.20%), Jason Red (50.30%), Jorgen (44.50%) under temperate climatic conditions of Romania.

Basra *et al*. (2014) informed that harvest index increased by increasing nitrogen treatments from 0 to 100 kg N ha^{-1} level but later decreased at 120 kg N ha^{-1} level. The increases in harvest index of quinoa with increasing nitrogen levels are mainly due to the role of N in stimulating metabolic activity which contributed to the increase in metabolites amount most of which is used building yield and its components (Shams, 2012). Erley *et al*. (2005) stated that harvest index of quinoa (31%) was not affected by nitrogen fertilization from 0 to 120 kg ha^{-1}.

Thanapornpoonpong (2004) reported that in a greenhouse study, quinoa has shown a positive reaction to nitrogen and specifically, harvest index was positively correlated with nitrogen fertilization. According to Rojas (2003), the harvest index for quinoa ranged from 6.00% to 87.00%.

2.1.3 Quality parameters

2.1.3.1 Protein content (%) and oil content (%) in grain and plant

Ali *et al*. (2023) stated that the highest significant crude protein and crude fat values of quinoa were recorded in 190 kg K_2O ha^{-1}. In contrast the lowest values were observed in 90 kg K_2O ha^{-1}. Higher protein content (21.30%) was found in quinoa by applying 240 kg N ha^{-1} by Wang *et al.* (2020).

A field experiment was conducted by Almadini *et al*. (2019) to evaluate the response of the quinoa yield to nitrogen (N) fertilization. Three levels of N fertilizer (*i.e.,* 0, 80 and 160 kg N ha^{-1}) were used and laid out in a randomized complete block design with four replicates to evaluate the response of the quinoa yield to nitrogen (N) fertilization. He reported that fertilizing quinoa with 160 kg N ha^{-1} resulted in maximum fat content 6.64%, protein contents in the dry grain flour of quinoa plant 17.13%. These results are in consistent with the findings presented in other studies by Geren (2015), Abou-Amer and Kamel (2011), Bhargava *et al.* (2007), Erley *et al.*(2005), Sa-Nguansak (2004) and Jacobsen *et al*. (1994).

According to Geren (2015) the soil application of N at 150 kg ha^{-1} to quinoa plants resulted in increased quality of crude protein content (16%) with the application of nitrogen content under Mediterranean ecological conditions of Bornova. Azarpour *et al*. (2014) stated that foliar application of ascorbic acid combined with application of N increased yield and nutrient contents in quinoa.

Kakabouki *et al*. (2014) stated that there were significant differences in quinoa crude protein (CP) content among fertilizer treatments (2000 kg ha^{-1} cow manure, 100 and 200 kg N ha^{-1}) and all fertilization treatments resulted in values higher than those of the control and, the highest CP content (27%) in quinoa was observed for 200 kg N ha^{-1} application. He also reported that increasing nitrogen level increased CP content of quinoa from 7% to 27% under different tillage system.

The major fact that determines the grain protein content is nitrogen availability, and quinoa is highly responsive to nitrogen fertilizer (Basra *et al*., 2014) and higher CP content, in a crop with high yield, can be obtained just by application of higher nitrogen quantities. Gomaa (2013) reported that the application of nitrogen and phosphorus increased crude protein and nutrients content in quinoa seeds.

Nutrients have several functions and affect quinoa yield parameters, the photosynthetic processes in leaves and plant growth are improved by N fertilization, they contribute greatly in protein synthesis, cell structure and carbohydrate production (Weisany *et al*., 2013). Bilalis *et al*. (2012) reported that 2000 kg cow manure ha^{-1} by 100 kg N ha^{-1} fertilizer gave the highest protein yield of 2481 kg protein ha^{-1}.

The progressive increase in protein contents of quinoa seed with the increasing nitrogen rates were also reported by many research workers (Shams, 2012; Erley *et al*., 2005 and Jacobsen *et al*., 1994). The higher protein content at higher nitrogen levels was mainly due to the structural role of nitrogen in building up amino acids (Bhargava *et al*., 2006 and Finck, 1982).

Erley *et al*. (2005) informed that average CP content of quinoa cultivars (Faro and Cochabamba) increased gradually (12.30% to 14.60%, respectively) with the increasing nitrogen levels from 0 kg N to 120 kg N ha^{-1}. Thanapornpoonpong (2004) reported that in a greenhouse study, quinoa has shown a positive reaction to nitrogen and specifically, protein content was positively correlated with nitrogen fertilization.

2.2 Performance of quinoa at different sowing methods

To test the hypothesis, Ali *et al*. (2020) carried out a two-year field investigation (2013–14 and 2014–15) at the University of Agriculture, Faisalabad, Pakistan. The experiment was carried out using a split plot design. Four planting techniques - bed sowing (BS), ridge sowing (RS), flat line sowing (FLS) and sowing in standing water (SSW) were used in the main plots, along with two quinoa accessions (A7 and A9) in subplots. According to the study, the BS method is a considerably superior planting strategy.

The findings demonstrated that planting methods had a substantial impact on quinoa accessions' growth characteristics. The maximum leaf area index (LAI) was achieved using the BS approach. The SSW, however, displayed the lowest LAI. Similar to this, after 70 DAE, BS showed the least dropping tendency of LAI, while SSW showed the largest decline.

Both planting method and quinoa accessions had a considerable impact on total dry matter (TDM) production in both years. Bed sowing was superior to the rest of the planting techniques followed by RS, FLS and SSW respectively. Plant height was greatly increased by planting methods. In comparison to the RS and FLS, the SSW produced plants that were 15% and 32% taller. With the exception of SSW, the BS plants had diameters of 1.6 cm and 1.7 cm that were comparable to those of the other planting procedures and generated the thickest stems. In comparison to SSW throughout both years, BS produced panicles that were 57% and 78% longer. BS had the highest chlorophyll a content, followed by RS, FLS, and SSW, in that order.

In 2013–14, the FLS method generated the highest Panicle number per plant (PNPP) of 17, whereas BS produced the highest PNPP in 2014–15. In contrast, BS outperformed the other planting methods and generated the highest main panicle weight (MPW), thousand-grain weight (TGW), grain yield (GY) and harvest index (HI) in comparison to the SSW in both years by, 35% and 67%, 21% and 26%, 75% and 64%, and 63% and 56% respectively. The current study showed that the growth, biomass output, and yield of quinoa accessions were significantly influenced by planting methods.

The procedure for planting in both quinoa accessions, BS preferred the growth characteristics, such as stem diameter, branch number per plant, leaf number per plant, and major panicle length. By implementing the BS approach in both crop seasons, quinoa plant biomass accumulation was improved.

Dao *et al*. (2020) suggested sowing seeds and cultivating quinoa in ridge method to get higher yield. Bakht *et al*. (2011) report maximum yields when planting in ridges, whereas minimum yields under broadcasting.

CHAPTER III

MATERIAL AND METHODS

The goal of the experiment was to determine how quinoa will respond to various sowing techniques and fertilizer managements. The materials and methods for this experiment include a brief explanation of the experimental site's location, soil conditions and climate, as well as the materials used, the experiment's design, data collection methods and data analysis procedures. The following list of headings serves as a detailed summary of the materials and procedures used for this experiment.

3.1 Description of the experimental site

3.1.1 Experimental period

The experiment was conducted during the period from November to February, 2021-2022.

3.1.2 Experimental location

The experiment was conducted at the Research Farm of Sher-e-Bangla Agricultural University, Dhaka and it was located in 23° 77′N latitude and 90º 26′ E longitudes. As per the Bangladesh Meteorological Department, Agargaon, Dhaka-1207 the altitude of the location was 8 m above the sea level. The location has been shown in Appendix I.

3.1.3 Characteristics of soil

The Shallow Red Brown Terrace soil was the predominant soil type in the experimental field and it is a member of the Tejgaon series in the Madhupur Tract of the Agro ecological Zone (AEZ-28). The test location was level, had a drainage and irrigation system and was above flood level. The chosen plot was a medium-high piece of land. Before the experiment began, soil was taken at a depth of 0 to 15 cm from several locations throughout the experimental field to create a composite sample. At the Soil Resources Development Institute (SRDI), Farmgate, Dhaka, the composite soil was air-dried, grounded and put through a 2 mm filter before being examined for several crucial physical and chemical characteristics. The pH and organic matter of the soil were 5.6 and 0.78%, respectively with a silty clay texture. The findings indicated that the soil was 26% sand, 45% silt and 29% clay.

3.1.4 Climatic condition

The experimental site's geographic position fell under a subtropical climate with three different seasons: Rabi from November to February, hot season or pre-monsoon from March to April, and monsoon from May to October. In Appendix III and IV, the monthly averages for temperature, relative humidity and rainfall during the crop-growing season are shown.

3.2 Experimental details

3.2.1 Treatments of the experiment

The experiment comprised of two factors

Factor A: Sowing methods (3)

i. Broadcast method - M_1
ii. Sowing in line - M_2
iii. Sowing in bed - M_3

Factor B: Fertilizer management (5)

i. No fertilizer (control) - F_1
ii. 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1} - F_2
iii. 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1} +10 t cowdung ha^{-1}- F_3

iv. 150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1} - F_4

v. 150-100-100 kg N, P_2O_5, K_2O ha^{-1} - F_5

There were total 15 (3×5) treatment combinations as,

M_1F_1, M_1F_2, M_1F_3, M_1F_4, M_1F_5, M_2F_1, M_2F_2, M_2F_3, M_2F_4, M_2F_5, M_3F_1, M_3F_2, M_3F_3, M_3F_4, M_3F_5.

3.2.2 Planting material

The Sher-e-Bangla Agricultural University's Agronomy department provided the seeds of SAU Quinoa-1. The seed's germination was tested before seeding.

3.2.3 Germination test

Before sowing the seeds in the field, a germination test was conducted. Petri dishes were covered with filter paper, which had been moistened with water. Petri dishes were filled at random with seeds. After 24 hours, the seeds began to emerge and by 48 hours, it was fully developed. The variety's germination rate was found as 85%.

3.2.4 Land preparation and field layout

A tractor-drawn disc plough was used to plow the experimental field on October 31, 2021. The soil in the field was repeatedly plowed to achieve the desired tilt using cross-ploughing, harrowing and laddering. The tilth soil was cleared of weeds and stubble. The last land preparation took place on November 12, 2021. According to the experimental design of this trial, experimental land was divided into unit plots. On November 13, 2021, the field layout was made in accordance with the experimental needs.

3.2.5 Experimental design

A split-plot design with three replications was used for the two factors experiment. An area of 15.25 m × 14.50 m was divided into three blocks. Three sowing methods were assigned in the main plot and five different fertilizer doses in sub-plot. The size of the each unit plot was 2.50 m × 1.25 m. The space between two blocks and two plots were 0.50 m and 0.50 m, respectively. The experimental design has been shown in Appendix II.

3.2.6 Fertilizer application

Urea, triple super phosphate (TSP), muriate of potash (MoP), gypsum, zinc sulphate, boric acid and cowdung were used in the experimental soil as a source of nitrogen (N), phosphorous (P_2O_5), potassium (K_2O), sulfur (S), zinc (Zn), boron (B) and organic matter, respectively. Urea, TSP, MoP, gypsum, zinc sulfate, boric acid and cowdung were applied in the soil @ 326 kg ha^{-1}, 218 kg ha^{-1}, 166 kg ha^{-1}, 269 kg ha^{-1}, 27 kg ha^{-1}, 29 kg ha^{-1} and 9.6 t ha^{-1} respectively, according to the treatments of the experiment. For 150 kg N ha^{-1}, 105 g urea $plot^{-1}$; 100 kg P_2O_5 ha^{-1}, 70 g TSP $plot^{-1}$; 100 kg K_2O ha^{-1}, 50 g MoP $plot^{-1}$; 50 kg S ha^{-1}, 84 g gypsum $plot^{-1}$; 10 kg Zn ha^{-1}, 10 g zinc sulfate $plot^{-1}$; 5 kg B ha^{-1}, 1 g boric acid $plot^{-1}$ and 10 t cowdung ha^{-1}, 3 kg cowdung $plot^{-1}$ was applied. TSP, MoP, gypsum, zinc sulfate, boric acid, cowdung and one third of urea were applied during the final land preparation. Rest of the urea as per treatment was applied as top dressing at 30 and 50 DAS.

3.3 Growing of crops

3.3.1 Sowing of seeds in the field

Quinoa seeds were sown in the experimental plot on 17th November 2021 by broadcasting, line sowing and bed sowing method. In case of line sowing and bed sowing methods, the spacing between row to row was 25cm. In each planting method 8 g seed was sown per plot.

3.3.2 Intercultural operations

3.3.2.1 Weeding, thinning and mulching

Various weeds (*Elusine indica, Physalis heterophylla, Vicia sativa, Brassica kaber* etc.) have been found during the whole cultivation period of quinoa but at the early stage of cultivation, the infestation was comparatively more. First weeding, thinning and mulching (breaking down the top soil) were done on 2nd December, 2021, which was 15 days after sowing. Second weeding, thinning and mulching (breaking down the top soil) were done on 15th December, 2021, that was 12 days after first operations.

3.3.2.2 Irrigation and drainage

Before sowing of quinoa seeds heavy rainfall was recorded from 4.12.2021 to 7.12.2021 in Dhaka. That is why after seed sowing, irrigation was only given on 17.12.2021 and 21.12.2021 for proper vegetative growth and flowering. To maintain optimum soil moisture all plots were irrigated as and when necessary. The last irrigation was done 20 days before harvesting. Proper drain was also made around plots for draining out excess water from irrigation and also rainfall from the experimental plot.

3.3.2.3 Plant protection measures

During seed sowing, only Sevin was mixed with the seeds to save them from taking by ants. Otherwise no other pesticide and insecticides were applied during the whole cultivation period, as the crop was not infected by any insect pests and diseases.

3.4 Harvest and post harvesting operations

Harvesting was done when 90% of the grain became green to reddish yellow in color and almost all the remaining leaves in the plants turned into yellow. Harvesting was done in the morning. Quinoa harvest was carried out on 5th February, 2022. The matured crops were collected by hand picking from each plot. The collected crops were sun dried properly by spreading them over floor, threshed and weighted to a control moisture level. For the seeds to be at a safe moisture level, they were separated, cleaned and dried in the sun for 5 days straight. The crop was sun dried for five days by placing them on the open threshing floor. Seeds were separated from the plant by thrashing with hand. Additionally, the straws and husk were dried in the sun and then dried seed and straws were cleaned and weighed. The total of the seed yield and straw yield was used to compute the biological yield.

3.5 Crop sampling and data collection

Five quinoa plants from each plot were randomly selected and marked with red cotton thread. The following data on growth and yield parameters were collected during the experimentation.

A. Crop growth characters

a. Plant height at 20, 40 and 60 DAS and at harvest
b. Number of leaves plant^{-1} at 20, 40 and 60 DAS
c. Number of branches plant^{-1} at 40 and 60 DAS and at harvest
d. Root length at harvest
e. Dry weight plant^{-1} at 25 and 55 DAS and at harvest
f. SPAD value at 55 DAS

B. Yield and other crop characters

a. Number of inflorescence plant^{-1}
b. 1000-seed weight
c. Seed yield plant^{-1}
d. Seed yield
e. Straw yield
f. Biological yield
g. Harvest index

3.6 Procedure of data collection

3.6.1 Crop growth characters

i. Plant height

A scale was used to measure plant height in centimeters (cm) at 20, 40, 60 DAS (days after sowing) and at harvest. Data were collected from five randomly chosen plants from each plot and average plant height was recorded according to treatment. From the ground tip of the shoots, the height was measured in cm.

ii. Number of leaves plant^{-1}

Five randomly selected plants from each plot were analyzed for data at 20, 40, and 60 DAS (days after sowing). The process was completed by counting every leaf on every plant that was sampled and the average findings were then noted.

iii. Number of branches plant^{-1}

Data were collected from five randomly chosen plants from each plot at 40, 60 DAS (days after sowing) and at harvest. The process was finished by counting all of the branches on all of the sampled plants, after which the average results were recorded.

iv. Root length

Five plants from each plot were chosen randomly to collect data from at harvest. After uprooting the plants, the roots were cleaned properly. The operation was finished after measuring all of the root lengths (cm) of the examined plants using a measuring scale and the average results were recorded.

v. Dry weight plant^{-1}

For recording dry weight of plants five plants were selected randomly from the second line of each plot and data was recorded at 25, 55 DAS (days after sowing), and at harvest. After uprooting the plants they were oven dried until reach to a constant weight and then their weight was measured by a digital weighing machine and average data of five sampled plants' dry weight of each plot was recorded.

vi. SPAD value

A portable chlorophyll meter, also known as a SPAD (Soil-Plant Analyses Development) meter, was created by the Minolta Camera Company to measure the amount of chlorophyll in leaves. The essential component of chlorophyll molecules, which absorb sunlight and are employed in photosynthesis, is N. Thus, in a nondestructive manner, the chlorophyll meter offers instant crop N status as SPAD value (Minolta, 1989). The figures calculated by this gadget represent all of the chlorophyll (a, b) in plants (Ramesh *et al*., 2002; Ichie *et al*., 2002 and Feibo *et al*., 1998). Five plants were selected randomly from each plot and SPAD value (leaf chlorophyll concentration) was recorded from fully matured leaves on 55 DAS (days after sowing) using SPAD meter.

3.6.2 Yield and other crop characters

i. Number of inflorescence plant^{-1}

Five randomly chosen plants from each plot were counted for the number of inflorescence at 40 and 60 DAS and at harvest. Five randomly selected plants were used to count the number of inflorescence plant^{-1}. The process was finished by counting all of the inflorescences produced by the sampled plants, after which the average data were recorded.

ii. 1000-seed weight

The 1000 seed were counted manually, which were taken from the seeds sample of each plot separately during harvest, they were cleaned and dried properly and then weighed in an electrical balance and data were recorded in gram.

iii. Seed yield plant^{-1}

After separating seeds from the five sample plants of each plot, the seeds were cleaned and sun dried. Then the weight of total seed from all plants taken and weighed using a digital balance. After that, the data was converted into g plant^{-1} for each plot.

iv. Seed yield

The crops from 1.25 m^2 harvested area (leaving the boarder lines and destructive harvest line) were harvested as per experimental treatments and were threshed. Seeds were cleaned and properly dried under sun. Then seed yield in 1.25 m^{-2} was recorded and converted into t ha^{-1}.

v. Straw yield

After separation of seeds from plant, the straw and chaff (separated from dried seeds) of each plant from 1.25 m^2 harvested area (leaving boarder lines and destructive harvest line) were sun dried and the weight of total straw was taken using a digital machine and converted the yield in t ha^{-1}.

vi. Biological yield

Biological yield was defined as the total of seed yield and straw yield. The biological yield was calculated with the following formula:

Biological yield (t ha^{-1}) = Seed yield (t ha^{-1}) + Straw yield (t ha^{-1})

vii. Harvest Index

Harvest index (%) was determined by dividing the economic (grain) yield by the total biological yield (grain yield + straw yield) from the same area and multiplying by 100.

$$\text{Harvest index (\%)} = \frac{\text{Grain or seed yield (t ha}^{-1}\text{)}}{\text{Biological yield (t ha}^{-1}\text{)}} \times 100$$

3.7 Data analysis technique

With the use of the computer program Cropstat 7.2, the obtained data were assembled and statistically analyzed using the analysis of variance (ANOVA) approach. The mean differences were determined using the Least Significant Difference (LSD) test at the 5% level of significance.

CHAPTER IV

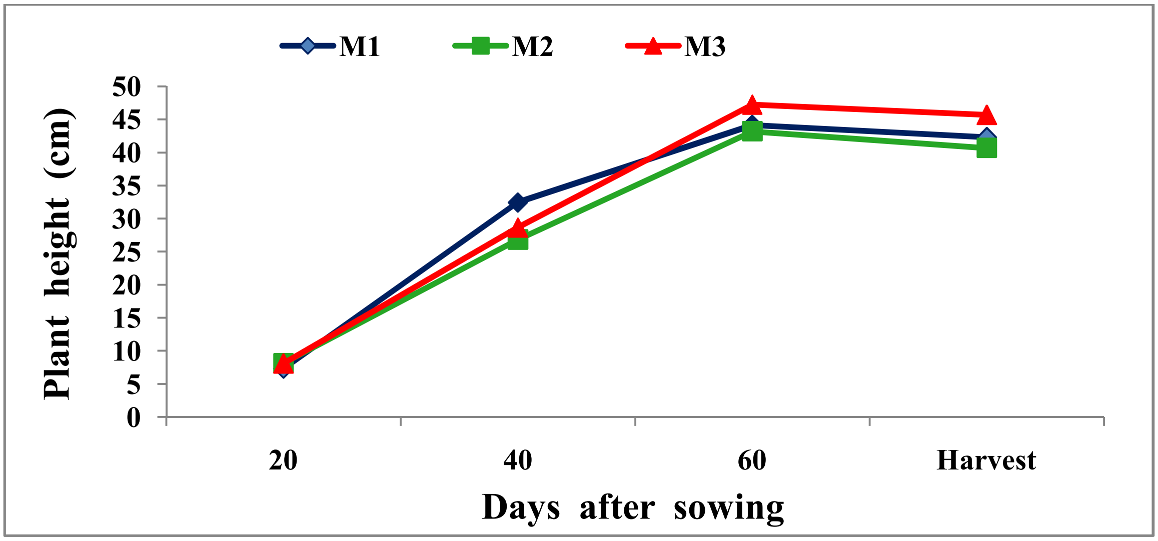
RESULTS AND DISCUSSION

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

4.1 Plant height

4.1.1 Effect of sowing methods

Plant height of quinoa at 20 and 40 DAS showed significant variation for different sowing methods but at 60 DAS and 80 DAS (harvest) showed non-significant variation (Figure 1 and Appendix V). From figure 1, it was clearly visible that, in all of the sowing methods, the height of the plants increased up to 60 DAS (days after sowing) and after that, plant height decreased. The result revealed that at 20 DAS, longest plant height (8.15 cm) was recorded from line sowing method (M_2) which was statistically similar with 8.09 cm, that came from bed sowing method (M_3) and the shortest plant height (7.31 cm) was found from broadcast sowing method (M_1). At 40 DAS, the longest plant height (32.44 cm) was recorded from broadcast sowing method (M_1) and the shortest plant height (26.82 cm) was found from line sowing method (M_2) which was statistically similar with the plant height 28.62 cm from bed sowing method (M_3). At 60 DAS and at harvest (80 DAS), no significant variation was observed in quinoa plant height. But numerically at 60 DAS and at harvest the longest plant heights (47.20 cm and 45.66 cm), came from bed sowing method (M_3) and the lowest plant heights (43.18 cm and 40.68 cm) came from line sowing method (M_2), respectively. But according to Ali *et al*. (2020) plant height in BS (bed sowing) was lower than in SSW (sowing in standing water). Belachew and Abera (2010) and Bakht *et al.* (2011) both confirmed that the BS (bed sowing) approach increased the efficiency of fertilizer usage and was a successful method for preventing lodging and the same phenomenon had happened with the present study.



