# Quinoa (*Chenopodium quinoa* Willd.) Growth Dynamics and Yield under Varied Geometry and Fertility Levels

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## ABSTRACT

**Background:** The investigation was conducted to study the effect of various agronomic factors *viz.,* geometry and fertility levels on growth dynamics and yield of quinoa (*Chenopodium quinoa* Willd.), often referred to as superfood and also called "the mother grain".

**Methods:** The investigation was conducted in *kharif* 2022, with genotype "EC507742" at mid-hill region of Uttarakhand, India comprising of two factors *viz*., geometry (S): S1- 20 cm × 10 cm, S2- 30 cm × 10 cm and S3- 40 cm × 10 cm as main plots and fertility levels (F): F1- Control, F2- 75% NPKS, F3- 100% NPKS and F4- 125% NPKS as sub plots with total of 12 treatment combinations that were evaluated in split plot design with three replications and analysed using OPSTAT with figures from SAS (proc glm).

**Result:** The 30 cm × 10 cm spacing was found effective in field conditions compared to other crop geometries, indicating to be more suited for quinoa cultivation under 100% NPKS fertilizer application which produced best growth dynamics, yield characteristics and yield for quinoa. The interaction between the 30 cm × 10 cm spacing and 100% NPKS fertilizer was significant in recording the highest growth dynamics and yield. Analysis indicates that quinoa responds very well to fertilizer dose of 100% NPKS at an optimum spacing of 30 cm × 10 cm.

**Key words:** Crop growth rate, Geometry, Growth dynamics, Quinoa, Yield.

## INTRODUCTION

Quinoa (*Chenopodium quinoa*) is a remarkable, resilient and versatile crop with deep historical roots dating back over 5,000 years. Indigenous to the Andean region of South America, it was cultivated by ancients and revered sacred status as the "mother grain". Today, quinoa has transformed from a traditional dietary staple into much sought-after superfood, embraced by health-conscious individuals worldwide. One of quinoa's most compelling attributes is its exceptional nutritional content as it is gluten-free and contains all nine essential amino acids, making it a complete protein vital for human well-being. Additionally, it is rich in dietary fibre, vitamins, minerals and antioxidants, making it a powerhouse of nutrition addressing malnutrition concerns besides promoting overall health and vitality. The rising global demand for quinoa has created significant economic opportunities for farmers and exporters in quinoa cultivating regions. As consumers recognize its nutritional benefits, the crop's market value continues to grow, becoming a vital income source for small-scale farmers. This economic advancement empowers local communities in developing areas.

Fertility level can play a crucial role in enhancing seed quality of quinoa, which directly enhances the plant growth and development, besides increasing seed yield and better seed quality. Proper nutrient application also influences the nutritional composition of quinoa seeds. The research by Miranda *et al.* (2012) found that increasing nitrogen levels boosts seed protein content, while higher fertility levels can increase the concentration of essential minerals.

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However, excessive fertilization should be avoided, as it can compromise seed quality. The overuse of fertilizers, combined with inefficient resource management, deteriorate soil health and pose environmental risks (Yadav *et al*., 2024). In addition to fertility, plant geometry is a key agronomic factor for improving crop yields (Cha *et al*., 2016). The lack of proper crop geometry in the broadcasting method results in poor plant distribution, difficulties in intercultural operations, inefficient use of soil moisture and nutrients and higher competition among plants (Kumbhar *et al.,* 2026). Quinoa is sensitive to afferent spacing, fertilizer types and application rate. However, optimal plant density ensures efficient resource utilization like water, nutrients and sunlight resulting in better plant growth and development, higher seed production and enhanced nutrient accumulation in seeds. Plant geometry can affect the competition for resources among individual plants, which lead to a decrease in stress and promoting more consistent seed yield.