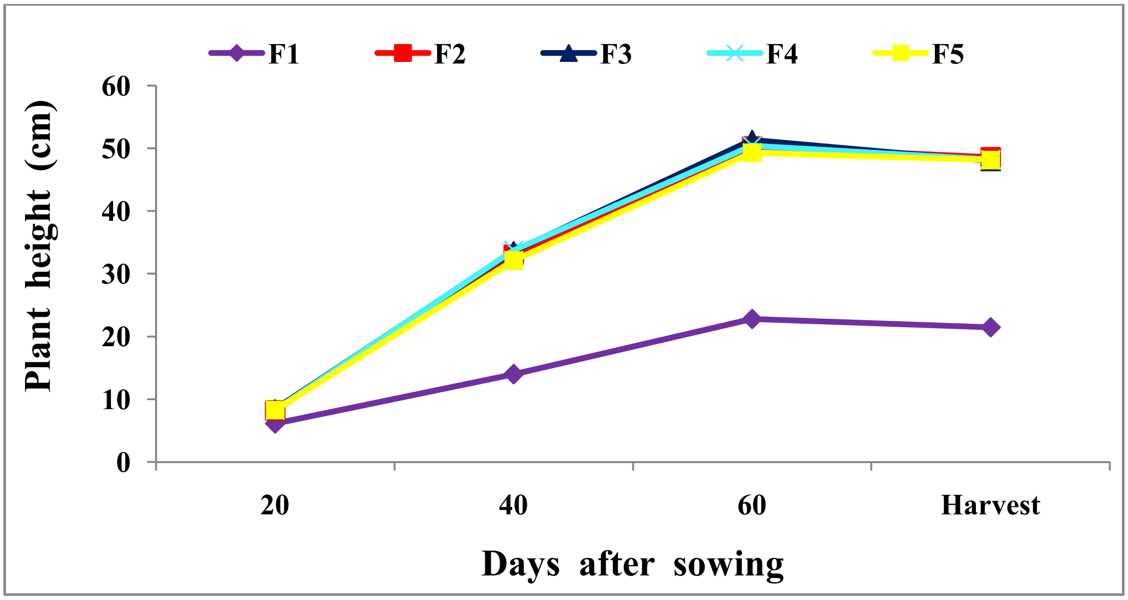
M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

Figure 1. Effect of sowing methods on plant height of quinoa at different growth stages ($LSD_{(0.05)}$ = 0.576, 2.969, NS and NS at 20 DAS, 40 DAS, 60 DAS and at harvest, respectively).

4.1.2 Effect of fertilizer levels

Plant height of quinoa was significantly influenced by fertilizer at all studied dates (Figure 2 and Appendix V). From figure 2, it was found that in all five levels of fertilizer management, the height of the plants increased up to 60 DAS (days after sowing) and after that, plant height started to decrease. At 20 DAS, the longest plant height (8.39 cm) was found in F_3 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}) that was statistically similar with 8.28 cm found in F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}), 8.24 cm recorded in F_5

(150-100-100 kg N, P_2O_5, K_2O ha^{-1}) and 8.23 cm found in F_2 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}); whereas the shortest plant height (6.12 cm) was in F_1 (control). Almost similar trend was also observed at 40 DAS, 60 DAS and at harvest. At 40 DAS, the longest plant height (33.77 cm) was observed in F_4, which was statistically similar with the plant height 33.58 cm recorded in F_3, 33.06 cm found in F_2 and 32.08 cm observed in F_5; whereas the shortest plant height (13.98 cm) was found F_1 (control). At 60 DAS, the shortest plant height (22.77 cm) was recorded in F_1 (control) and the longest plant height (51.34 cm) was observed in F_3, which was statistically at par with the value 50.43 cm resulted in F_4, 50.32 cm found in F_2 and 49.28 cm founded in F_5. And at harvest the longest plant height (48.59 cm) was obtained from F_2, which was statistically similar with 48.23 cm observed in F_4, 48.12 cm recorded in F_5 and 47.99 cm resulted in F_3; whereas the shortest plant height (21.46 cm) was obtained from F_1 (control). Application of 150- 100- 100 kg N, P_2O_5 and K_2O ha^{-1} with S, Zn and B in soil supplied essential plant nutrient to the plants for proper growth and significantly increased plant height of quinoa at harvest and F_1 fertilizer (control) treatment gave the shortest plant height of quinoa plants. Naik *et al.* (2020) also reported that 150:75:75 kg NPK ha^{-1} recorded the highest growth parameters like plant height and the finding was quite similar with the result of the present study. On the other side, though at harvest F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1} + 10 t cowdung ha^{-1}) did not show the highest plant height (48.23 cm) but it was statistically similar with the value 48.59 cm found in F_2 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}). Not only that, from 20 DAS to harvest F_4 gave higher plant heights values which were statistically similar with treatments, those gave highest plant heights. Here soil application of 150- 100- 100 kg N, P_2O_5 and K_2O ha^{-1} with cowdung, ensured required plant nutrient supply (by using less synthetic fertilizer) and helped in soil heath improvement, at the same time. Fawy *et al*. (2017) stated that soil application of organic manure in comparison with those without application gave 9.0% greater plant height (cm) of quinoa.



F_1= No fertilizer
F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}
F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1} + 10 t cowdung ha^{-1}
F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

Figure 2. Effect of fertilizer levels on plant height of quinoa at different growth stages ($LSD_{(0.05)}$ = 0.506, 2.371, 3.521 and 3.872 at 20 DAS, 40 DAS, 60 DAS and at harvest, respectively).

4.1.3 Interaction effect of sowing methods and fertilizer levels

Plant height was significantly influenced by the interaction effect of sowing methods and fertilizer levels (Table 1 and Appendix V). At 20 DAS, the longest plant height (8.75 cm) was found in bed sowing method (M_3) and F_2 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}) interaction (M_3F_2), which was statistically similar with M_2F_4 (8.74 cm), M_2F_5 (8.55 cm), M_2F_3 (8.53 cm), M_3F_3 (8.51 cm), M_3F_4 (8.51 cm), M_2F_2 (8.22 cm), M_3F_5 (8.21 cm), M_1F_3 (8.12 cm) and M_1F_5 (7.95 cm); whereas the lowest plant height (5.17 cm) was observed in between broadcast sowing method (M_1) and no fertilizer (F_1) interaction (M_1F_1). At 40 DAS, the shortest plant height (11.89 cm) was observed in between line sowing method (M_2) and no fertilizer (F_1) interaction (M_2F_1), which was statistically similar with M_3F_1 (12.89 cm) and the longest plant height (37.10 cm) was observed in broadcast sowing method (M_1) and 150-100-100 kg N, P_2O_5, K_2O ha^{-1} (F_5) interaction (M_1F_5), which was statistically similar with M_1F_4 (36.54 cm), M_1F_2 (36.51 cm), M_3F_3 (35.43 cm) and M_1F_3 (34.92 cm). At 60 DAS, the longest plant height (54 cm) was observed in between line sowing method (M_2) and 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1} + 10 t cowdung ha^{-1} (F_3) interaction (M_2F_3), which was statistically similar with M_3F_3 (52.97 cm), M_3F_5 (52.83 cm), M_3F_4 (52.47 cm), M_3F_2 (52.03 cm), M_1F_2 (50.60 cm), M_2F_4 (50.60 cm), M_2F_2 (48.33 cm) and M_1F_4 (48.23 cm); whereas the shortest height (18.57 cm) was found in line sowing method (M_2) and no fertilizer (F_1) interaction (M_2F_1), which was statistically similar with M_1F_1 (25.05 cm). At harvest the longest plant height (51.18 cm) was found in bed sowing method (M_3) and 150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1} (F_4) interaction (M_3F_4), which was statistically at par with M_3F_4 (51.18 cm), M_3F_5 (51.17 cm), M_3F_3 (51.07 cm), M_1F_5 (50.90cm), M_3F_2 (50.13 cm), M_2F_3 (49.50 cm), M_1F_2(49.33), M_2F_4 (47.97 cm), M_2F_2 (46.30 cm) and M_1F_4 (45.53 cm). during harvesting time the shortest plant height (17.34 cm) was observed in between line sowing method (M_2) and no fertilizer (F_1) interaction (M_2F_1), which was statistically similar with M_1F_1 (22.27 cm).

Table 1. Interaction effect of sowing methods and fertilizer levels on plant height of quinoa at different growth stages

Treatment combinations	Plant height (cm) at			
	20 DAS	40 DAS	60 DAS	Harvest
$M_1 F_1$	5.17 f	17.15 e	25.05 de	22.27 cd
$M_1 F_2$	7.71 bc	36.51 ab	50.60 ab	49.33 ab
$M_1 F_3$	8. 12 abc	34.92 abc	47.07 bc	43.40 b
$M_1 F_4$	7.59 c	36.54 ab	48.23 abc	45.53 ab
$M_1 F_5$	7.95 abc	37. 10 a	50.60 b	50.90 a
$M_2 F_1$	6.73 de	11.89 f	18.57 e	17.34 d
$M_2 F_2$	8.22 abc	30.48 d	48.33 abc	46.30 ab
$M_2 F_3$	8.53 ab	30.38 d	54.00 a	49.50 ab
$M_2 F_4$	8.74 a	32.71 bcd	50.60 ab	47.97 ab
$M_2 F_5$	8.55 ab	28.62 d	44.40 c	42.30 b
$M_3 F_1$	6.46 e	12.89 f	25.70 d	24.77 c
$M_3 F_2$	8.75 a	32.20 cd	52.03 ab	50.13 a
$M_3 F_3$	8.51 ab	35.43 abc	52.97 ab	51.07 a
$M_3 F_4$	8.51 ab	32.05 cd	52. 47 ab	51.18 a
$M_3 F_5$	8.21 ab	30.51 d	52 83 ab	51.17 a
$LSD_{(0.05)}$	0.876	4.107	6.098	6.707
CV (%)	6.62	3.32	8.07	9.28

M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

F_1= No fertilizer, F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1},

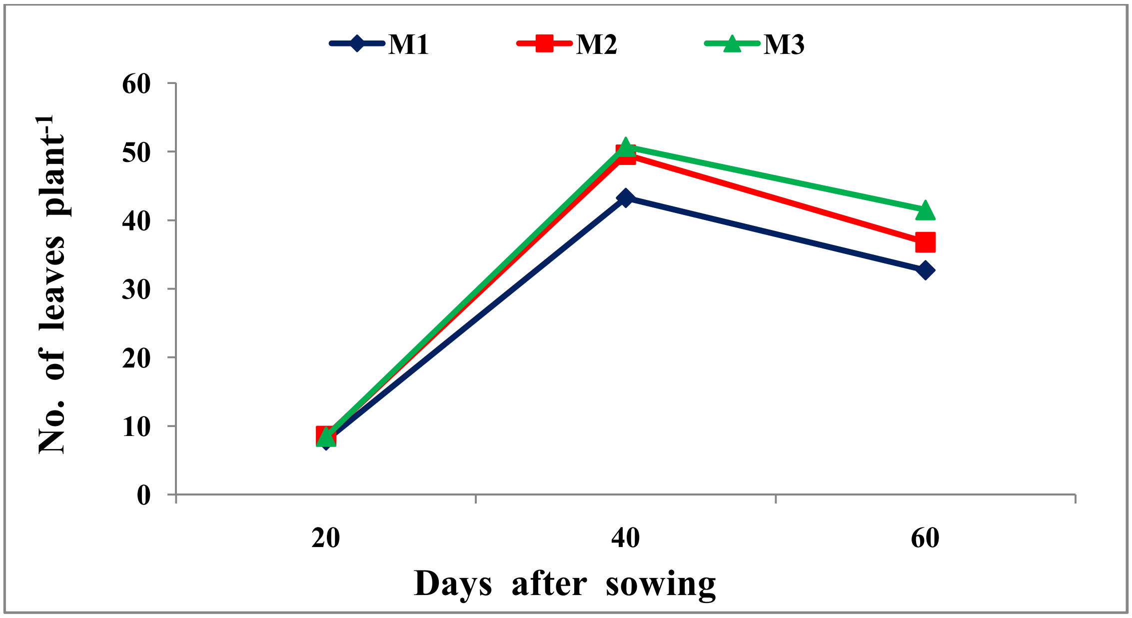
F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1},

F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}, F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

4.2 Number of leaves plant^{-1}

4.2.1 Effect of sowing methods

Different sowing methods showed significant effect on number of leaves plant^{-1} at 20 and 60 DAS but at 40 DAS, it did not show any significant difference (Figure 3 and Appendix VI). From figure 3, it was clearly visible that the number of leaves plant^{-1} gradually increased up to 40 DAS, and after that it started to fall down. At 20 DAS, the maximum number of leaves plant^{-1} (8.55) was found from line sowing method (M_2), which was statistically similar with number of leaves plant^{-1} (8.47), observed in bed sowing method (M_3), on the other hand minimum number of leaves plant^{-1} (7.93) was recorded in broadcast sowing method (M_1). At 40 DAS, there was no significant variation found in number of leaves plant^{-1}, yet numerically the maximum value (50.71) was observed in bed sowing method (M_3) and minimum value (43.25) was observed in broadcast sowing method (M_1). Maximum number of leaves plant^{-1} (41.51) was recorded in bed sowing method (M_3) at 60 DAS, which was statistically similar with the number of leaves plant^{-1} (36.80) found in line sowing method (M_2); whereas the minimum number of leaves plant^{-1} (32.72) was found in broadcast sowing method (M_1), which was statistically similar with the number of leaves plant^{-1} of 36.80 that found in line sowing method (M_2). From these results it could be said that, in all three growth stages (20, 40 and 60 DAS), broadcast sowing method gave lowest number of leaves plant^{-1} and at 40 DAS and 60 DAS bed sowing method performed better. In this study, bed sowing method increased the number of leaves plant^{-1} might be because of the better soil condition and better root growth which indicated that bed sowing method provided a suitable condition for the plants to uptake nutrients that also reported by Ali *et al*. (2020), bed sowing method showed best result in case of plants' LAI (leaf area index) and number of leaves.

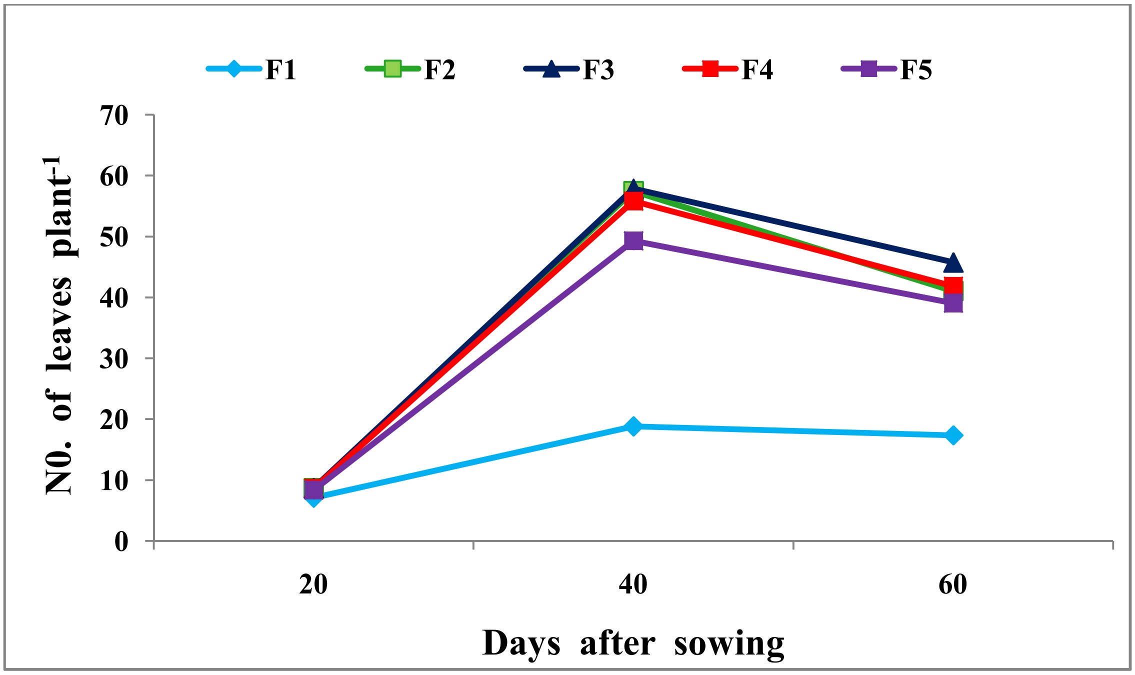


M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

Figure 3. Effect of sowing methods on number of leaves plant^{-1} of quinoa at different growth stages ($LSD_{(0.05)}$ = 0.311, NS and 5.555 at 20 DAS, 40 DAS and 60 DAS, respectively).

4.2.2 Effect of fertilizer levels

The number of leaves plant^{-1} of quinoa was significantly influenced by fertilizer at all studied dates (Figure 4 and Appendix VI). From figure 4, it was observed that in all five levels of fertilizer management, the number of leaves plant^{-1} increased up to 40 DAS and after that, leaf numbers started to decrease. At 20 DAS, the maximum number of leaves plant^{-1} (8.71) was got from F_3 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}), which was statistically similar with the number of 8.70 that found in both F_2 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}) and F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}) and lastly 8.36, recorded in F_5 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}). At 20 DAS, the lowest number of leaves plant^{-1} (7.13) was found in F_1 (control).



F_1= No fertilizer
F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}
F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1} + 10 t cowdung ha^{-1}
F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

Figure 4. Effect of fertilizer levels on number of leaves plant^{-1} of quinoa at different growth stages ($LSD_{(0.05)}$ = 0.409, 5.992 and 6.346 at 20 DAS, 40 DAS and 60 DAS, respectively).

The highest number of leaves plant^{-1} (57.84) at 40 DAS was observed in F_3, which was statistically similar with the number of leaves plant^{-1} of 57.42 that found in F_2 and 55.8, observed in F_4. The lowest number of leaves plant^{-1} (18.82) at 40 DAS was recorded in F_1 (control). At 60 DAS, the maximum number of leaves plant^{-1} (45.73) was found in F_3, which was statistically similar with 41.84, observed in F_4 and 41.04, found in F_2; whereas the minimum number of leaves plant^{-1} (17.36) was resulted in F_1 (control). From the results of the present study it was found that F_3 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}) fertilizer level resulted in maximum number of leaves plant^{-1} numerically, in all three growth stages (20, 40 and 60 DAS) of quinoa plant. It might be because all the plants under this fertilizer management got all the required nutrients from both synthetic and organic fertilizer sources. On the other hand, number of leaves resulted in F_4 were statistically similar with F_3 in all three growth stages, but less synthetic fertilizers were applied under F_4 fertilizer treatment than F_3. In the present study control fertilizer management always produced minimum number of leaves plant^{-1}. Biswas *et al.* (2021) recorded the highest number of leaves plant^{-1} (77.53) at 150 kg N ha^{-1} and the lowest number of leaves plant^{-1} in control plants. According to Almadini *et al*. (2019) among three levels of N fertilizer ha^{-1} (*i.e.* 0, 80 and 160 kg N ha^{-1}) 160 kg N ha^{-1} resulted in greater number of leaves plant^{-1} (43). Afrin (2018) stated that for different fertilizer levels, at 30 DAS leaf number was highest (22.59) in 120-50-50 kg NPK ha^{-1}, and in 45 and 60 DAS the highest leaf number was (48.53 and 30.44) in 120-50 kg NK ha^{-1}. All these findings were quite similar with result of the present study.

4.2.3 Interaction effect of sowing methods and fertilizer levels

The sowing method and fertilizer level interaction effect had a significant impact on number of leaves plant^{-1} (Table 2 and Appendix VI). At 20 DAS, the maximum number of leaves plant^{-1} (9.23) was recorded in between line sowing method (M_2) and 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1} (F_3) interaction (M_2F_3), which was statistically similar with M_3F_2 (9.00), M_2F_4 (8.97), M_3F_3 (8.77), M_3F_4 (8.67), M_1F_2 (8.60), M_2F_5 (8.60) and the minimum number of leaves plant^{-1} (6.40) were founded in broadcast sowing method (M_1) and no fertilizer (F_1) interaction (M_1F_1). At 40DAS, the highest number of leaves plant^{-1} (65.80) were observed in between bed sowing method (M_3) and 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1} (F_3) interaction (M_3F_3), which was statistically similar with M_2F_4 (62.47), M_2F_3 (61.93), M_2F_2 (57.60), M_3F_2 (57.40), M_1F_2 (57.27) and M_3F_4 (56.93).

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

Treatment combinations	Number of leaves plant^{-1} at		
	20 DAS	40 DAS	60 DAS
M_1 F_1	6.40 e	19.27 e	17.47 e
M_1 F_2	8.60 abc	57.27 abc	39.13 bcd
M_1 F_3	8.13 cd	45.80 d	32.20 d
M_1 F_4	8.47 bc	48.00 cd	36.47 bcd
M_1 F_5	8.07 cd	45.93 d	38.33 bcd
M_2 F_1	7.47 d	17.13 e	13.60 e
M_2 F_2	8.50 bc	57.60 abc	38.60 bcd
M_2 F_3	9.23 a	61.93 ab	54.13 a
M_2 F_4	8.97 ab	62.47 ab	43.87 abc
M_2 F_5	8.60 abc	48.60 cd	33.80 cd
M_3 F_1	7.53 d	20.07 e	21.00 e
M_3 F_2	9.00 ab	57.40 abc	45.40 ab
M_3 F_3	8.77 abc	65.80 a	50.87 a
M_3 F_4	8.67 abc	56.93 abc	45.20 ab
M_3 F_5	8.40 bc	53.33 bcd	45.07 ab
$LSD_{(0.05)}$	0.708	10.379	10.991
CV (%)	50.05	12.88	17.62

M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

F_1= No fertilizer, F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1},

F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1},

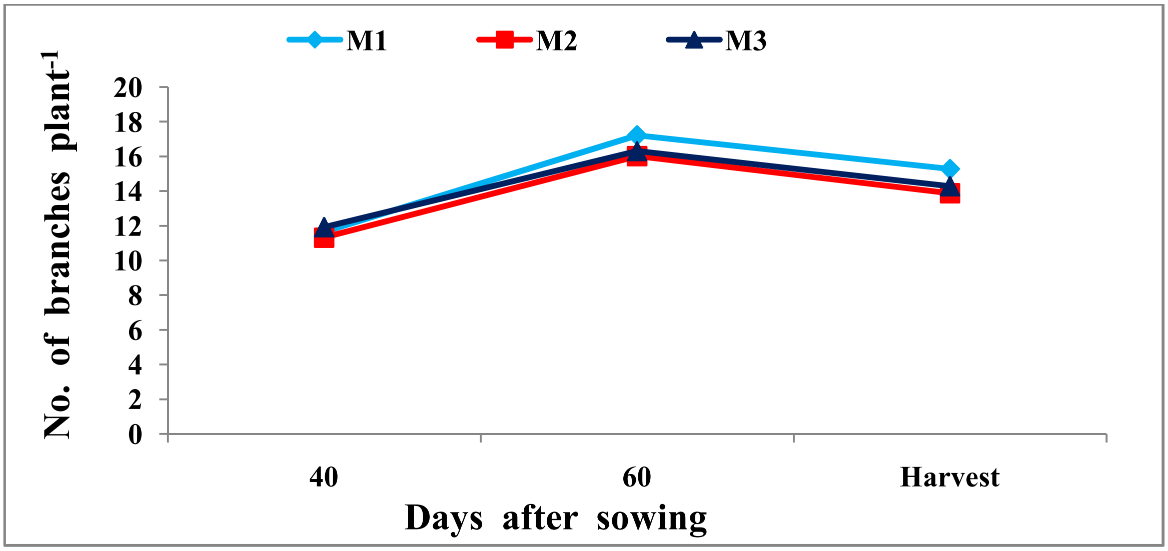
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}, F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

At 40 DAS, the lowest number of leaves plant^{-1} (17.13) was found in between line sowing method (M_2) and no fertilizer (F_1) interaction (M_2F_1), which was statistically similar with M_3F_1 (20.07) and M_1F_1 (19.27) . At 60 DAS, the maximum number of leaves plant^{-1} (54.13) was found in the interaction between line sowing method (M_2) and 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1} + 10 t cowdung ha^{-1} (F_3) fertilizer level, which was statistically similar with M_3F_3 (50.87), M_3F_2 (45.40), M_3F_4 (45.20), M_3F_5 (45.07) and M_2F_4 (43.87); whereas the minimum number of leaves plant^{-1} (13.60) were found in the combination between line sowing method (M_2) and no fertilizer (F_1), which was statistically at par with M_3F_1 (21.00) and M_1F_1 (17.47). In all three growth stages, broadcast sowing method combining with no fertilizer level resulted in lowest number of leaves plant^{-1}.

4.3 Number of branches plant^{-1}

4.3.1 Effect of sowing methods

Different sowing methods showed non-significant results at 40 DAS and at harvest but were significant at 60 DAS, in case of number of branches plant^{-1} (Figure 5 and Appendix VII). From figure 5, it was observed that number of branches plant^{-1} increased continuously up to 60 DAS, but after that the values started to decrease gradually till harvest. At 40 DAS, sowing methods showed no significant results on plants' branch number. Numerically the highest value (11.92) was observed in bed sowing method (M_3) and lowest value (11.32) was found in line sowing method (M_2). At 60 DAS, maximum number of branches plant^{-1} (17.22) was recorded in broadcast sowing method (M_1) and minimum number of branches plant^{-1} (16.02) was observed in line sowing method (M_2). At harvest, though sowing methods did not contribute to bring significant difference in number of branches plant^{-1}, still broadcast sowing method (M_1) resulted in numerically the highest number of branches plant^{-1} (15.28) and line sowing method (M_2) gave the lowest number (13.88). According to Ali *et al*. (2020), bed sowing method showed best result in case of plants' brunch number. And the result of the present experiment (number of branches plant^{-1}) does not go unanimously with the result found by Ali *et al*. (2020).



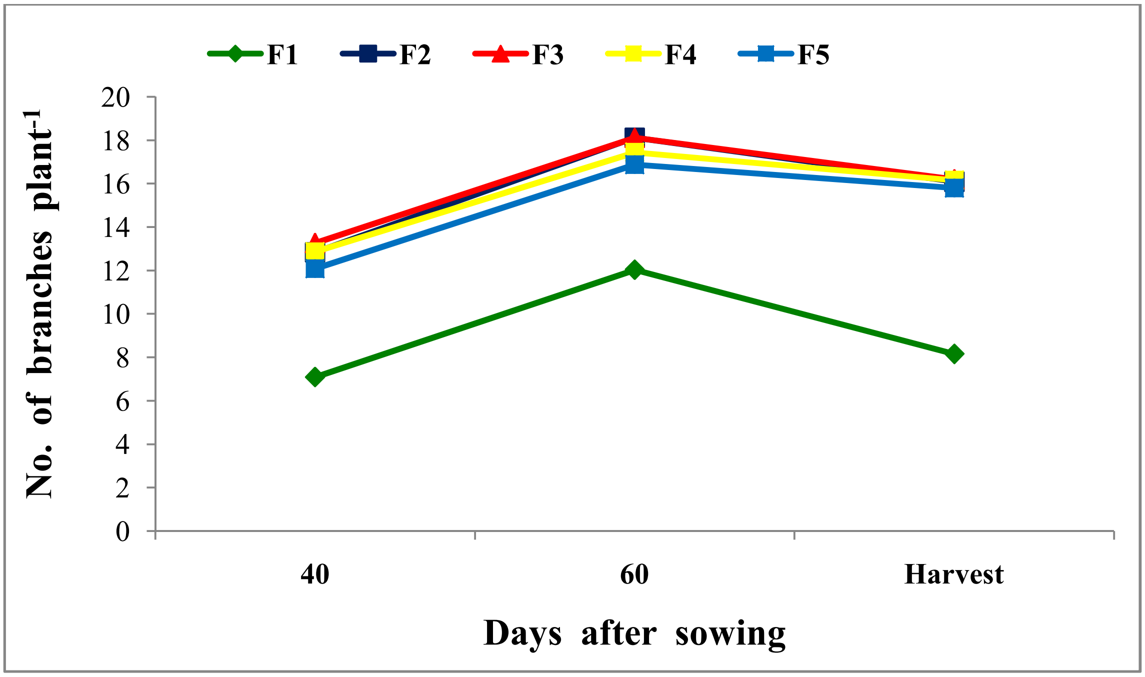
M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

Figure 5. Effect of sowing methods on number of branches plant^{-1} of quinoa at different growth stages ($LSD_{(0.05)}$ = NS, 0.273 and NS at 40 DAS, 60 DAS and at harvest, respectively).

4.3.2 Effect of fertilizer levels

Number of branches plant^{-1} of quinoa was significantly influenced by fertilizer at all studied dates (Figure 6 and Appendix VII). From figure 6, it was found that in all five levels of fertilizer management, the number of branches plant^{-1} increased up to 60 DAS and after that, branch numbers started to decrease. At 40 DAS, the highest number of branches plant^{-1} (13.27) was recorded in F_3 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}), which was statistically similar with the number of branches plant^{-1} of 12.87 recorded in F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}), 12.84 found in F_2 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}) and 12.09 resulted in F_5 (150-100-100 kg N,

P_2O_5, K_2O ha^{-1}). The lowest number of branches $plant^{-1}$ (7.09) recorded in F_1 (control). The maximum number of branches $plant^{-1}$ (18.11) at 60 DAS was observed in both F_2 and F_3 fertilizer levels and the value was statistically similar with 17.40 resulted in F_4; whereas the minimum number of branches $plant^{-1}$ (12.03) was recorded in F_1 (control). At harvest the highest number of branches $plant^{-1}$ (16.20) was observed in F_3, which was statistically similar with 16.16 resulted in F_4, 16.09 found in F_2 and 15.80 observed in F_5. On the other side, the lowest number of branches $plant^{-1}$ (8.15) was resulted in F_1 (control). F_3 fertilizer level (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+10 t cowdung ha^{-1}) ensured numerically the highest number of branches $plant^{-1}$ at all studied dates. All the plant nutrients supplied by both synthetic and organic fertilizer sources ensured this higher value. But on the other side, though F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}) did not show numerically the maximum number of branches $plant^{-1}$, but it was always statistically at par with the highest value resulted in F_3. At all studied dates, F_4 ensured statistically similar higher number of branches $plant^{-1}$ by using cowdung and less number of synthetic fertilizers. This practice at the same time supplying plants required nutrients for growth and taking care of soil. Biswas *et al.* (2021) stated that 100 kg N ha^{-1} gave highest number of branches $plant^{-1}$ (17.07). According to Naik *et al.* (2020) and Afrin (2018), application of 150:75:75 kg NPK ha^{-1} and 120-50-50 kg NPK ha^{-1} made the highest total number of branches $plant^{-1}$ 17.70 and 20.03, respectively. Fawy *et al*. (2017) found that more quinoa branches were found in soil applied with organic manure. These statements support the result of the present experiment. In the present study F_1 (control) fertilizer level resulted in lowest brunch number $plant^{-1}$ at all studied dates, but Biswas *et al.* (2021) and Afrin (2018) informed that, at harvest the lowest number of branches $plant^{-1}$ of quinoa plants were found in 250 kg N ha^{-1} and 50 kg K ha^{-1} , respectively.



F_1= No fertilizer
F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}
F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1} + 10 t cowdung ha^{-1}
F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

Figure 6. Effect of fertilizer levels on number of branches plant^{-1} of quinoa at different growth stages ($LSD_{(0.05)}$ = 1.559, 1.229 and 0.832 at 40 DAS, 60 DAS and at harvest, respectively).

4.3.3 Interaction effect of sowing methods and fertilizer levels

The interaction between sowing methods and fertilizer levels had a substantial impact on the number of branches plant^{-1} of quinoa at different growth stages (Table 3 and Appendix VII). At 40 DAS, the maximum number of branches plant^{-1} (14.27) was found in between line sowing method (M_2) and 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1} (F_3) interaction (M_3F_3), which was statistically similar with M_3F_3 (13.53), M_1F_2 (13.47), M_3F_4 (13.40), M_2F_4 (13.20), M_1F_5 (12.93), M_3F_2 (12.73), M_2F_2 (12.33), M_1F_3 (12.00), M_1F_4 (12.00) and M_3F_5 (11.93) and minimum number of branches plant^{-1} (5.400) were found in between line sowing (M_2) and no fertilizer (F_1) interaction (M_2F_1), which was statistically similar with M_3F_1 (8.00) and M_1F_1 (7.87).

Table 3. Interaction effect of sowing methods and fertilizer levels on number of branches plant^{-1} of quinoa at different growth stages

Treatment combinations	Number of branches plant^{-1} at		
	40 DAS	**60 DAS**	**Harvest**
M_1 F_1	7.87 c	12.20 d	8.47 gh
M_1 F_2	13.47 ab	19.87 a	17.93 a
M_1 F_3	12.00 ab	18.93 ab	17.73 ab
M_1 F_4	12.00 ab	17.60 bc	16.07 cde
M_1 F_5	12.93 ab	17.50 bc	16.20 cde
M_2 F_1	5.40 c	11.50 d	7.27 h
M_2 F_2	12.33 ab	17.60 bc	14.80 ef
M_2 F_3	14.27 a	17.47 bc	16.40 bcd
M_2 F_4	13.20 ab	17.20 bc	15.87 cdef
M_2 F_5	11.40 b	16.33 c	15.07 def
M_3 F_1	8.00 c	12.40 d	8.73 g
M_3 F_2	12.73 ab	16.87 bc	15.53 cdef
M_3 F_3	13.53 ab	17.93 abc	14.47 f
M_3 F_4	13.40 ab	17.53 bc	16.53 abc
M_3 F_5	11.93 ab	16.80 c	16.13 cde
$LSD_{(0.05)}$	2.70	2.128	1.44
CV (%)	13.78	7.65	5.90

M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

F_1= No fertilizer, F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1},

F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1},

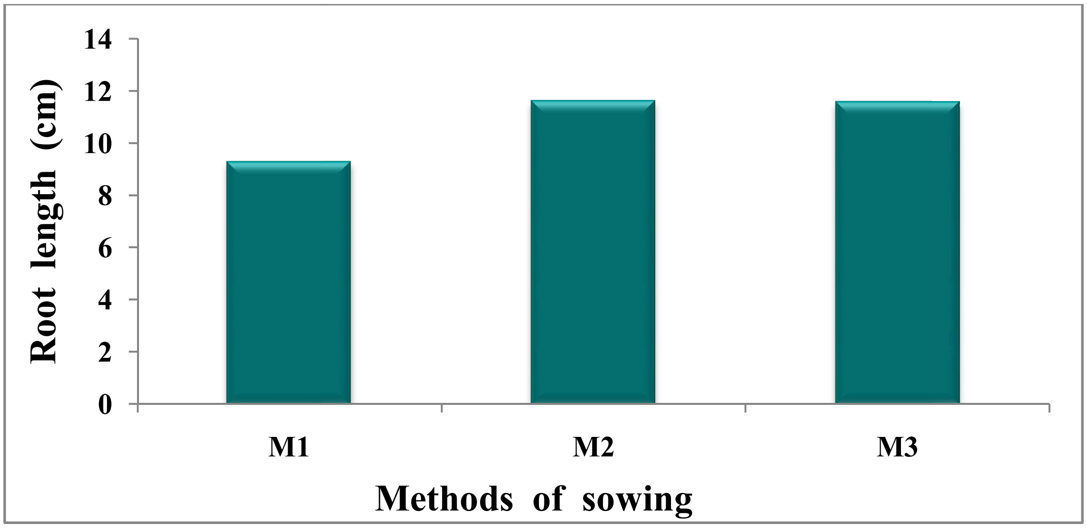
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}, F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

At 60 DAS, the highest number of branches plant^{-1} (19.867) were recorded in between broadcast sowing method (M_1) and 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1} (F_2) interaction (M_1F_2), which was statistically similar with M_1F_3 (18.93) and M_3F_3 (17.93); whereas the lowest number of branches plant^{-1} (11.50) was found in line sowing method (M_2) and no fertilizer (F_1) interaction (M_2F_1), which was statistically similar with M_3F_1 (12.40) and M_1F_1 (12.20). At harvest, in broadcast sowing method (M_1) and 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1} (F_2) combination, highest number of branches plant^{-1} (17.93) was found which was statistically similar with M_1F_3 (17.733) and M_3F_4 (16.53); whereas line sowing method (M_2) and no fertilizer (F_1) combination brought lowest number of branches plant^{-1} (7.27), which was statistically similar with M_1F_1 (8.47). Here it was observed that, both at 60 DAS (19.87) and at harvest (17.93), the interaction between broadcast sowing method (M_1) and 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1} (F_2) fertilizer level, resulted in most number of branches plant^{-1} respectively and line sowing method (M_2) combined with no fertilizer (F_1), resulted in lowest number of branches plant^{-1} (5.40, 11.50 and 7.27) and in all three (40 and 60 DAS and at harvest) growth stages respectively.

4.4 Root length

4.4.1 Effect of sowing methods

Sowing methods showed significant effect on quinoa plants' root length at harvest (Figure 7 and Appendix VIII). From figure 7, it was visible that line sowing method (M_2) and bed sowing method (M_3) showed similar result and their values were statistically similar. At harvest line sowing method (M_2) gave the highest root length (11.58 cm) which was statistically similar with 11.54 cm that found in bed sowing method (M_3); whereas the lowest root length (9.25cm) was found in broadcast sowing method (M_1). From the result of the present study it could be expressed that, little earthing up at the base of quinoa plants in line sowing and bed sowing method helped in better root growth than in broadcast sowing method, where earthing up was not practiced.

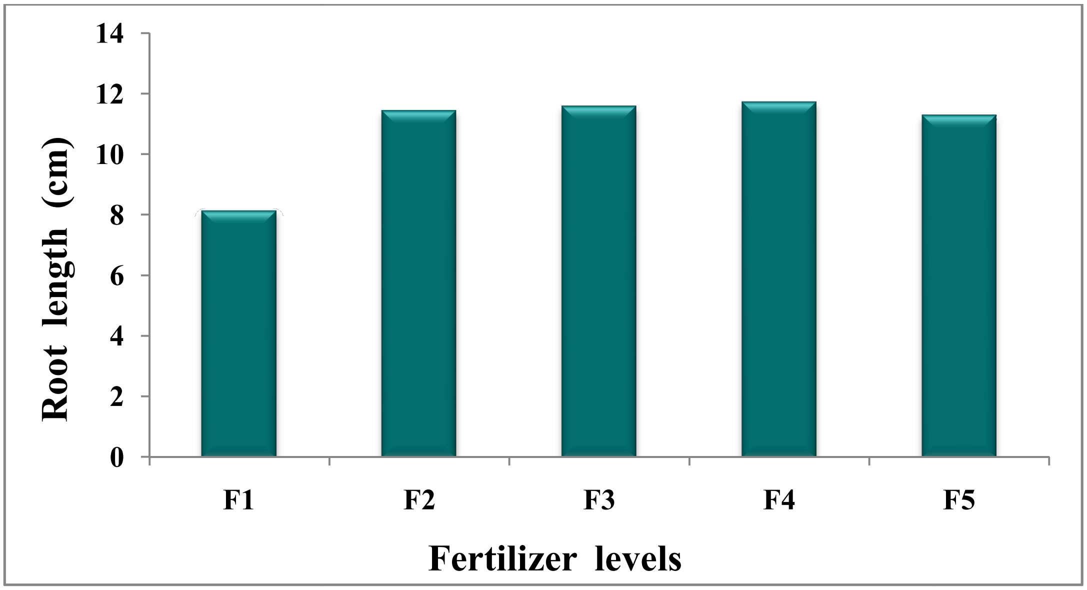


M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

Figure 7. Effect of sowing methods on root length of quinoa plant ($LSD_{(0.05)}$ = 0.798).

4.4.2 Effect of fertilizer levels

Different fertilizer levels showed significant effect on root length variation of quinoa plant at harvest (Figure 8 and Appendix VIII). The root length value in F_4 was slightly better than F_3, whereas F_1 showed a poor performance compared to others. At harvest, numerically the maximum length of root (11.68 cm) was recorded in F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}) which was statistically similar with the root length value of 11.54 cm resulted in F_3 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}), 11.39 cm that was found in F_2 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}) and 11.24 cm observed in F_5 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}). The minimum length of root (8.09 cm) was found in F_1 (control).



F_1= No fertilizer
F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}
F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1} + 10 t cowdung ha^{-1}
F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

Figure 8. Effect of fertilizer levels on root length (cm) of quinoa plant ($LSD_{(0.05)}$ = 1.049).

4.4.3 Interaction effect of sowing methods and fertilizer levels

The interaction effect between sowing techniques and fertilizer levels showed significant impact on root length of quinoa plants' (Table 4 and Appendix VIII). At harvest, maximum length of root (12.90 cm) was resulted in between bed sowing method (M_3) and 150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1} (F_4) interaction (M_3F_4), which was statistically similar with M_3F_4 (12.90 cm), M_2F_3 (12.65 cm), M_2F_5 (12.51 cm), M_3F_2 (12.43 cm), M_2F_2 (12.17 cm), M_2F_4 (12.17 cm) and M_3F_5 (11.87 cm). The minimum root length (7.23 cm) was recorded in broadcast sowing method (M_1) and control (F_1) fertilizer level interaction (M_1F_1), which was statistically similar with M_3F_1 (8.57 cm) and M_2F_1

(8.47 cm). Irrespective of planting method control fertilizer (F_1) had an impact on the root length, which was found to be the lowest (cm).