To maximize quinoa yields, farmers must adopt an integrated approach that carefully balances fertility management, plant geometry, irrigation and pest control. Optimal spacing and nutrient application ensure uniform seed development and improved germination rates, while adequate nutrient availability contributes to a high germination rate. Moreover, genetic factors and environmental conditions also significantly influence seed quality. By understanding these interconnected factors, farmers can enhance their production systems to achieve higher yields. Sustainable farming practices are essential to maintain quinoa's nutritional value while preserving ecosystem health. Considering these critical aspects, this study was conceived to determine the ideal cropping geometry and fertility levels for optimizing quinoa growth, yield characteristics and productivity in the mid-hill regions of Uttarakhand, India.

## MATERIALS AND METHODS

A field experiment was conducted in *kharif* 2022 at Research and Extension Centre, Gaja, College of Forestry, Ranichauri (Tehri Garhwal), located in latitude 30°16′17″N, longitude 78°25′21″E at an altitude of 1700-1760 m above sea level in the chilly temperature. The experiment was laid out in spilt plot design with three replications having three different crop geometries (S1: 20 cm × 10 cm, S2: 30 cm × 10 cm and S3: 40 cm x 10 cm) in main plot and four fertility levels (F1: Control, F2: 75% NPKS, F3: 100% NPKS and F4: 125% NPKS) in sub plot under tropical to subtropical zone of Uttarakhand. The mean maximum and minimum temperature, rainfall, relative humidity at morning and afternoon, wind speed and bright sunshine was 24.2°C, 13.1°C, 7.7 mm, 87.1%, 76.7%, 4.0 kmph and 6.0 hr/day, respectively during the crop growing period (Fig 1).

The experimental soil was silty clay loam in texture, medium in availability of nitrogen (242 kg/ha) and phosphorus (22 kg/ha), higher in available potassium (404 kg/ha) and organic carbon (0.75%) with slightly acidic pH (6.1). The genotype "EC507742" was used for the experiment, sown on 26 May 2022. The crop was applied with recommended dose of fertilizer *i.e.,* 40:20:20:20 NPKS in the form of urea, NPK (12:32:16) and Bentonite S, respectively. Entire dose of NPK and S was applied as basal through placement in the furrows made with hand hoes 5 cm away from seed rows and at a depth of 2 cm below the seed zone as per the treatments. Thinning after one irrigation was done to facilitate uniform germination of the crop at 25 days after sowing (DAS). Two hand weedings were done manually at 30 and 60 DAS to keep the crop free from weeds. During the seed formation stage, sucking pest was noticed and was controlled by spraying imidacloprid @ 0.2 ml $l^{-1}$ of water. Anthracnose was observed after heavy rainfall in crop and was controlled by mancozeb @ 2 g $l^{-1}$ of water. Growth dynamics, yield attributes and yield from random selected five plants from each net plot was recorded and the mean value was worked out. The crop was harvested on 02 September 2022. The experimental data obtained during the course of investigation was analysed by using split plot design (SPD) with OPSTAT Programme designed and development by O.P. Sheoran, Computer Programmer at CCS HAU, Hisar, India and figure from SAS (proc glm).