Table 4. Interaction effect of sowing methods and fertilizer levels on root length of quinoa at harvest

Treatment combinations	Root length (cm)
$M_1 F_1$	7.23 c
$M_1 F_2$	9.59 b
$M_1 F_3$	10.03 b
$M_1 F_4$	10.03 b
$M_1 F_5$	9.35 b
$M_2 F_1$	8.47 bc
$M_2 F_2$	12.17 a
$M_2 F_3$	12.65 a
$M_2 F_4$	12.17 a
$M_2 F_5$	12.51 a
$M_3 F_1$	8.57 bc
$M_3 F_2$	12.43 a
$M_3 F_3$	11.94 a
$M_3 F_4$	12.90 a
$M_3 F_5$	11.87 a
$LSD_{(0.05)}$	1.819
CV (%)	10.00

M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

F_1= No fertilizer, F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1},

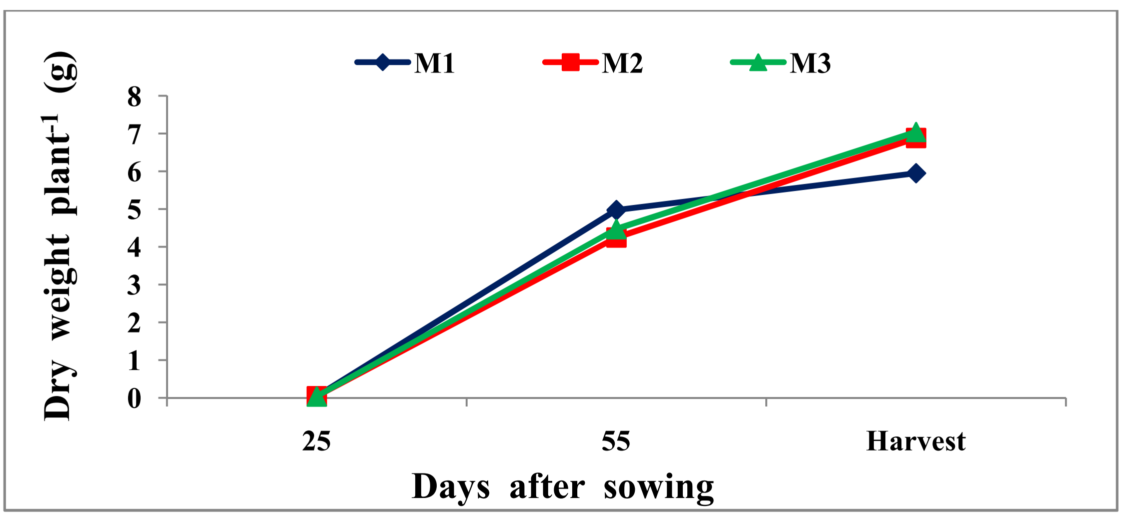
F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1},

F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}, F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

4.5 Dry weight plant^{-1}

4.5.1 Effect of sowing methods

At different growth stages sowing method did not show any statistically significant variation on dry weight value plant^{-1} of quinoa (Figure 9 and Appendix IX). From figure 9, it was observed that, in broadcast sowing method at 55 DAS, the dry weight value did not increase much but in case of line sowing method and bed sowing method, the dry weight value of whole quinoa plants increase gradually up to harvest. At 25 and 55 DAS, numerically the maximum dry weight values (0.05 g plant^{-1} and 4.97 g plant^{-1}) were recorded in broadcast sowing method (M_1) and the minimum dry weights (0.04 g plant^{-1} and 4.25 g plant^{-1}) were found in bed sowing (M_3) and line sowing method (M_2) respectively. At harvest, numerically the highest dry weight value (7.04 g plant^{-1}) was recorded in bed sowing method (M_3) and the lowest value (5.95 g plant^{-1}) was observed in broadcast sowing method (M_1).

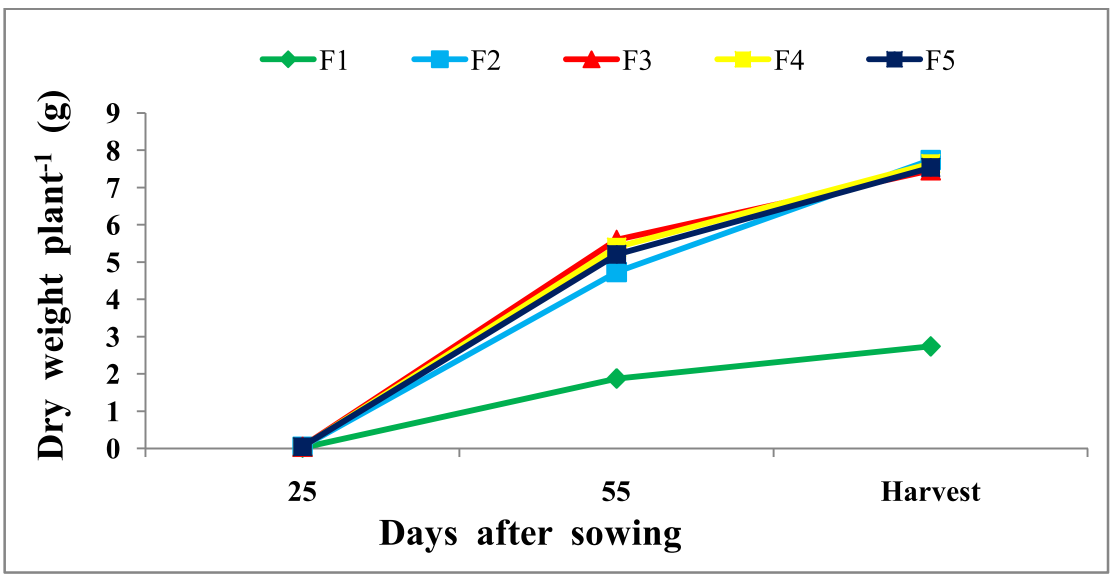


M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

Figure 9. Effect of sowing methods on dry weight of quinoa plant at different growth stages ($LSD_{(0.05)}$ = NS, NS and NS at 25 DAS, 55 DAS and at harvest, respectively).

4.5.2 Effect of fertilizer levels

Different fertilizer levels showed significant effect on the dry weight variation of quinoa plants (Figure 10 and Appendix IX). From figure 10, it was clearly visible that from 25 DAS to harvest the increment was a continuous phenomenon for every fertilizer level, but the rate of increment slightly decreased after 55 DAS. At 25 DAS, the highest dry weight value (0.049 g plant^{-1}) was recorded in F_5 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}), which was statistically similar with the dry weight value of 0.048 g plant^{-1} resulted in F_3 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}) and 0.045 g plant^{-1} that found in both F_2 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}) and F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}). At 25 DAS, the lowest (0.021 g plant^{-1}) dry weigh value was found in F_1 (control).



F_1= No fertilizer
F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}
F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cow dung ha^{-1}
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1} + 10t cow dung ha^{-1}
F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

Figure 10. Effect of fertilizer levels on dry weight (g) of quinoa plants at different growth stages ($LSD_{(0.05)}$ = 0.058, 0.991 and 0.938 at 25 DAS, 55 DAS and at harvest, respectively).

The maximum dry weight of whole quinoa plants (5.60 g plant^{-1}) was found in F_3 fertilizer level at 55 DAS, and the value was statistically similar with the dry weight value 5.40 g plant^{-1} resulted in F_4, 5.21 g plant^{-1} recorded in F_5 and 4.73 g plant^{-1} observed in F_2. The minimum value (1.87 g plant^{-1}) at 55 DAS was resulted in F_1 (control). At harvest the highest dry weight value (7.74 g plant^{-1}) was observed in F_2 and that was statistically similar with the dry weight values of 7.65 g plant^{-1}, 7.54 g plant^{-1} and 7.45 g plant^{-1} resulted in F_4, F_5 and F_3 fertilizer levels respectively; whereas the lowest dry weight (2.74 g plant^{-1}) was observed in F_1 (control). From the result of the present study it could be said only F_1 treatment showed constantly the lowest dry weight value throughout the whole growing season, other than this no single fertilizer level showed singly dominating the dry weight values in all three studied dates. Though Almadini *et al*. (2019) reported that among three levels of nitrogen fertilizer (*i.e.* 0, 80 and 160 kg N ha^{-1}) 160 kg N ha^{-1} resulted in maximum dry weight 18.11 g plant^{-1}. But the balanced nutrient levels supplied in the present experiment, ensured higher values of dry weight at harvest except the control fertilizer management.

4.5.3 Interaction effect of sowing methods and fertilizer levels

The sowing method and fertilizer level interaction effect had a significant impact on plants' dry weight (Table 5 and Appendix IX). At 25 DAS, broadcast sowing method (M_1) combining with 150-100-100 kg N, P_2O_5, K_2O ha^{-1} (F_5) fertilizer level (M_1F_5), resulted in maximum dry weight (0.06 g plant^{-1}), which was statistically at par with M_2F_3 (0.05 g plant^{-1}), M_1F_2 (0.05 g plant^{-1}), M_1F_4 (0.05 g plant^{-1}), M_1F_3 (0.05 g plant^{-1}) and M_3F_5 (0.05 g plant^{-1}); whereas the minimum dry weight (0.02 g plant^{-1}) was found in both broadcast sowing method (M_1) with no fertilizer (F_1) level interaction (M_1F_1) and bed sowing method(M_3) with control fertilizer (F_1) interaction, which was statistically similar with M_2F_1 (0.03 g plant^{-1}).

Table 5. Interaction effect of sowing methods and fertilizer levels on dry weight plant^{-1} of quinoa plant at different growth stages

Treatment combinations	Dry weight (g plant^{-1}) at		
	25 DAS	55 DAS	Harvest
M_1 F_1	0.02e	2.53 de	2.88 d
M_1 F_2	0.05 abc	5.93 ab	7.66 ab
M_1 F_3	0.05 abcd	5.06 abc	5.62 c
M_1 F_4	0.05abcd	5.03 abc	6.45 bc
M_1 F_5	0.06a	6.30 a	7.13 abc
M_2 F_1	0.03 e	1.58 e	2.58 d
M_2 F_2	0.04 d	4.50 abc	7.74 ab
M_2 F_3	0.05 ab	5.56 abc	8.26 ab
M_2 F_4	0.04bcd	5.35 abc	8.48 a
M_2 F_5	0.04 bcd	4.25 bcd	7.37 abc
M_3 F_1	0.02e	1.51 e	2.76 d
M_3 F_2	0.04 bcd	3.77 cd	7.82 ab
M_3 F_3	0.04bcd	6.19 a	8.52 a
M_3 F_4	0.04cd	5.82 ab	8.01 ab
M_3 F_5	0.05abcd	5.07 abc	8.10 ab
$LSD_{(0.05)}$	0.099	1.717	1.625
CV (%)	14.23	22.32	14.56

M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

F_1= No fertilizer, F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1},

F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1},

F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}, F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

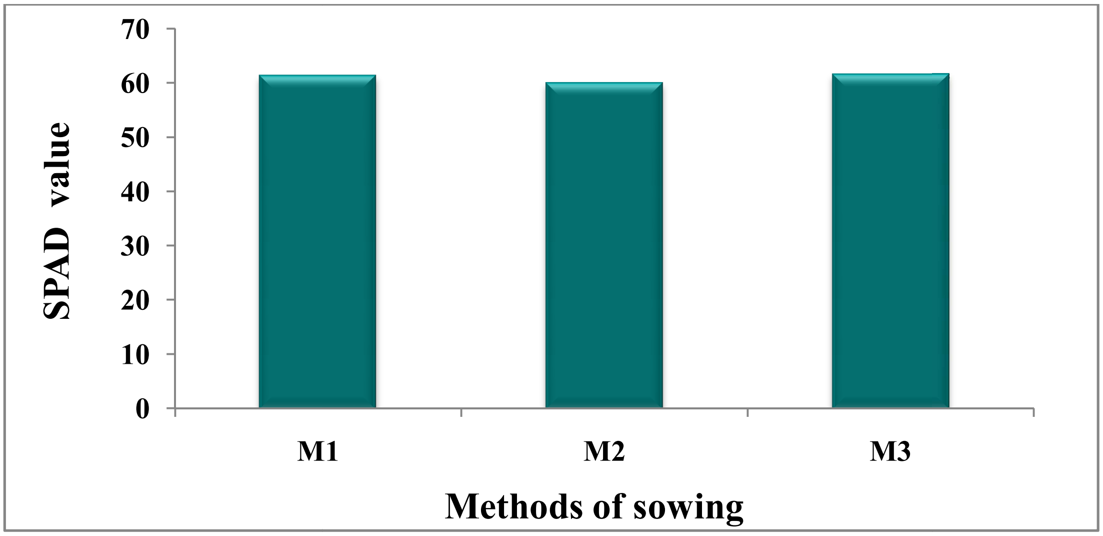
At 55 DAS, the highest value of plants' dry weight (6.30 g plant^{-1}) was recorded in between broadcast sowing method (M_1) and 150-100-100 kg N, P_2O_5, K_2O ha^{-1} (F_5) interaction (M_1F_5), which was statistically similar with M_3F_3 (6.19 g plant^{-1}),

M_1F_2 (5.93 g plant^{-1}), M_3F_4 (5.82 g plant^{-1}), M_2F_3 (5.56 g plant^{-1}), M_2F_4 (5.35 g plant^{-1}), M_3F_5 (5.07 g plant^{-1}), M_1F_3 (5.06 g plant^{-1}), M_1F_4 (5.03 g plant^{-1}) and M_2F_2 (4.50 g plant^{-1}). The lowest value (1.51 g plant^{-1}) at 55 DAS was found in bed sowing method (M_3) and no fertilizer (F_1) interaction (M_3F_1), which was statistically similar with M_2F_1 (1.58 g plant^{-1}) and M_1F_1 (2.53 g plant^{-1}). At harvest, the maximum value of dry weight (8.52 g plant^{-1}) was observed in bed sowing method (M_3) and 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1} (F_3) interaction (M_3F_3), which was statistically similar with M_2F_4 (8.48 g plant^{-1}), M_2F_3 (8.26 g plant^{-1}), M_3F_5 (8.10 g plant^{-1}), M_3F_4 (8.01 g plant^{-1}), M_3F_2 (7.82 g plant^{-1}), M_2F_2 (7.74 g plant^{-1}), M_1F_2 (7.66 g plant^{-1}), M_2F_5 (7.37 g plant^{-1}) and M_1F_5 (7.13 g plant^{-1}); whereas the minimum value of dry weight (2.58 g plant^{-1}) was found in between line sowing method (M_2) and no fertilizer (F_1) interaction (M_2F_1), which was statistically similar with M_3F_1 (2.76 g plant^{-1}) and M_1F_1 (2.88 g plant^{-1}).

4.6 SPAD value

4.6.1 Effect of sowing methods

On SPAD values, different sowing methods showed no significant difference (Figure 11 and Appendix X). At 55 DAS, bed sowing method (M_3) showed better performance in the field comparing to others. Though all SPAD values are statistically similar, till numerically bed sowing method (M_3) gave maximum SPAD value (61.42) and line sowing method (M_2) resulted in minimum SPAD value (59.81). Ali *et al.* (2020) also stated that, highest chlorophyll content was found in bed sowing method (BS) comparing to other sowing methods.

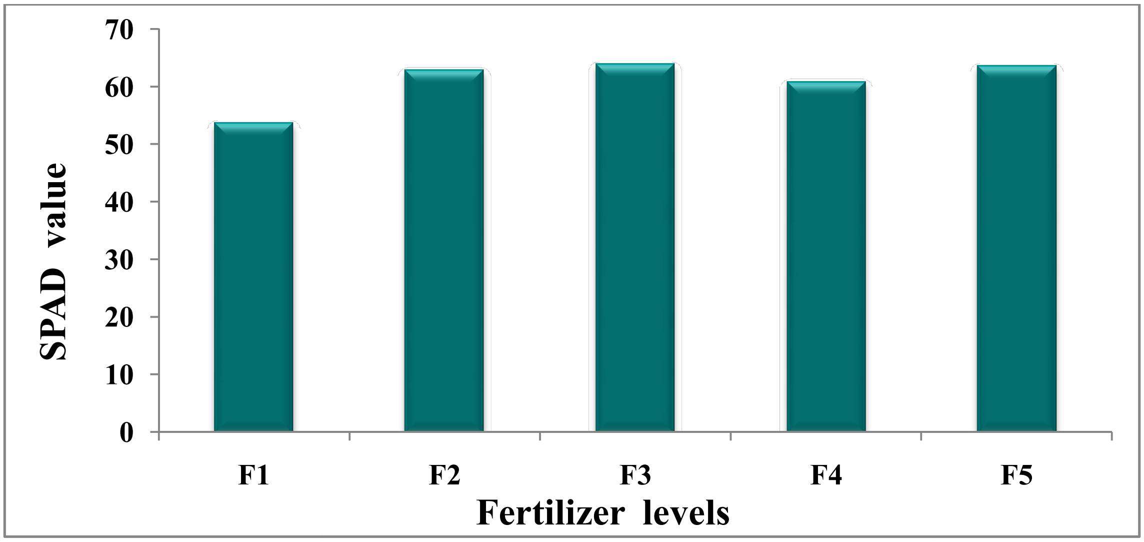


M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

Figure 11. Effect of sowing methods on SPAD values of quinoa plant at 55 DAS ($LSD_{(0.05)}$ = NS).

4.6.2 Effect of fertilizer levels

Different fertilizer levels have significant effect on SPAD values of quinoa plants (Figure 12 and Appendix X). From figure 12, it was visible that among four fertilizer levels (except F_1), F_3 fertilizer management resulted in slightly higher number of SPAD values. At 55 DAS, except F_1 (control) fertilizer level, all the other fertilizer levels were resulted in statistically similar SPAD values. The highest SPAD value (63.70) was recorded in F_3 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}), which was statistically at par with the SPAD values 63.45, 62.68 and 60.63 and recorded in F_5 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}), F_2 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}) and F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}) and fertilizer levels. Abdolahpour *et al*. (2021) found that 120: 100: 80 kg ha^{-1} N: P: K combination resulted in the maximum mean value of Chl a, Chl b, Chl a+b of quinoa and the finding is quite similar with the result observed in present experiment.



F_1= No fertilizer
F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}
F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1} + 10 t cowdung ha^{-1}
F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

Figure 12. Effect of fertilizer levels on SPAD values of quinoa plant at 55 DAS ($LSD_{(0.05)}$ = 3.083).

According to Biswas *et al*. (2021) applying 200 kg N ha^{-1} in quinoa plant had the highest SPAD value (64.61) and Almadini *et al.* (2019) reported that application of 160 kg N ha^{-1} resulted in highest SPAD value (70.28) of quinoa, which means the SPAD value of the quinoa significantly depends on the nitrogen levels. On the other side, the lowest value (53.52) was found in F_1 (control) in the present experiment and the result supports the finding of Biswas *et al*. (2021).

4.6.3 Interaction effect of sowing methods and fertilizer levels

The sowing method and fertilizer level interaction effect had a significant impact on SPAD value (Table 6 and Appendix X). At 55 DAS, broadcast sowing method (M_1) combining with 150-100-100 kg N, P_2O_5, K_2O (F_5) fertilizer level gave the highest SPAD value (65.38) and this value is statistically similar with all the other values except M_2F_4 (59.25), M_3F_1 (55.17), M_1F_1 (53.01) and M_2F_1 (52.38).

Table 6. Interaction effect of sowing methods and fertilizer levels on SPAD value, number of inflorescence plant^{-1}, 1000-seed weight and seed yield plant^{-1} of quinoa

Treatment combinations	SPAD value at 55 DAS	Number of inflorescence plant^{-1}	1000-seed weight (g)	Seed yield plant^{-1} (g)
M_1 F_1	53.01 c	14.07 de	3.47	1.03 f
M_1 F_2	63.45 ab	20.37 a	3.50	2.36 de
M_1 F_3	63.85 ab	18.80 ab	3.52	2.22 de
M_1 F_4	60.13 ab	17.07 bc	3.58	2.34 de
M_1 F_5	65.38 a	17.90 bc	3.55	2.45 de
M_2 F_1	52.38 c	12.50 e	3.45	0.71 f
M_2 F_2	63.33 ab	17.27 bc	3.55	3.2163 bcd
M_2 F_3	63.51 ab	18.07 bc	3.43	4.46 a
M_2 F_4	59.25 b	17.27 bc	3.51	3.41 abcd
M_2 F_5	60.59 ab	17.33 bc	3.48	2.92 cd
M_3 F_1	55.17 c	13.47 e	3.42	1.28 ef
M_3 F_2	61.25 ab	16.80 bc	3.37	3.30 abcd
M_3 F_3	63.76 ab	16.20 cd	3.43	4.36 ab
M_3 F_4	62.51 ab	18.07 bc	3.51	3.90 abc
M_3 F_5	64.39 ab	17.13 bc	3.53	3.31 abcd
$LSD_{(0.05)}$	5.339	2.10	NS	1.087
CV (%)	5.21	7.66	4.35	23.44

M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

F_1= No fertilizer, F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1},

F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1},

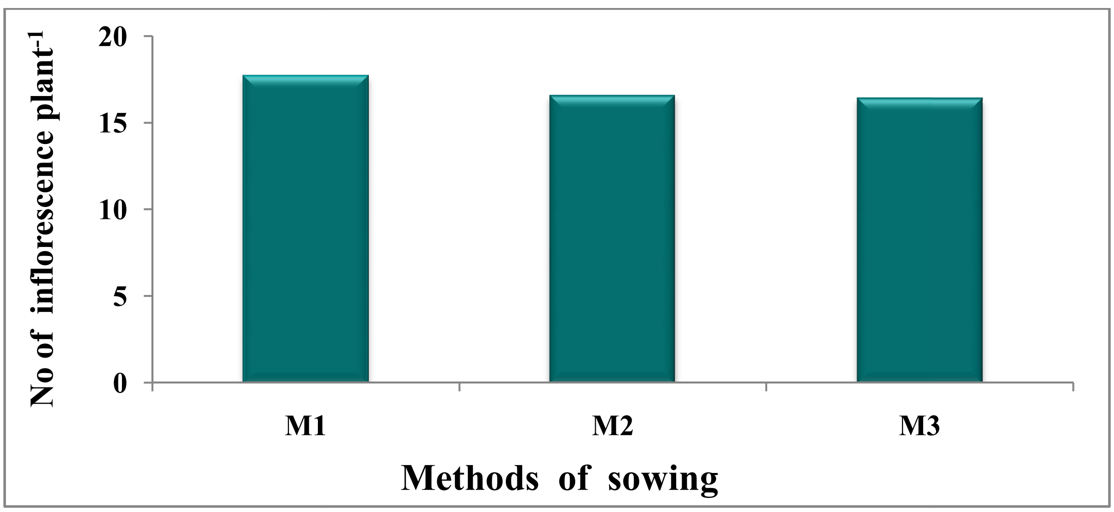
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}, F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

The lowest SPAD value (52.38) was found in M_2F_1, which was statistically similar with M_3F_1 (55.17) and M_1F_1 (53.01). Here it was observed that, interaction effect of different sowing methods and fertilizer levels on SPAD value, irrespective of any sowing method, only control fertilizer (F_1) was showing effect in bringing the lowest SPAD value.

4.7 Number of inflorescence plant^{-1}

4.7.1 Effect of sowing methods

Different sowing methods did not show any significantly variable results in the number of inflorescence plant^{-1} (Figure 13 and Appendix XI). Though all the values of number of inflorescence plant^{-1} were statistically similar, yet from Figure 13, it could be observed that broadcast sowing method (M_1) showed comparatively better performance.



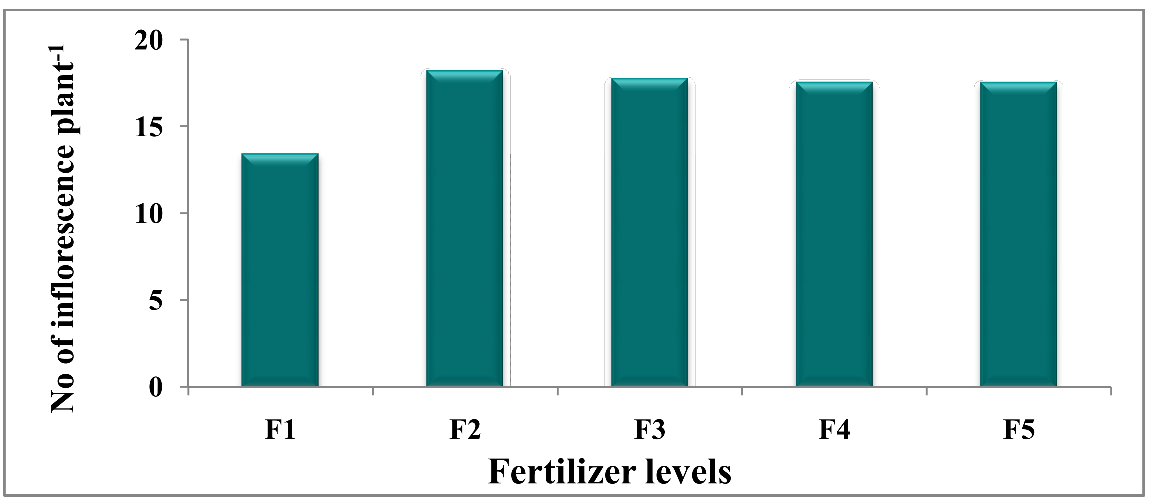
M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

Figure 13. Effect of sowing methods on number of inflorescence plant^{-1} of quinoa ($LSD_{(0.05)}$ = NS).

From broadcast sowing method (M_1) numerically the maximum number of inflorescence plant^{-1} (17.64) was found and from bed sowing method (M_3), the lowest value (16.33) was recorded. Though Ali *et al*. (2020) found that in first season flat line sowing method (FLS) and in second season bed sowing method (BS) resulted in highest number of inflorescence plant^{-1} of quinoa.

4.7.2 Effect of fertilizer levels

Number of inflorescence plant^{-1} of quinoa was significantly influenced by fertilizer levels at harvest (Figure 12 and Appendix XI). From figure 12, it was found that among four levels of fertilizer management (excluding F_1), F_2 fertilizer management caused slight increase in the number of inflorescence plant^{-1} than F_3, F_4 and F_5 fertilizer levels. Except F_1 (control) fertilizer management, all other levels of fertilizer produced statistically similar number of inflorescence plant^{-1}.



F_1= No fertilizer
F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}
F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1} + 10 t cowdung ha^{-1}
F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

Figure 14. Effect of fertilizer levels on number of inflorescence plant^{-1} of quinoa ($LSD_{(0.05)}$ = 1.253).

The highest number of inflorescence plant^{-1} (18.14) resulted in F_2 fertilizer level (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}), which was statistically similar with the number of inflorescence values plant^{-1} of 17.69, 17.47 and 17.46

found in F_3 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}), F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}) and F_5 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}) fertilizer levels, respectively. Naik *et al.* (2020) reported that 150:75:75 kg NPK ha^{-1} recorded the highest total number of panicles $plant^{-1}$ (17.63) and the result was quite similar with the result of the present study. The lowest value (13.34) was found in F_1 (control) at harvest in this experiment.

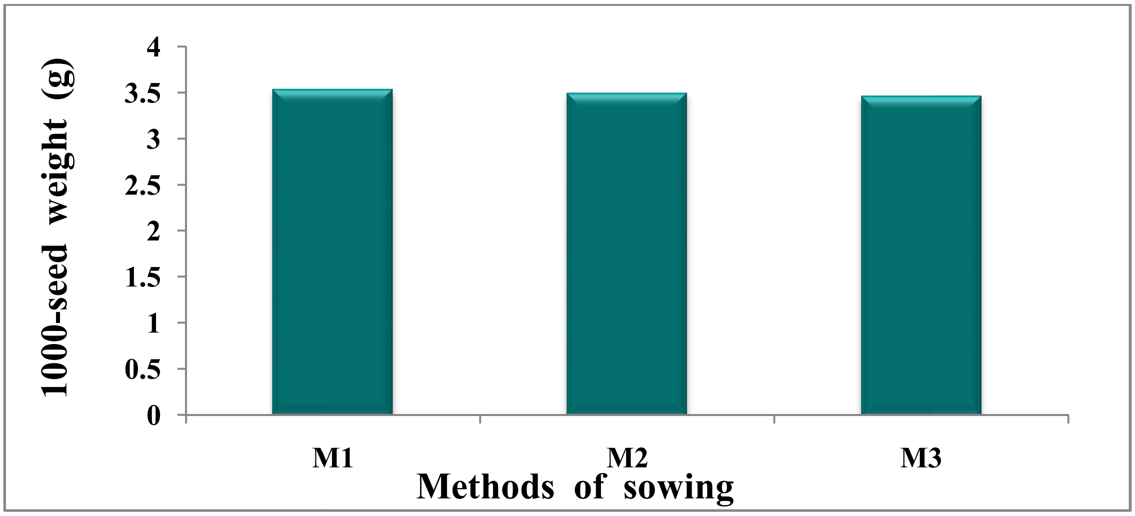
4.7.3 Interaction effect of sowing methods and fertilizer levels

The number of inflorescences $plant^{-1}$ produced by at various growth stages was significantly influenced by the combination between sowing techniques and fertilizer contents (Table 6 and Appendix XI). At harvest the maximum value of number of inflorescence $plant^{-1}$ (20.37) was observed in broadcast sowing method (M_1) interacting with 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1} (F_2) fertilizer level, and the value was statistically at par with M_1F_3 (18.80). The minimum number of inflorescence $plant^{-1}$(12.50) was found in line sowing method (M_2) and no fertilizer (F_1) level interaction (M_2F_1), which was statistically similar with the interaction value of M_1F_1 (14.07) and M_3F_1 (13.47).

4.8 1000-seed weight

4.8.1 Effect of sowing methods

The 1000-seed weight did not show any significant variation for different sowing methods (Figure 15 and Appendix XII). Yet, numerically the maximum 1000-seed weight (3.52 g) was recorded in broadcast sowing method (M_1) and the minimum value (3.45 g) was found in bed sowing method (M_3). Dao *et al.* (2020) also found no variation of 1000-seed weight of quinoa for different sowing methods that agreed with the present findings. But Ali *et al.* (2020) stated that bed sowing method resulted in highest value of 1000-seed weight of quinoa, but this statement was not similar with the result of 1000-seed weight of present study.

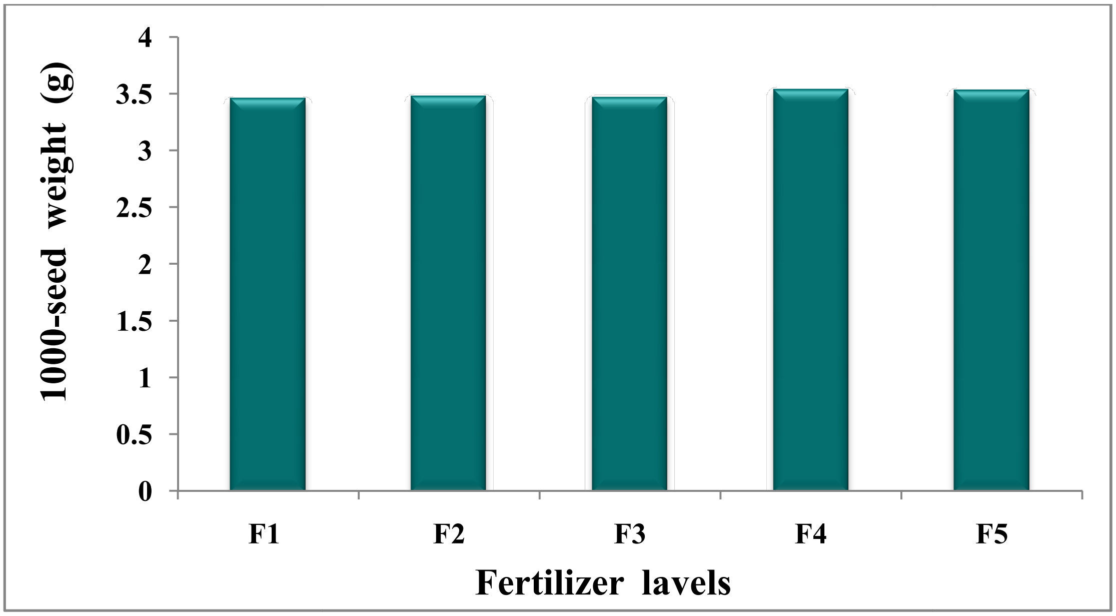


M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

Figure 15. Effect of sowing methods on 1000-seed weight of quinoa ($LSD_{(0.05)}$ = NS).

4.8.2 Effect of fertilizer levels

Different fertilizer levels showed no significant variation in 1000-seed weight (Figure 16 and Appendix XII). From figure 16, it was found that all most all the fertilizer level brought approximately same value, but among them F_4 did slightly better. Though all the fertilizer level resulted in statistically similar 1000-seed weight value, yet numerically the maximum 1000-seed weight (3.53 g) was observed in F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}) and the lowest value (3.45 g) was found in F_1 (control).



F_1= No fertilizer
F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}
F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1} + 10 t cowdung ha^{-1}
F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

Figure 16. Effect of fertilizer levels on 1000-seed weight of quinoa ($LSD_{(0.05)}$ = NS).

In the present experiment F_4 fertilizer level produced only 2.32 % higher 1000-seed weight than F_1 (control). Basra *et al.* (2014) stated that thousand grain weight of quinoa (2.10 g) was not affected by nitrogen fertilization from 0 to 120 kg ha^{-1}. The opinion is quite similar with the present study result.

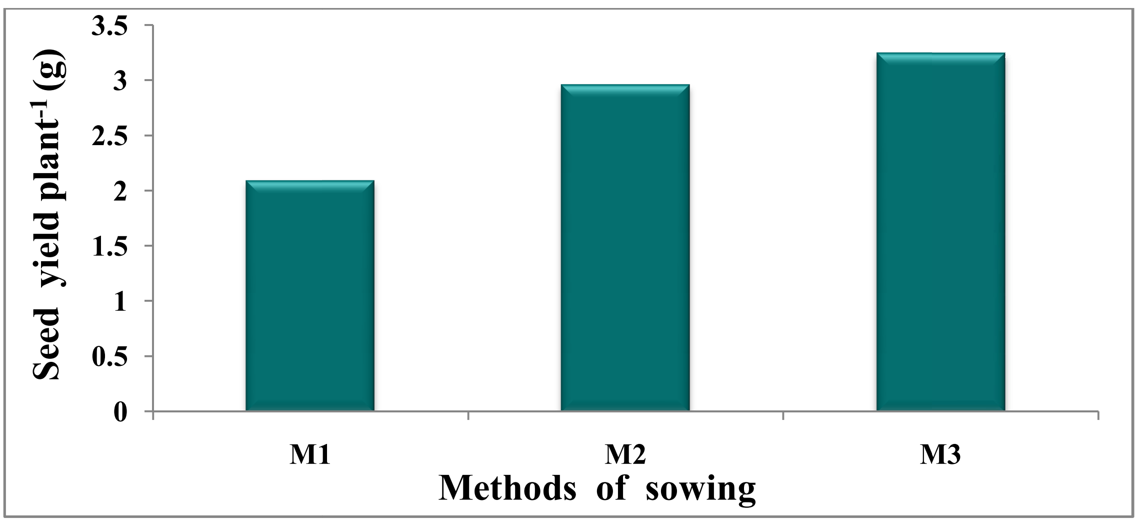
4.8.3 Interaction effect of sowing methods and fertilizer levels

From the interactions between sowing methods and fertilizer levels, they did not show any significant different result on 1000-seed weight (Table 6 and Appendix XII). All the values from different interactions were statistically similar, yet M_1F_4, the treatment combination between broadcast sowing method and 150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1} fertilizer level gave numerically the maximum value of 1000-seed weight (3.58 g) and bed sowing method (M_3) interacting with 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1} (F_2) fertilizer level, provided the minimum value (3.37 g) of 1000-seed weight numerically.

4.9 Seed yield plant^{-1}

4.9.1 Effect of sowing methods

Sowing methods had significant effect on seed yield of quinoa (Figure 17 and Appendix XII). From figure 17, it was visible that bed sowing method (M_3) performed better comparing to broadcast (M_1) and line sowing method (M_2).



M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

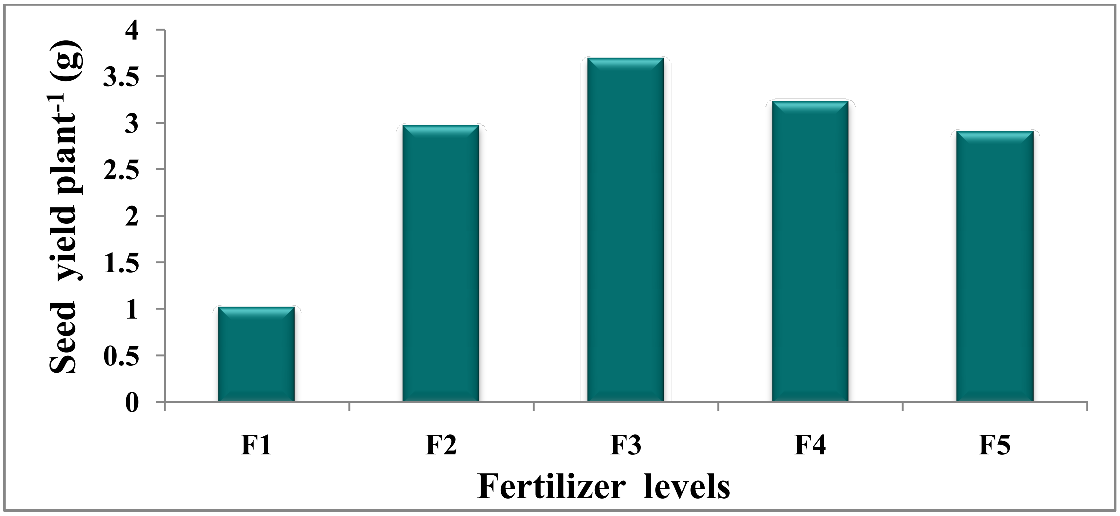
Figure 17. Effect of sowing methods on seed yield plant^{-1}of quinoa ($LSD_{(0.05)}$ = 0.892).

The maximum value (3.23 g plant^{-1}) was obtained from bed sowing method (M_3) and that was statistically similar with 2.944 g ha^{-1}, recorded in line sowing method (M_2). In case of minimum seed yield value (2.078 g plant^{-1}), it was observed in broadcast sowing method (M_1) and the value was statistically at par with 2.944 g plant^{-1}, obtained from line sowing method (M_2). In bed sowing method seed yield was the maximum (3.23 g $plant^{-1}$) and that might be because roots of quinoa plants' had developed better due to better soil aeration and tilth condition. Bakht *et al*. (2011) and Dao *et al*. (2020) also reported higher yield of quinoa in ridge sowing mainly due to in- depth tillage and soil aeration when preparing the ridges that supported the development of root system.

4.9.2 Effect of fertilizer levels

Different fertilizer levels had significant effect on seed yield of quinoa (Figure 18 and Appendix XII). From figure 18, it was clearly visible that F_3 showed better performance than others. The highest (3.68 g $plant^{-1}$) seed yield was recorded in F_3 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}), which was statistically similar with the seed yield of 3.22 g $plant^{-1}$ that resulted in F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}). The lowest seed yield (1.00 g $plant^{-1}$) was recorded in F_1 (control). Geren (2015) found that the highest seed yield (11.20 g $plant^{-1}$) was obtained from 150 kg N ha^{-1}, whereas the lowest yield (2.40 g $plant^{-1}$) was recorded in control plots. Shams (2012) reported that fertilizing quinoa with 360 kg N ha^{-1} resulted in maximum seed yield ($plant^{-1}$) of 10.07 g and 8.18 g. These findings were quite similar with the results of the present experiment.

Here, focusing carefully on the results of the present study it could be found that, as F_3 fertilizer level included all nitrogen, phosphorous, potassium, sulfur, zinc and cowdung, highest seed yield (3.68 g $plant^{-1}$) production in F_3 was logical. But comparing the number of sources of nutrient elements in F_4 it could be found that, it contained only nitrogen, phosphorous and potassium with cowdung (quantity same as F_3) and it resulted in 3.22 g seed yield $plant^{-1}$, which was statistically similar with the highest seed yield (3.68 g $plant^{-1}$) producer F_3 fertilizer level. That means by using less synthetic fertilizer with cowdung, higher yields can be achieved. And this practice was at the same time both economically and environmentally sound. Fawy *et al*. (2017) also stated that adding organic manure into the soil resulted in 9.4% increase in weight of seeds plant^{-1} (g).



F_1= No fertilizer
F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}
F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}
F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

Figure 18. Effect of fertilizer levels on seed yield plant^{-1}of quinoa ($LSD_{(0.05)}$ = 0.627).

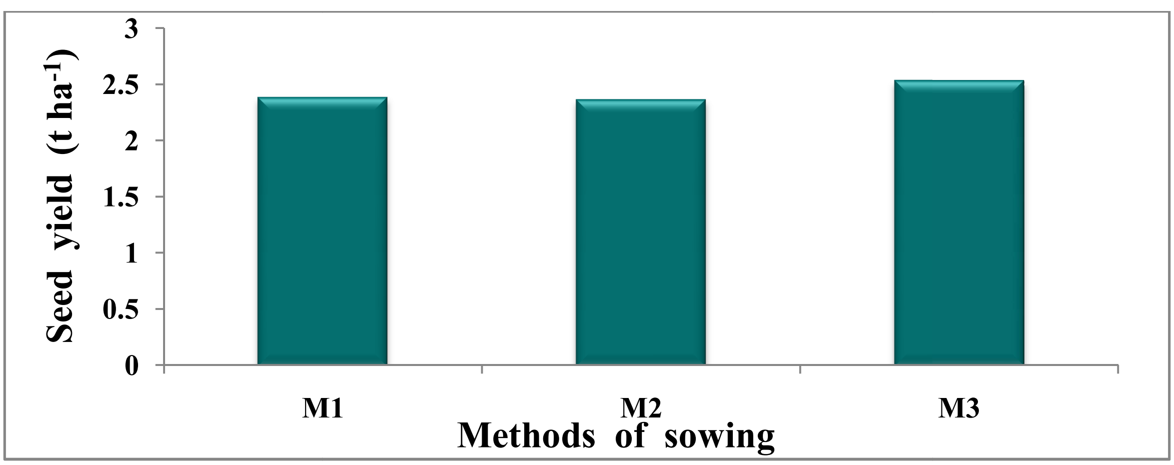
4.9.3 Interaction effect of sowing methods and fertilizer levels

The interaction between sowing methods and fertilizer levels showed significant effect on the values of seed yield plant^{-1} (Table 6 and Appendix XII). Numerically the best result (4.46 g plant^{-1}) was found in line sowing method (M_2) and 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1} (F_3) interaction (M_2F_3), which was statistically similar with M_3F_3 (4.36 g plant^{-1}), M_3F_4 (3.90 g plant^{-1}), M_2F_4 (3.41 g plant^{-1}), M_3F_5 (3.31 g plant^{-1}) and M_3F_2 (3.30 g plant^{-1}). On the other hand, the lowest result (0.71 g plant^{-1}) was found in line sowing method (M_2) and control (F_1) fertilizer level combination, which was statistically similar with M_1F_1 (1.03 g plant^{-1}) and M_3F_1 (1.28 g plant^{-1}). It could be said that whatever the sowing method was, here only control fertilizer level (F_1) was the reason behind for the lowest seed yield in the interaction effect. From Table 6 it could also be seen that, seed yield was comparatively poor in all the fertilizer levels (F_1, F_2, F_3, F_4 and F_5) combining with broadcast sowing method (M_1).

4.10 Seed yield

4.10.1 Effect of sowing methods

Seed yield did not show any significant difference for different sowing methods (Figure 19 and Appendix XIII). However, numerically the highest seed yield (2.52 t ha^{-1}) was recorded in bed sowing method (M_3) and the lowest seed yield (2.35 t ha^{-1}) was found in line sowing method (M_2). Figure 19 supports this statement too. Ali *et al.* (2020) also stated that bed sowing method provided better grain yield comparing to other sowing methods. But according to Bakht *et al.* (2011) minimum yields were found in broadcasting and this statement does not match with the result of the present study.

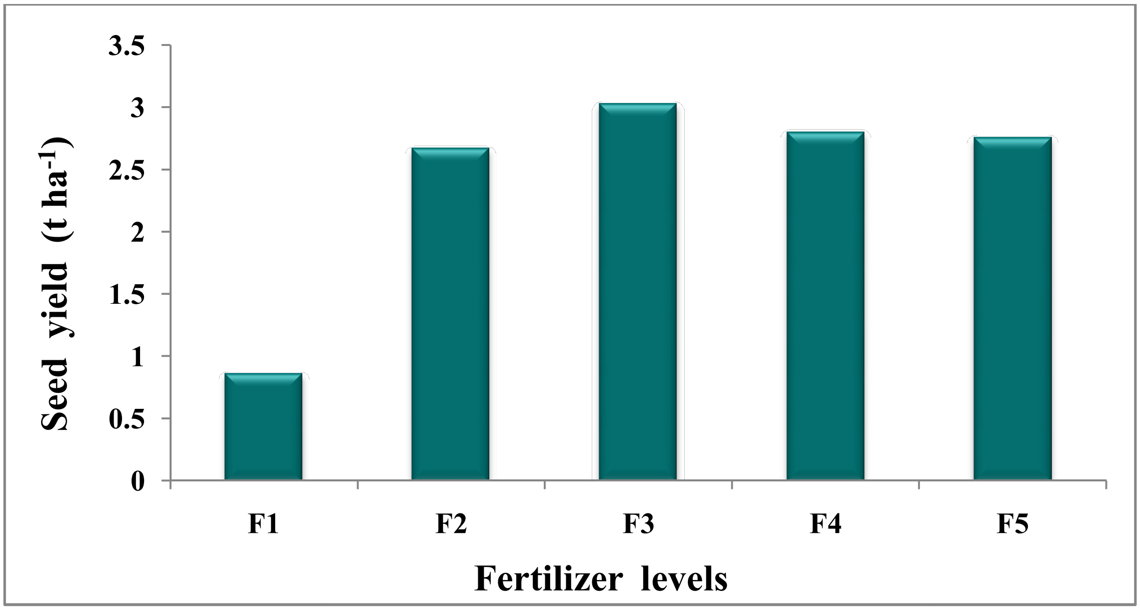


M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

Figure 19. Effect of sowing methods on seed yield of quinoa ($LSD_{(0.05)}$ = 0.473).

4.10.2 Effect of fertilizer levels

Seed yield of quinoa was significantly influenced by fertilizer (Figure 20 and Appendix XIII). From figure 20, it was found that F_3 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}) fertilizer level showed the highest seed yield value (3.02 t ha^{-1}), which was statistically at par with the seed yield values of 2.79 t ha^{-1} and 2.75 t ha^{-1} resulted in F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}) and F_5 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}) fertilizer levels, respectively. According to Biswas *et al.* (2021) and Geren (2015) maximum seed yield was observed in soil application of 150 kg N ha^{-1} and this statement was completely similar with the findings of the present experiment. As F_3 fertilizer level included all nitrogen, phosphorous, potassium, sulfur, zinc and cowdung providing required nutrients for plants' growth and development, the highest (3.02 t ha^{-1}) seed yield in F_3 was logical. But comparing the number of sources of nutrient elements in F_4 it could be found that, it contained only nitrogen, phosphorous and potassium with cowdung (quantity same as F_3) and it resulted in 2.79 t ha^{-1} seed yield, which was statistically similar with the highest seed yield (3.02 t ha^{-1}), produced in F_3 fertilizer level. That means by using cowdung and less synthetic fertilizer, higher seed yields can be achieved. And this practice was at the same time both economically and environmentally sound. Lavini *et al*. (2014) and Bilalis *et al*. (2012) also stated that combining treatments of N fertilizer with organic amendments significantly increased seed yields of quinoa. The lowest seed yield (0.85 t ha^{-1}) was observed in F_1 (control) fertilizer level in the present study. Biswas *et al.* (2021) also stated the same statement. But according to Afrin (2018) the minimum seed yield (144.40 kg ha^{-1}) was recorded in 50 kg P ha^{-1}. In the present experiment under F_3 and F_4 fertilizer level quinoa plants produced 255% and 194% higher seed yield than control. Biswas *et al.* (2021) stated that 150 kg N ha^{-1} resulted in 117.51% higher yield than control (no nitrogenous fertilizer application).



F_1= No fertilizer
F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}
F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}
F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

Figure 20. Effect of fertilizer levels on seed yield of quinoa ($LSD_{(0.05)}$ = 0.289).

4.10.3 Interaction effect of sowing methods and fertilizer levels

The interaction effect of sowing method and fertilizer level had a significant impact on seed yield (Table 7 and Appendix XIII). The highest seed yield (3.09 t ha^{-1}) was recorded from bed sowing method (M_3) and 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1} (F_3) interaction (M_3F_3), which was statistically similar with most of interaction values including M_1F_3 (3.01 t ha^{-1}), M_2F_3 (2.95 t ha^{-1}), M_3F_4 (2.94 t ha^{-1}), M_2F_4 (2.92 t ha^{-1}), M_3F_5 (2.90 t ha^{-1}), M_1F_5 (2.78 t ha^{-1}), M_2F_2 (2.67 t ha^{-1}), M_1F_2 (2.65t ha^{-1}) and M_3F_2 (2.65 t ha^{-1}). On the other hand, the lowest seed yield was observed in line sowing method (M_2) and control (F_1) fertilizer level interaction (M_2F_1), and the lowest seed yield (0.64 t ha^{-1}) value was statistically similar with M_3F_1 (1.02 t ha^{-1}) and M_1F_1 (0.88 t ha^{-1}).

Table 7. Interaction effect of sowing methods and fertilizer levels on seed yield, straw yield, biological yield and harvest index of quinoa

Treatment combinations	Seed yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
M_1 F_1	0.88 d	0.47 c	1.35 c	65.44 cd
M_1 F_2	2.65 abc	1.16 b	3.81 ab	69.65 ab
M_1 F_3	3.01 ab	1.39 ab	4.40 ab	68.63 abc
M_1 F_4	2.50 c	1.36 ab	4.11 ab	66.90 abcd
M_1 F_5	2.78 abc	1.31 ab	4.09 ab	69.01 abc
M_2 F_1	0.64 d	0.36 c	1.01 c	64.01 d
M_2 F_2	2.67 abc	1.23 b	3.88 ab	68.46 abcd
M_2 F_3	2.95 abc	1.29 ab	4.24 ab	69.55 ab
M_2 F_4	2.92 abc	1.55 a	4.47 a	65.51 bcd
M_2 F_5	2.55 bc	1.19 b	3.74 b	68.25 abcd
M_3 F_1	1.02 d	0.46 c	1.43 c	70.97 a
M_3 F_2	2.65 abc	1.33 ab	3.98 ab	66.52 abcd
M_3 F_3	3.09 a	1.42 ab	4.51 a	68.20 abcd
M_3 F_4	2.94 abc	1.40 ab	4.35 ab	67.70 abcd
M_3 F_5	2.90 abc	1.38 ab	4.28 ab	68.59 abc
$LSD_{(0.05)}$	5.02	0.280	0.694	0.039
CV (%)	12.36	14.43	11.52	3.44

M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

F_1= No fertilizer, F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1},

F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1},

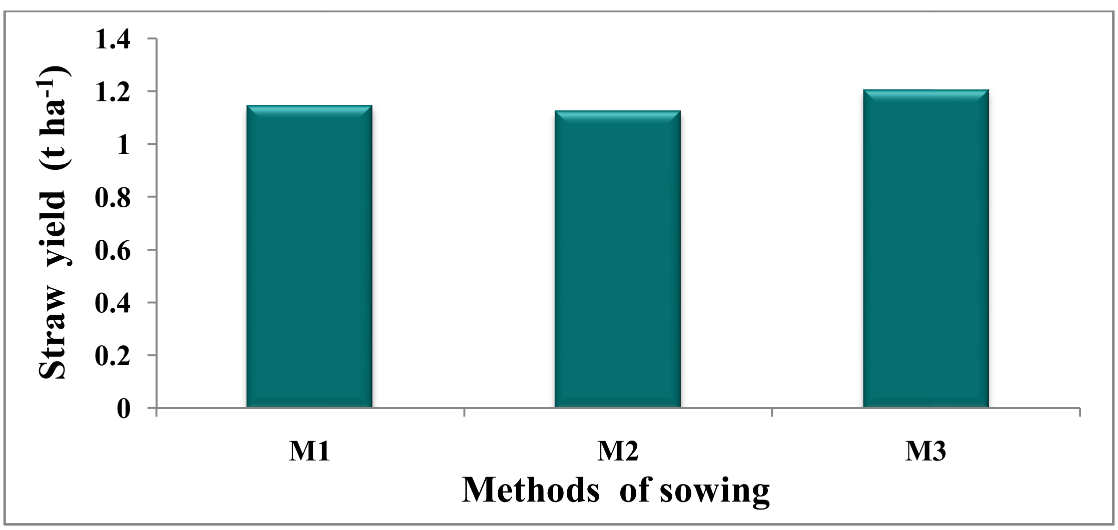
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}, F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

From these results it could be said that, the highest and lowest numerical seed yield values were found in bed sowing method (M_3) and line sowing method (M_2) respectively, but for the highest seed yield value (3.09 t ha^{-1}) fertilizer dose was F_3 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}) and the lowest seed yield (0.64 t ha^{-1}) was found in control fertilizer (F_1). From these interactions result it could also be found that, all three sowing methods contributed in getting statistically similar higher seed yield values, but it was the effect of difference in fertilizer management, that contributed in the variation of seed yield.

4.11 Straw yield

4.11.1 Effect of sowing methods

Different sowing methods showed no statistically significant difference in straw yield (Figure 21 and Appendix XIII). From figure 21, it was observed that bed sowing method (M_3) performed comparatively better than others. At harvest, numerically the maximum value (1.20 t ha^{-1}) was recorded in bed sowing method (M_3) and the minimum value (1.12 t ha^{-1}) was recorded in line sowing method (M_2).

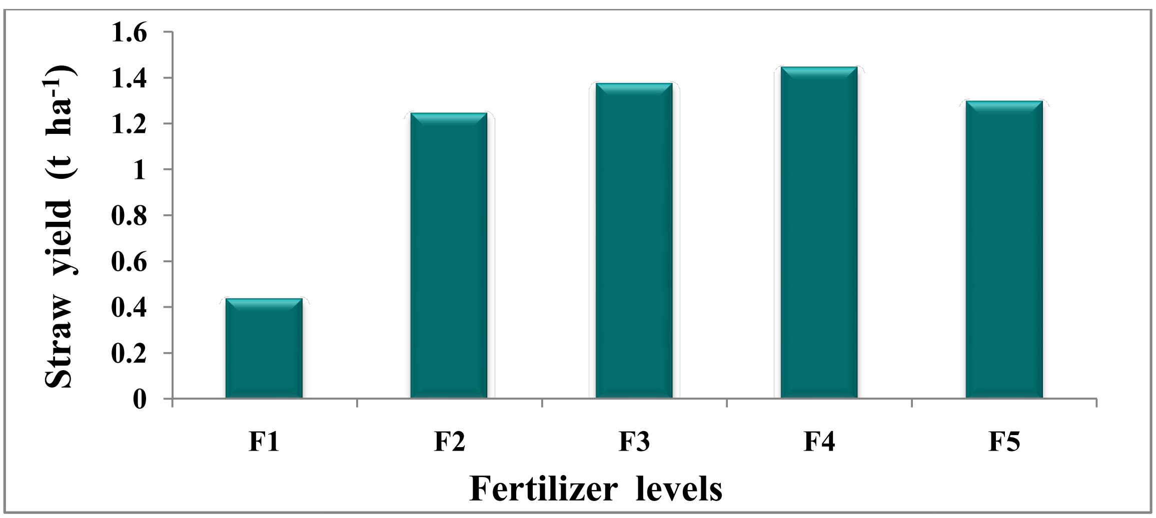


M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

Figure 21. Effect of sowing methods on straw yield of quinoa ($LSD_{(0.05)}$ = 0.284).

4.11.2 Effect of fertilizer levels

Different fertilizer levels expressed significant variation on straw yield of quinoa (Figure 22 and Appendix XIII). From figure 22, it was observed that F_4 fertilizer level performed comparatively better than others. The highest (1.44 t ha^{-1}) straw yield was observed in F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}), which was statistically similar with straw yield values 1.37 t ha^{-1} and 1.29 t ha^{-1} resulted in F_3 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}) and F_5 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}) fertilizer levels, respectively. Afrin (2018) found the maximum straw yield (725.04 kg ha^{-1}) was recorded in 120-50-50 kg NPK ha^{-1}. The increase of fertilizer rate has positive effect on the increment of straw yield. The lowest (0.43 t ha^{-1}) straw yield value was recorded from F_1 (control) in the present study. On the other experiment conducted by Afrin (2018), minimum straw yield (222.29 kg ha^{-1}) was recorded in 50 kg P ha^{-1}.



F_1= No fertilizer
F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}
F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1} + 10 t cowdung ha^{-1}
F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

Figure 22. Effect of different fertilizer levels on straw yield of quinoa ($LSD_{(0.05)}$ = 0.162).

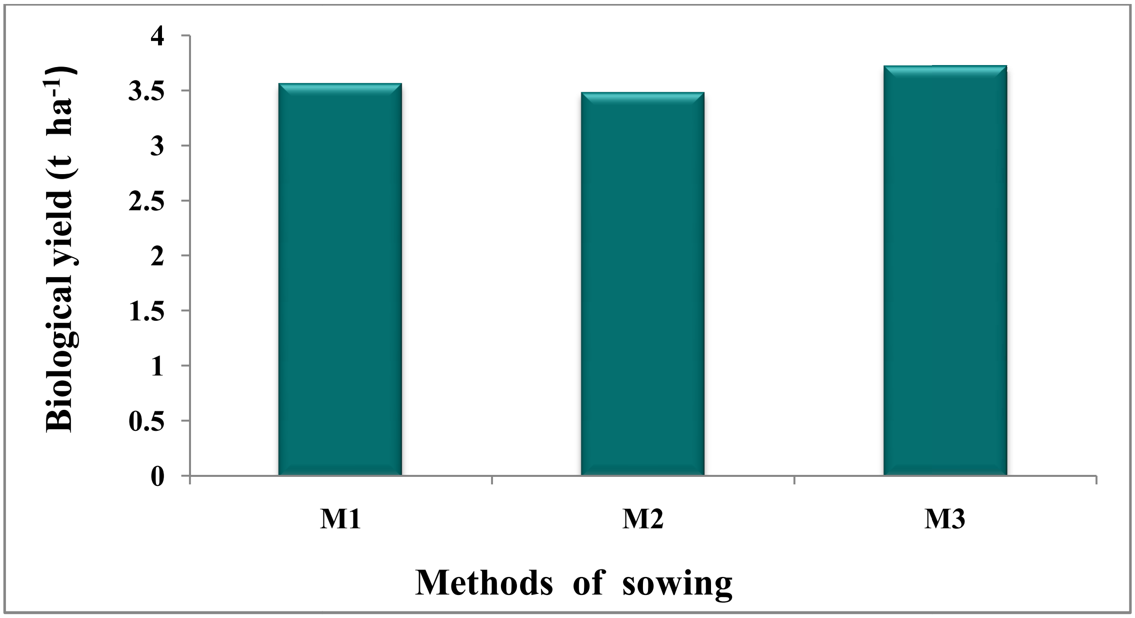
4.11.3 Interaction effect of sowing methods and fertilizer levels

Straw yield significantly varied with different sowing methods and fertilizer levels (Table 7 and Appendix XIII). At harvest, line sowing (M_2) and 150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1} (F_4) fertilizer dose interaction (M_2F_4) resulted in maximum straw yield value (1.55 t ha^{-1}), which was statistically similar with M_3F_3 (1.42 t ha^{-1}), M_3F_4 (1.40 t ha^{-1}), M_1F_3 (1.39 t ha^{-1}), M_3F_5 (1.38 t ha^{-1}), M_1F_4 (1.36 t ha^{-1}), M_3F_2 (1.33 t ha^{-1}), M_1F_5 (1.31 t ha^{-1}) and M_2F_3 (1.29 t ha^{-1}). In case of minimum straw yield value (0.36 t ha^{-1}), it was found in line sowing method (M_2) and no fertilizer (F_1) interaction (M_2F_1) and the value was statistically similar with M_1F_1 (0.47 t ha^{-1}) and M_3F_1 (0.46 t ha^{-1}). Here it was found that, interaction effect of different sowing methods and fertilizer levels on straw yield, irrespective of any sowing method, only control fertilizer (F_1) was showing effect in bringing the lowest value of straw yield.

4.12 Biological yield

4.12.1 Effect of sowing methods

There was no significant effect of sowing methods on biological yield of quinoa (Figure 23 and Appendix XIII). From figure 23, it was visible that bed sowing method (M_3) performed comparatively better. Though all the values were statistically similar still, numerically the maximum biological yield (3.71 t ha^{-1}) was recorded in bed sowing method (M_3) and the minimum (3.47 t ha^{-1}) was found in line sowing method (M_2).

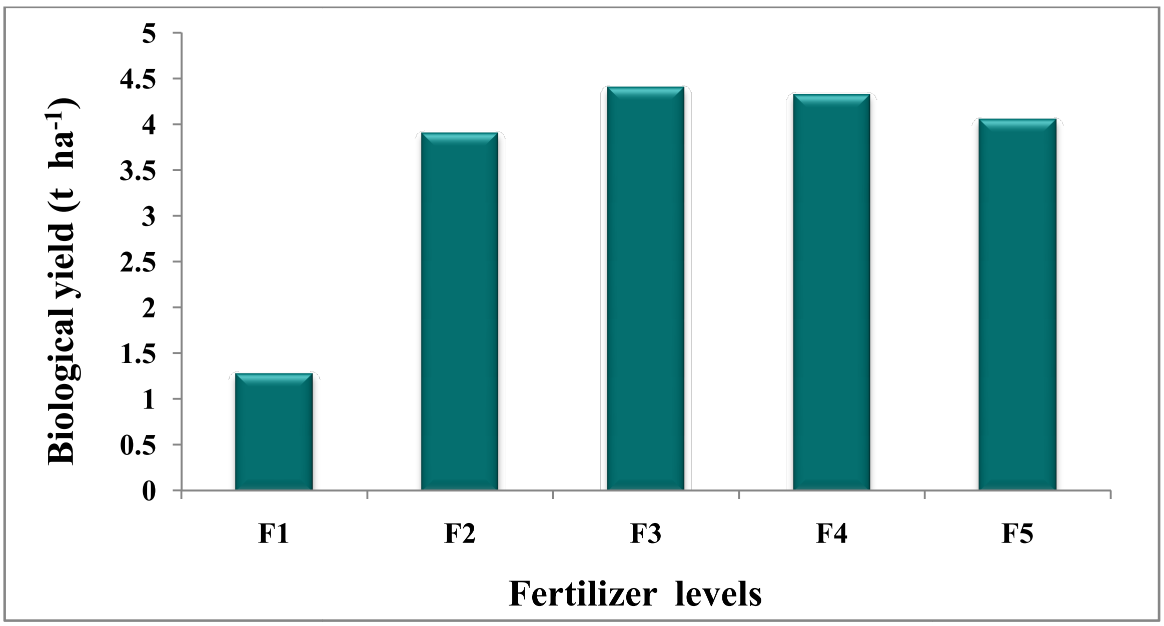


M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

Figure 23. Effect of sowing methods on biological yield of quinoa ($LSD_{(0.05)}$ = NS).

4.12.2 Effect of fertilizer levels

Different fertilizer levels showed statistically significant variation in quinoa plants' biological yield (Figure 24 and Appendix XIII). From figure 24, it was clearly visible that F_3 showed comparatively better result. The maximum biological yield (4.39 t ha^{-1}) was observed in F_3 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}), which was statistically similar with the values of 4.31 t ha^{-1} and 4.04 t ha^{-1} resulted in F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}) and F_5 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}), respectively. Minimum result (1.26 t ha^{-1}) was recorded in F_1 (control). But according to Afrin (2018), the higher biological yield (1721.5 kg ha^{-1}) was found in 120-50-50 kg NPK ha^{-1} and the minimum biological yield 182.4 kg ha^{-1} was recorded in 50 kg P ha^{-1}. From these findings it could be said that, increment in biological yield of quinoa plant has a positive relation with quality and quantity of nutrient elements used during cultivation. In the present study, higher doses of nitrogen, phosphorous, potassium with sulfur, zinc, boron and cowdung ensured higher biological yield. On the other side, comparing the two higher biological yields 4.39 t ha^{-1} and 4.31 t ha^{-1} (statistically similar), resulted in F_3(150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}) and F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}) fertilizer levels in the present experiment, F_4 ensured higher biological yield with less synthetic fertilizer application, which was at the same time both environment friendly and economical.



F_1= No fertilizer
F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}
F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1} + 10 t cowdung ha^{-1}
F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

Figure 24. Effect of fertilizer levels on biological yield of quinoa ($LSD_{(0.05)}$ = 0.40).

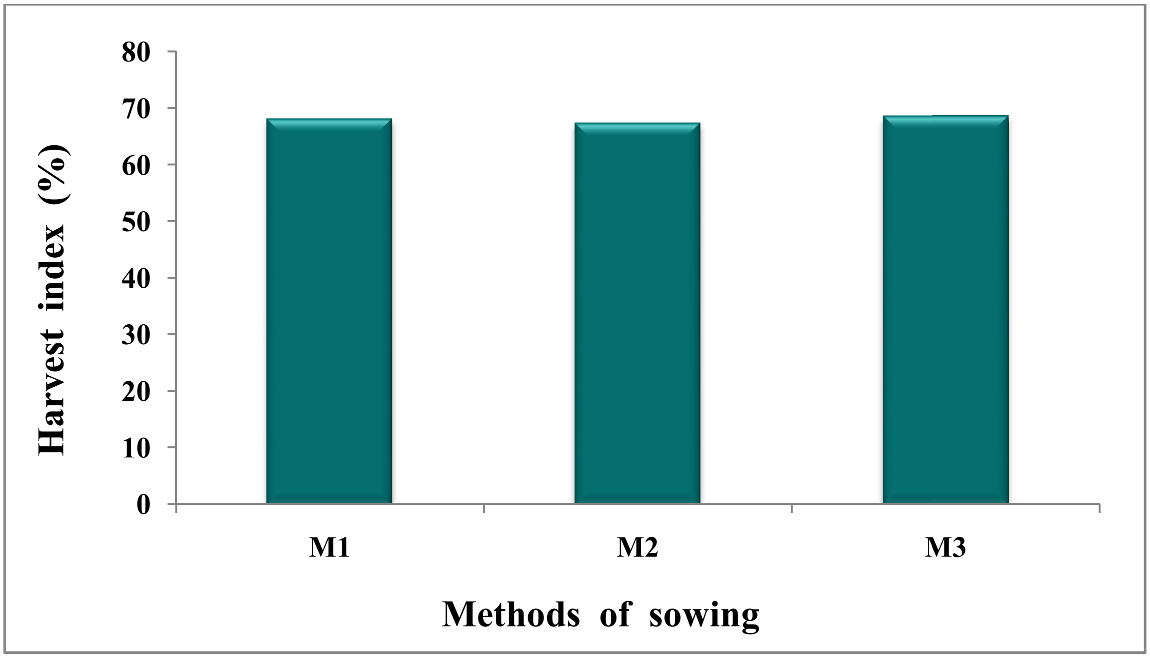
4.12.3 Interaction effect of sowing methods and fertilizer levels

Different sowing methods and fertilizer levels had shown statistically significant level of influence on biological yield (Table 7 and Appendix XIII). The highest value of biological yield (4.51 t ha^{-1}) was found from the interaction between bed sowing method (M_3) and 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1} (F_3) fertilizer level and this value was statistically similar with different interactions including M_2F_4 (4.47 t ha^{-1}), M_1F_3 (4.40 t ha^{-1}), M_3F_4 (4.35 t ha^{-1}), M_3F_5 (4.28 t ha^{-1}), M_2F_3 (4.24 t ha^{-1}), M_1F_4 (4.11 t ha^{-1}), M_1F_5 (4.09 t ha^{-1}), M_3F_2 (3.98 t ha^{-1}), M_2F_2 (3.88 t ha^{-1}) and M_1F_2 (3.81 t ha^{-1}). The lowest biological yield (1.01 t ha^{-1}) was found from the combined effect of line sowing method (M_2) and control fertilizer (F_1) management, and the value was statistically similar with M_3F_1 (1.43 t ha^{-1}) and M_1F_1 (1.35 t ha^{-1}).

4.13 Harvest index

4.13.1 Effect of sowing methods

Sowing methods did not show any significant variation on quinoa plants' harvest index (Figure 25 and Appendix XIII). But from figure 25, it was visible that bed sowing method (M_3) showed comparatively better performance. The harvest index values observed in different sowing methods were 67.93, 67.16 and 68.37%. Though these values were statistically similar, yet numerically the maximum harvest index value (68.37%) was found in bed sowing method (M_3) and the minimum one (67.16%) was observed in line sowing method (M_2). Ali *et al.* (2020) also stated that bed sowing method showed the best result in case of harvest index of quinoa.

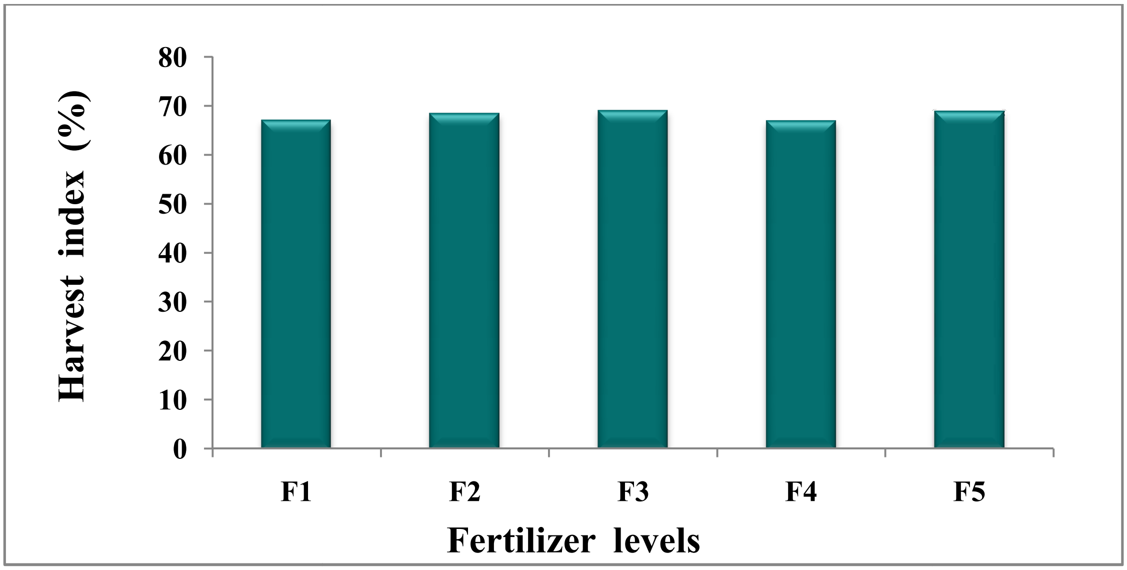


M_1= Broadcast sowing method, M_2= Line sowing method, M_3= Bed sowing method

Figure 25. Effect of sowing methods on harvest index of quinoa ($LSD_{(0.05)}$ = NS).

4.13.2 Effect of fertilizer levels

Different fertilizer level showed no significant difference in harvest index of quinoa (Figure 26 and Appendix XIII). Though all the harvest index values were statistically similar, yet among them F_3 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}) fertilizer level ensured numerically the maximum harvest index of 68.79% and the minimum harvest index value (66.70%) was recorded in F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}).



F_1= No fertilizer
F_2= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}
F_3= 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1}
F_4= 150-100-100 kg N, P_2O_5, K_2O ha^{-1} + 10 t cowdung ha^{-1}
F_5= 150-100-100 kg N, P_2O_5, K_2O ha^{-1}

Figure 26. Effect of fertilizer levels on harvest index of quinoa ($LSD_{(0.05)}$ = NS).

4.13.3 Interaction effect of different sowing methods and fertilizer levels

Interaction effect between sowing methods and fertilizer levels showed significant impact on quinoa plants' harvest index value (Table 7 and Appendix XIII).The maximum value of harvest index (70.97%) was observed in between bed sowing method (M_3) and control fertilizer (F_1) level interaction (M_3F_1), and the value was statistically similar with all the other interaction values except, M_1F_1 (65.44%), M_2F_1 (64.01%) and M_2F_4 (65.51%). On the other side, the lowest harvest index value (64.01%) was recorded from the line sowing method (M_2) and control fertilizer (F_1) interaction (M_2F_1), which was statistically similar with all other interaction values of harvest index except M_3F_1 (70.97%), M_1F_2 (69.65%), M_2F_3 (69.55%), M_1F_5 (69.01%) and M_3F_5 (68.59%). From the results it was observed that, in both highest (70.97%) and lowest (64.01%) numerical values of harvest index, the common factor was control fertilizer management (F_1); the highest value of harvest index was recorded in M_3 (bed sowing method) and the lowest value was from M_2 (line sowing method). Higher harvest index (87.00%) of quinoa was also reported by Rojas (2003) and 69% harvest index by Thiam *et al.* (2021).

CHAPTER V

SUMMARY AND CONCLUSION

The field experiment was conducted at the experimental field of Sher-e-Bangla Agricultural University, Dhaka, during the period from November 2021 to February 2022 to study growth and yield of quinoa (*Chenopodium quinoa* Willd.) as affected by planting method and fertilizer management under the Modhupur Tract (AEZ-28). The factors under study comprised of (A) Sowing methods (3 levels): M_1- Broadcast method , M_2- Sowing in line and M_3- Sowing in bed which were kept in main plots and (B) Fertilizer management (5): F_1- No fertilizer (control), F_2- 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}, F_3- 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1} and F_4- 150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1} and F_5- 150-100-100 kg N, P_2O_5, K_2O which were kept in sub plots. The experiment was conducted in split plot design which was replicated thrice. Data on different growth stage, yield contributing characters and yield were recorded and statistically significant variation was observed for different treatment. The final land preparation was done on November 12, 2021 and layout was made on November 13, 2021 according to the experimental design. TSP, MoP, gypsum, zinc sulfate, boric acid, cowdung and one third of urea were applied during the final land preparation. Rest urea was applied as top dressing at 30 and 50 DAS. The sowing date was on 17th November 2021 and seeds were sown by following broadcasting (M_1), line sowing (M_2) and bed sowing method (M_3). Five quinoa plants from each treatment were randomly selected from each plot (excluding boarder lines) and marked with red cotton thread for the purpose of data collection. The data on growth parameters *viz.* plant height (cm) at 20 DAS, 40 DAS, 60 DAS and at harvest; number of leaves $plant^{-1}$ at 20 DAS, 40 DAS and 60 DAS; number of branches $plant^{-1}$ at 40 DAS, 60 DAS and at harvest; dry weight $plant^{-1}$ (g) at 25 DAS, 55 DAS and at harvest; SPAD value at 55 DAS and root length (cm) at harvest were recorded. And for crop yield and yield attributing characters *viz*. number of inflorescence plant^{-1}, 1000-seed weight (g), seed yield (g plant^{-1}), seed yield (t ha^{-1}) and straw yield (t ha^{-1}) data were recorded at harvest. Thousand 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 sowing methods had significant effect on different growth parameters except plant height (at 60 DAS and at harvest), number of leaves plant^{-1} (at 40 DAS), number of branches plant^{-1} (at 40 DAS and at harvest), dry weight g plant^{-1} (at 25 DAS, 55 DAS and at harvest) and SPAD value (at 55 DAS). In case of plant height, at 20 DAS and 40 DAS, line sowing method (M_2) and broadcast sowing method (M_1) resulted in highest plant heights of 8.15 cm and 32.44 cm respectively; whereas at 20 DAS the lowest plant height (7.31 cm) was found from broadcast sowing method (M_1) and at 40 DAS the lowest plant height (26.82 cm) was found from line sowing method (M_2). At 60 DAS and at harvest, numerically the highest plant heights (47.2 cm and 45.66 cm) resulted in bed sowing method (M_3) and the lowest plant heights (43.18 cm and 40.68 cm) came from line sowing method (M_2), respectively. Same as plant height, at 20 DAS the maximum number of leaves plant^{-1} (8.55) was found from line sowing method (M_2) and minimum number of leaves plant^{-1} (7.93) was recorded in broadcast sowing method (M_1). By observing same trend at 40 DAS and 60 DAS, maximum number of leaves plant^{-1} (50.71 and 41.51) and minimum number of leaves plant^{-1} (43.25 and 32.72) were found in bed sowing method (M_3) and broadcast sowing method (M_1) respectively. In case of number of branches plant^{-1}, at 40 DAS bed sowing method showed the maximum value (11.92) and at 60 DAS and harvest, broadcast sowing method resulted in maximum values of 17.22 and

15.28 respectively. In all three studied dates (40 DAS, 60 DAS and at harvest) the lowest value of number of branches plant^{-1} (11.32, 16.02 and 15.28) was found in line sowing method (M_2). The highest root length (11.58 cm) was recorded in line sowing method (M_2) and minimum value (9.25 cm) was found in broadcast sowing method (M_1). At 25 DAS and 55 DAS, the maximum dry weight values (0.05 g plant^{-1} and 4.97 g plant^{-1}) resulted in broadcast sowing method (M_1); whereas the minimum values (0.04 g plant^{-1} and 4.25 g plant^{-1}) were recorded in bed sowing (M_3) and line sowing (M_2) respectively. But at harvest, maximum dry weight value (7.04 g plant^{-1}) and at 55 DAS maximum SPAD value was (61.42) observed in bed sowing method (M_3) but minimum dry weight value (5.95 g plant^{-1}) was observed in broadcast method (M_3) and minimum SPAD value (59.81) was found in line sowing method (M_2).

Different sowing methods did not show any statistically significant effect on quinoa plants' yield and yield attributing characters like number of inflorescence plant^{-1}, 1000- seed weight, seed yield (t ha^{-1}), straw yield (t ha^{-1}), biological yield (t ha^{-1}), harvest index (%) except seed yield (g plant^{-1}). Broadcast sowing method resulted (M_1) the highest number of inflorescence plant^{-1} (17.64) and from bed sowing method (M_3), the lowest value (16.33) was recorded. At harvest, maximum straw yield (1.20 t ha^{-1}), seed yield (3.23 g plant^{-1} and 2.52 t ha^{-1}), biological yield (3.71 t ha^{-1}) and harvest index (68.369%) values were recorded in bed sowing method (M_3); whereas broadcast sowing method (M_1) ensured second best seed yield (2.37 t ha^{-1}), straw yield (1.14 t ha^{-1}), biological yield (3.05 t ha^{-1}) and harvest index (67.93%) values at harvest and was statistically similar with the highest values resulted in bed sowing method (M_3). Besides these, the minimum seed yield (2.35 t ha^{-1}), straw yield (1.12 t ha^{-1}), biological yield (3.47 t ha^{-1}) and harvest index (67.16%) were observed in line sowing method (M_2). The lowest seed yield (2.08 g plant^{-1}) was observed in broadcast sowing method (M_1). Maximum value of 1000- seed weight (3.52 g) was recorded in broadcast sowing method (M_1) and the minimum value (3.45 g) was found in bed sowing method (M_3).

Different fertilizer levels showed significant effect on quinoa plants' different growth characters. Higher plant heights at 20 DAS (8.39 cm and 8.28 cm), at 40 DAS (33.58 cm and 33.77 cm) and at 60 DAS (51.34 cm and 50.43 cm) were recorded in F_3 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1} + 10 t cowdung ha^{-1}) and F_4 (150-100-100 kg N, P_2O_5, K_2O ha^{-1}+ 10 t cowdung ha^{-1}) fertilizer levels respectively. But at harvest, higher plant heights (48.59 cm and 48.23 cm) were found in F_2 (150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}) and F_4 fertilizer level respectively. In all four studied dates lowest pant height values (6.12 cm, 13.98 cm, 22.77 cm and 21.46 cm) was observed in F_1 (control) fertilizer management. At 20 DAS (8.71 and 8.7) and 60 DAS (45.73 41.84) higher number of leaves $plant^{-1}$ was got from F_3 and F_4 fertilizer levels respectively. At 40 DAS, higher numbers of leaves $plant^{-1}$ (57.84 and 57.42) were got from F_3 and F_2 fertilizer levels. The F_1 (control) fertilizer level showed lowest number of leaves $plant^{-1}$ (7.13, 18.82 and 17.36) in three growth stages. Higher number of branches $plant^{-1}$ at 40 DAS (13.27 and 12.87), 60 DAS (18.11 and 17.44) and at harvest (16.20 and 16.16) was recorded in F_3 and F_4 fertilizer levels respectively; whereas in three studies dates F_1 (control) fertilizer management resulted in minimum number of branches $plant^{-1}$ (7.09, 12.03 and 8.15). At harvest, higher root length values (11.68 cm and 11.54 cm) were recorded in F_4 and F_3 fertilizer level; whereas minimum length of root (8.09 cm) was found in F_1 (control). At 25 DAS, the higher dry weight values (0.049 g $plant^{-1}$ and 0.048 g $plant^{-1}$) was recorded in F_5 and F_3; at 55 DAS, F_3 and F_4 resulted in higher dry weight values (5.60 g $plant^{-1}$ and 5.40 g $plant^{-1}$) and at harvest the higher dry weight values (7.74 g $plant^{-1}$ and 7.65 g $plant^{-1}$) was found in F_2 and F_4 respectively. The lowest dry weight values (0.021 g $plant^{-1}$, 1.87 g $plant^{-1}$ and 2.74 g $plant^{-1}$) was recorded from F_1 (control) in all three studied dates. Higher SPAD values (63.70 and 63.45) was observed in F_3 and F_5 fertilizer level; the lowest value (53.52) was recorded in F_1 (control).

Various fertilizer management levels showed statistically significant effect on quinoa plants' yield and yield attributing characters except 1000-seed weight and harvest index. Higher number of inflorescence plant^{-1} (18.14 and 17.69) was resulted in F_2 and F_3. The maximum 1000-seed weight (3.53 g) was found in F_4. Higher seed yield plant^{-1} values (3.68 g plant^{-1} and 3.22 g plant^{-1}), seed yield (3.02 t ha^{-1} and 2.79 t ha^{-1}) and biological yield values (4.39 t ha^{-1} and 4.31 t ha^{-1}) were found in F_3 and F_4 fertilizer level. Higher straw yield (1.44 t ha^{-1} and 1.37 t ha^{-1}) were found in F_4 and F_3 fertilizer level. The maximum harvest index (68.79%) was found in F_3. The lowest number of inflorescence plant^{-1} (13.34), 1000-seed weight (3.45 g), seed yield (1.00 g plant^{-1}), seed yield (0.85 t ha^{-1}), straw yield (0.43 t ha^{-1}) and biological yield (1.26 t ha^{-1}) were observed in F_1 (control) but the lowest harvest index (66.70%) was observed in $F_{4.}$

Interaction effect of different sowing methods and fertilizer management also significantly affected growth, yield and yield contributing characters of quinoa except 1000-seed weight. Higher plant heights at 20 DAS (8.75 cm) in M_3F_2 and; at 40 DAS (37.10 cm) in $M_1F_{5;}$ at 60 DAS (54 cm) in M_2F_3 and at harvest (51.18 cm) in M_3F_4 were recorded. At 20 DAS (9.23) in M_2F_3; at 40 DAS (65.80) in M_3F_3 and at 60 DAS (54.13) in M_2F_3 higher number of leaves plant^{-1} were found. Higher number of branches plant^{-1} at 40 DAS (14.27) in M_2F_3; at 60 DAS (19.87) in M_1F_2 and at harvest (17.93) in M_1F_2 were observed. At harvest, maximum length of root (12.90 cm), number of inflorescence plant^{-1} (20.37) and SPAD value (65.38) at 55 DAS resulted in M_3F_4, M_1F_2 and M_1F_5 respectively. Maximum dry weight plant^{-1} at 25 DAS (0.06 g plant^{-1}) in M_1F_5; at 55 DAS (6.30 g plant^{-1}) in M_1F_5 and at harvest (8.52 g plant^{-1}) in M_3F_3 were observed. Maximum 1000-seed weight (3.58 g) in M_1F_4, seed yield (4.46 g plant^{-1}) in M_2F_3, seed yield (3.09 t ha^{-1}, 3.01 t ha^{-1} and 2.95 t ha^{-1}) in M_3F_3, M_1F_3 and M_2F_3, straw yield (1.55 t ha^{-1}) in

M_2F_4, biological yield (4.51 t ha^{-1}) in M_3F_3 and highest harvest index (70.97%) in M_3F_1 were recorded at harvest. M_2F_1 resulted in lowest values of plant height (11.89 cm, 18.57 cm and 17.34 cm) at 40 DAS, 60 DAS and at harvest, lowest numbers of leaves $plant^{-1}$ (17.13 and 13.60) at 40 DAS and 60 DAS, lowest numbers of branches $plant^{-1}$ (5.40, 11.50 and 7.27) at all three studied dates, lowest dry weight (2.58 g $plant^{-1}$) and lowest SPAD value (52.38) at 55 DAS. At harvest, lowest values of number of inflorescence $plant^{-1}$(12.50), seed yield (0.71 g $plant^{-1}$), seed yield (0.64 t ha^{-1}), straw yield (0.36 t ha^{-1}), biological yield (1.01 t ha^{-1}) and harvest index (64.01%) was also found in M_2F_1. Besides these, the lowest plant height (5.17 cm) at 20 DAS, numbers of leaves $plant^{-1}$ (6.40) at 20 DAS, minimum root length (7.23 cm) and dry weight at 25 DAS (0.015 g $plant^{-1}$) were recorded in M_1F_1. At 55 DAS, the lowest dry weight value (1.51g $plant^{-1}$) and at harvest the lowest 1000- seed weight (3.37 g) were found in M_3F_1 and M_3F_2 respectively.

Keeping in view the limitations of present investigation that, it was conducted for only one cropping season. The following conclusion can be drawn:

- The highest number of branches $plant^{-1}$ (at 60 DAS and at harvest) and number of inflorescence $plant^{-1}$ (at harvest) observed in broadcast sowing method (M_1). But bed sowing method resulted in highest SPAD value (at 55 DAS), plant height (cm), dry weight (g $plant^{-1}$) and seed yield value (g $plant^{-1}$) at harvest and highest number of leaves $plant^{-1}$ at 40 DAS and 60 DAS. Though maximum straw yield (t ha^{-1}), seed yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index (%) values were recorded in bed sowing method (M_3) but in all these parameters broadcast sowing method (easy to perform and less laborious) ensured second best result and was statistically similar with the highest values found in bed sowing method (M_3). Besides these at harvest, bed sowing method (M_3) ensured only 5%, 5.95%, 17.79% and 0.65% higher values of straw yield (t ha^{-1}), seed yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index (%) than broadcast sowing method (M_1).

- The F_3 fertilizer level resulted in highest plant height (at 20 DAS, 40 DAS and 60 DAS), number of leaves $plant^{-1}$ (at 20 DAS, 40 DAS and 60 DAS), number of branches $plant^{-1}$ (at 40 DAS, 60 DAS and at harvest), dry weight (g $plant^{-1}$) and SPAD value at 55 DAS, seed yield (g $plant^{-1}$), seed yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index values; but at harvest highest plant height, dry weight value and number of inflorescence $plant^{-1}$ were recorded in F_2. On the contrary except harvest index, F_4 fertilizer level ensured second best and statistically similar result in all the studied dates of plant height, number of branches $plant^{-1}$, number of leaves $plant^{-1}$ (at 20 DAS and 60 DAS), dry weight $plant^{-1}$ values (at 55 DAS and at harvest), seed yield (g $plant^{-1}$), seed yield (t ha^{-1}) and biological yield (t ha^{-1}). The F_4 also resulted in highest straw yield (t ha^{-1}) and 1000- seed weight value by containing less synthetic fertilizer compared to F_2 and F_3. In all the growth, yield and yield attributing characters, lowest values were observed in F_1 (control) at all studied dates.
- Interaction of bed sowing method (M_3) with 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1} (F_3) fertilizer level resulted in the highest seed yield (3.09 t ha^{-1}) and biological yield (4.51 t ha^{-1}). Besides, broadcast sowing method (M_1) and F_3 fertilizer level interaction ensured second best seed yield (3.01 t ha^{-1}) and line sowing method (M_2) and F_3 fertilizer level interaction ensured third best seed yield (2.95 t ha^{-1}).
- These results indicated that, F_3 fertilizer level ensured higher seed yield irrespective of different sowing method. Broadcast sowing method was less laborious and easy to practice than bed sowing method. On the other hand, recommended fertilizer dose with cowdung (F_3) not only ensured proper nutrient supply for plant growth, development and better seed yield but also the cowdung included in the fertilizer management enriched soil fertility

and maintained soil health. That is why for higher seed yield, broadcast sowing method (M_1) and 150-100-100-50-10-5 kg N, P_2O_5, K_2O, S, Zn, B ha^{-1}+ 10 t cowdung ha^{-1} (F_3) fertilizer management level combination can be suggested for quinoa cultivation in Bangladesh. But further research under different agroecological zones of Bangladesh is needed to reach a specific conclusion and recommendation.

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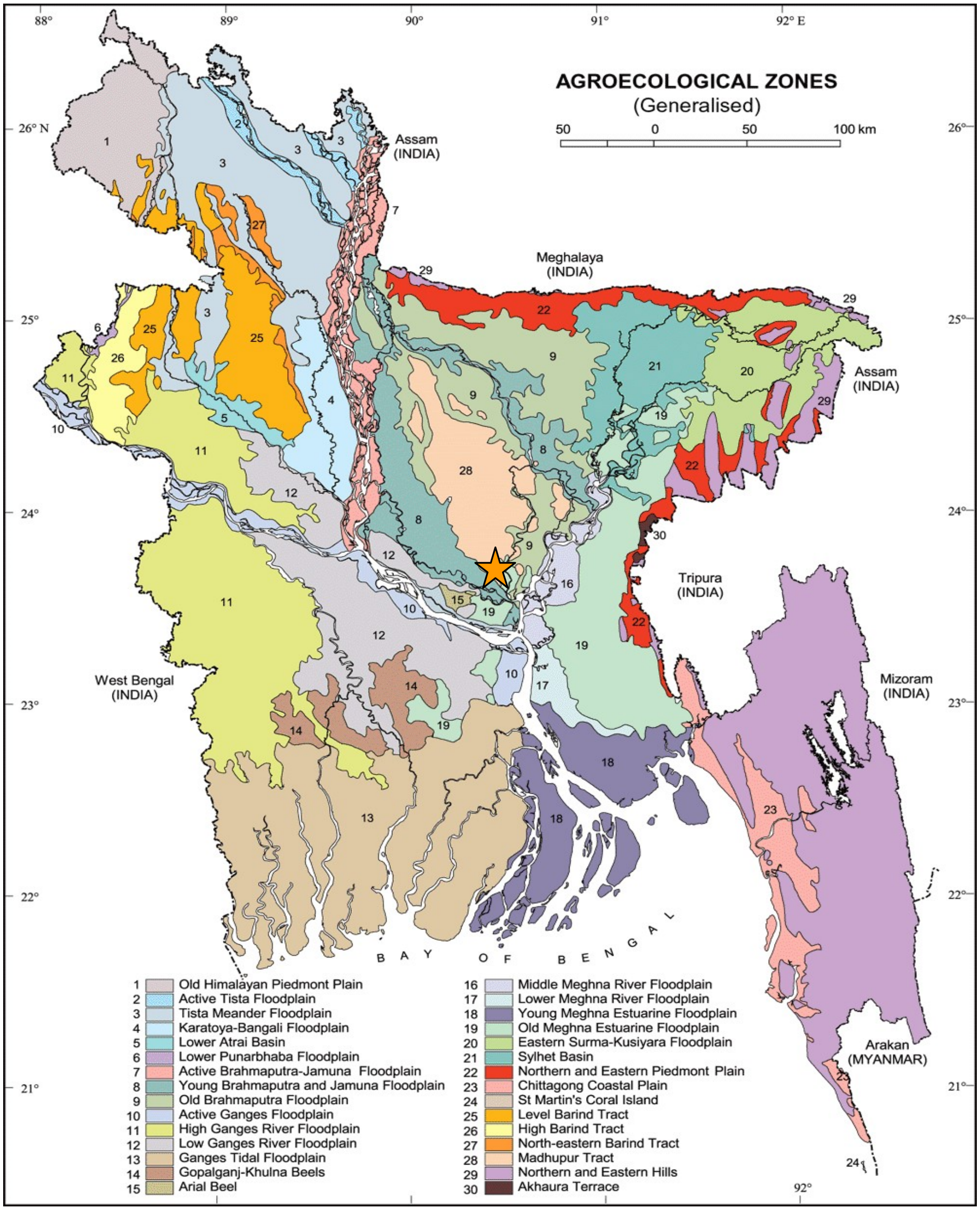
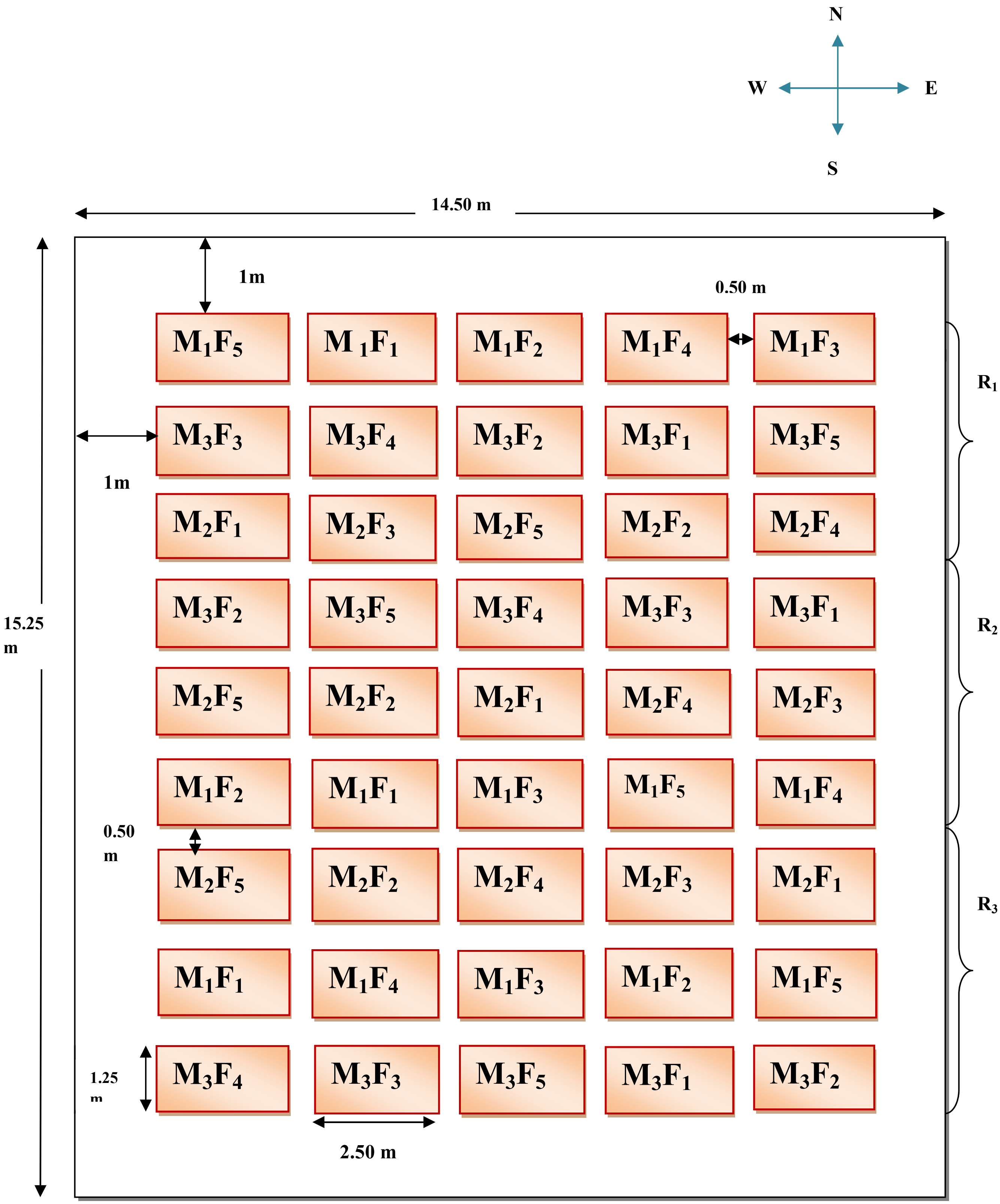
APPENDICES

Appendix I. Map showing the experimental sites under study

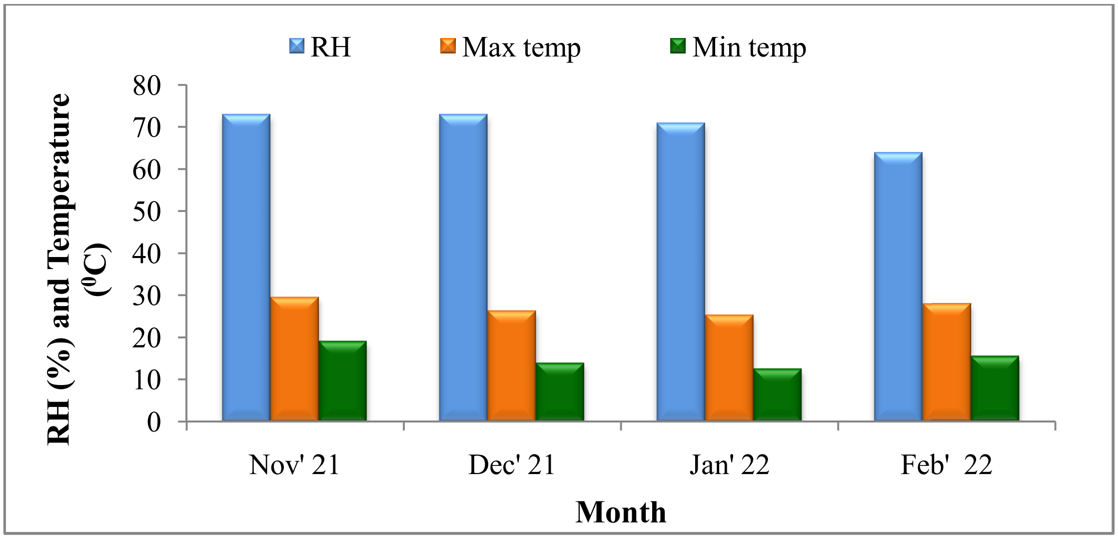


☆ **The experimental site under study**

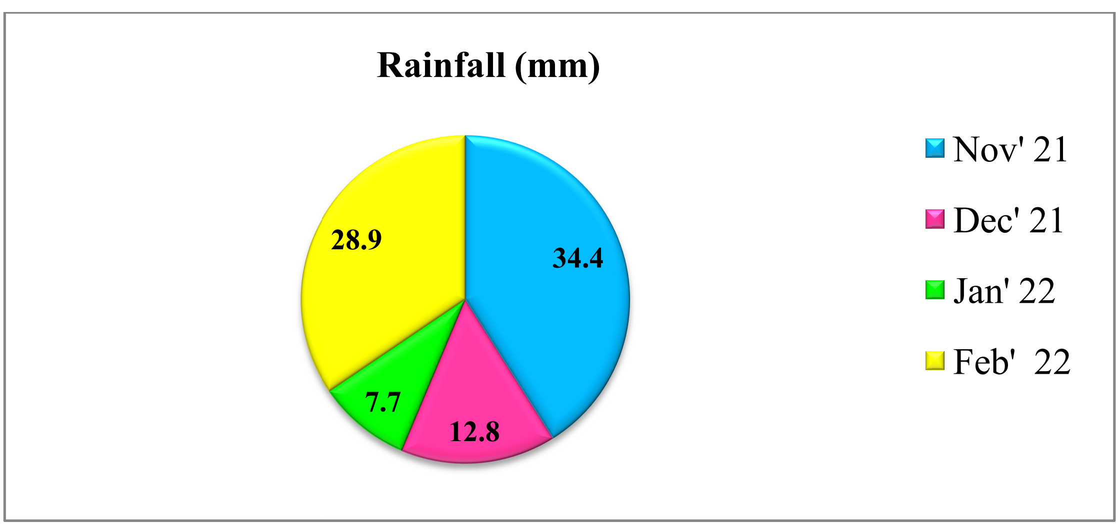
Appendix II. Layout of the experimental field



Appendix III. Monthly average relative humidity, maximum and minimum temperature of the experimental site during the period from November to February, 2021-2022 [Source: Bangladesh Meteorological Department, Agargoan, Dhaka-1212]



Appendix IV. Monthly average rainfall (mm) of the experimental site during the period from November to February, 2021-2022 [Source: Bangladesh Meteorological Department, Agargoan, Dhaka-1212



Appendix V. Mean square values for plant height of quinoa at different crop growth stages

Source of variation	Degrees of freedom	Mean square values of Plant height			
		20DAS	**40 DAS**	**60 DAS**	**At harvest**
Replication	2	0.110907	8.97416	51.9695	22.0018
Sowing method	2	3.30494*	123.843*	66.4407^{NS}	96.0018^{NS}
Error I	4	0.322427	8.57690	31.2839	29.5151
Fertilizer management	4	8.45265*	663.587*	1373.35*	1290.65*
Sowing method ×Fertilizer management	8	0.279273*	7.18321*	24.6442*	26.9320*
Error II	24	.270201	5.94049	13.0950	15.8402

* Significant at 5% level
NS = Non-significant

Appendix VI. Mean square values for number of leaves plant^{-1} of quinoa at different crop growth stages

Source of variation	Degrees of freedom	Mean square values Number of leaves plant^{-1}		
		20 DAS	**40 DAS**	**60 DAS**
Replication	2	0.702000	36.6515	54.7982
Sowing method	2	1.706000*	241.260 NS	290.011*
Error I	4	0.940000	91.1542	30.0302
Fertilizer management	4	4.16522*	2473.65*	1139.11*
Sowing method ×Fertilizer management	8	0.259889*	76.3329*	94.2238*
Error II	24	0.176667	37.9367	42.5407

* Significant at 5% level
NS = Non-significant

Appendix VII. Mean square values for number of branches plant^{-1} of quinoa at different crop growth stages

Source of variation	Degrees of freedom	Mean square values		
		Number of branches plant^{-1}		
		40 DAS	60 DAS	At harvest
Replication	2	3.7342	3.3136	2.659
Sowing method	2	1.3556^{NS}	5.8909*	7.800^{NS}
Error I	4	2.5222	0.0726	1.927
Fertilizer management	4	59.6591*	58.8959*	112.715*
Sowing method ×Fertilizer management	8	3.4044*	1.2434*	2.937*
Error II	24	2.5673	1.5946	.731

* Significant at 5% level
NS = Non-significant

Appendix VIII. Mean square values for root length of quinoa

Source of variation	Degrees of freedom	Mean square values
		Root length
		At harvest
Replication	2	2.4604
Sowing method	2	26.7477*
Error I	4	0.6189
Fertilizer management	4	20.7649*
Sowing method ×Fertilizer management	8	0.6839*
Error II	24	1.1645

* Significant at 5% level

Appendix IX. Mean square values of dry weight plant^{-1}of quinoa at different crop growth stages

Source of variation	Degrees of freedom	Mean square values		
		Dry weight plant^{-1}		
		25 DAS	55 DAS	At harvest
Replication	2	4.740	1.868	5.784
Sowing method	2	1.323^{NS}	2.050^{NS}	5.258^{NS}
Error I	4	6.137	0.918	2.014
Fertilizer management	4	1.211*	21.374*	42.633*
Sowing method ×Fertilizer management	8	1.012*	1.792*	1.6820*
Error II	24	3.493	1.038	0.930

* Significant at 5% level
NS = Non-significant

Appendix X. Mean square values of SPAD value of quinoa at 55 DAS

Source of variation	Degrees of freedom	Mean squares
		SPAD value
		55 DAS
Replication	2	45.5571
Sowing method	2	11.1729^{NS}
Error I	4	9.68003
Fertilizer management	4	162.091*
Sowing method ×Fertilizer management	8	6.90728*
Error II	24	10.0389

* Significant at 5% level
NS = Non-significant

Appendix XI. Mean square values for number of inflorescence plant^{-1} of quinoa

Source of variation	Degrees of freedom	Mean squares
		Number of inflorescence plant^{-1}
		At harvest
Replication	2	0.140001
Sowing method	2	7.65266^{NS}
Error I	4	1.73467
Fertilizer management	4	34.6741*
Sowing method ×Fertilizer management	8	3.05044*
Error II	24	1.65833

* Significant at 5% level

NS = Non-significant

Appendix XII. Mean square values of seed yield plant^{-1}and 1000-seed weight of quinoa

Source of variation	Degrees of freedom	Mean squares	
		At harvest	
		Seed yield plant^{-1}	1000-seed weight
Replication	2	2.64521	0.345800
Sowing method	2	5.41495*	0.188067^{NS}
Error I	4	0.77456	0.459666
Fertilizer management	4	9.44210 *	0.129145^{NS}
Sowing method ×Fertilizer management	8	0.74072*	0.635111^{NS}
Error II	24	0.41574	0.230439

* Significant at 5% level

NS = Non-significant

Appendix XIII. Mean square values of straw yield, seed yield, biological yield and harvest index of quinoa

Source of variation	Degrees of freedom	Mean squares			
		At harvest			
		Straw yield	Seed yield	Biological yield	Harvest index
Replication	2	0.298607	0.768870	2.26141	12.0537
Sowing method	2	0.237683[NS]	0.130620[NS]	0.220034[NS]	5.8910[NS]
Error I	4	0.787296	0.216184	0.473922	12.9424
Fertilizer management	4	1.52548*	7.04135*	15.4508 *	9.0246[NS]
Sowing method ×Fertilizer management	8	0.202206*	0.663121*	0.824283*	11.9082*
Error II	24	0.277050	0.888140	0.169628	5.4393

* Significant at 5% level
NS = Non-significant

LIST OF PLATES

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Plate 6. One month old quinoa seedlings in experimental plots (bed sowing method at left and line sowing method at right side of the picture)

Plate 7. Two months old quinoa plants in experimental plots (effect of different fertilizer levels is visible)

Plate 8. Eighty days old quinoa plants in experimental plots

Plate 9. Quinoa plants after harvest

Plate 10. Sun drying quinoa plants and grains after harvest

Plate 11. Sun dried quinoa seeds and chaff

Plate 12. Sun dried quinoa seeds

Plate 13. Field visit by supervisor

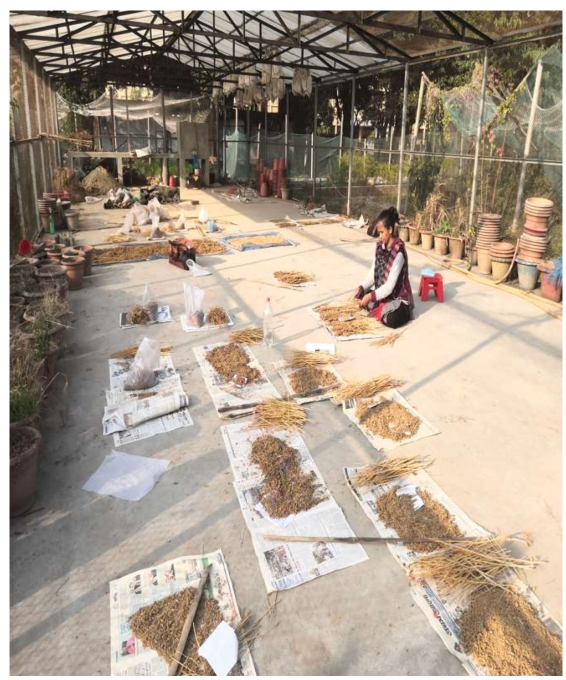

Plate 14. Harvesting, threshing and drying of quinoa