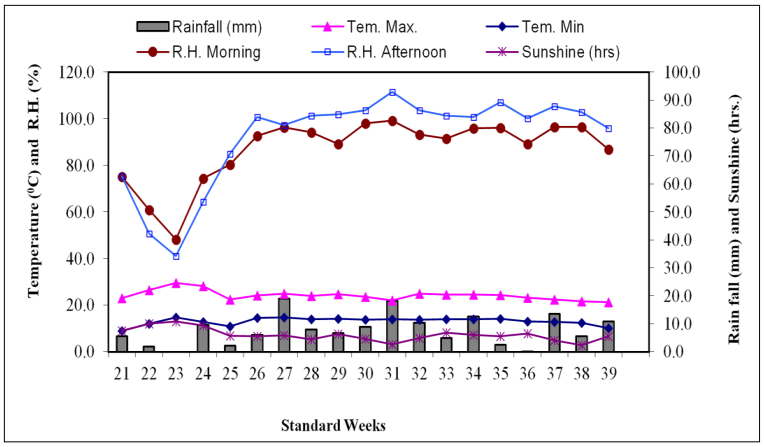



**Fig 1:** Weekly meteorological data during crop season (26 May to 30 September, 2022).

## RESULTS AND DISCUSSION

### Growth dynamics

#### Plant population growth rate

Plant population growth rate of quinoa was significantly influenced by geometry and fertility levels at different stages of crop growth *i.e.* 30-60 DAS, 60-90 DAS and 90 DAS-harvest (Table 1). Among different geometries, significantly higher plant population growth rate was attained in S2 than other geometry. Among different fertility levels, plant population growth rate was statistically more in F3 being at par with F4 at 30-60 DAS, F4 which was at par with F3 at 60-90 DAS and significantly highest in F4 at 90 DAS-harvest. Plant population growth rate showed significant variations in interaction effect among geometries with different fertility levels at various stages of crop growth *i.e.* 30-60 DAS, 60-90 DAS and 90 DAS-harvest as per tukey grouping. The plant population growth rate was significantly more in S2F3 among all the interactions between geometries with different fertility levels that was at par with S2F4 and S1F4 as per tukey grouping at 30-60 DAS (Fig 2) and at 60-90 DAS along with S2F2 (Fig 3). However, at 90 DAS-harvest significantly higher plant population growth rate was found in S2F4 being at par with S2F3, S1F4 and S2F2 as per tukey grouping (Fig 4). This significant increase might be potentially attributable to favourable conditions such as ample sunlight, moisture and accessible nutrients which are conducive to promoting rapid plant propagation, a finding corroborated by Parameswari *et al.* (2003). The wider spacing between plants resulted in improved growth parameters, primarily because it minimized the competition among plants for crucial resources such as space, light, moisture and nutrients, are indispensable for their optimal growth and development. This observation concurs with the findings of Sarkar and Malik (2004). A marked increase in plant height at close spacing might be attributed to higher plant population density which might have resulted in less plant canopy area and more vertical growth by producing weak and tall plants due to competition for space, light, nutrients and moisture compared to those at wider spacing (Shrikanth *et al.,* 2008). Attar *et al.* (2013) also reported increased plant height with narrow spacing. Nutrients are crucial elements of proteins, nucleotides, chlorophyll and enzymes and hence facilitate numerous metabolic processes in plants, resulting in increased output (Sharma *et al.,* 2023).

#### Crop growth rate

Crop growth rate of quinoa was not significantly influenced by geometry while it was significantly influenced by fertility levels at different stages of crop growth *i.e.* 30-60 DAS and 60-90 DAS except 90 DAS-harvest. Among different geometries, higher crop growth rate was attained in S2 followed by S1 and S3 at 30-60 DAS and S1 followed by S2 and S3 at 60-90 DAS and at 90 DAS-harvest. Among different fertility levels, crop growth rate was significantly higher in F4 at 30-60 DAS and at 60-90 DAS that was statistically at par with F2 at 30-60 DAS. However, it was higher in F4 followed by F2, F3 and F1 at 90 DAS-harvest (Table 1).

Crop growth rate showed significant variations in interactive effect among geometries with different fertility levels at various stages of crop growth *i.e.* 30-60 DAS and

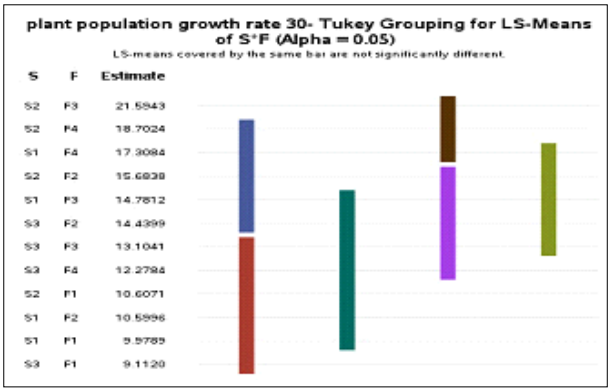



**Fig 2:** Plant population growth rate at 30-60 DAS as per Tukey grouping of geometry and fertility levels.

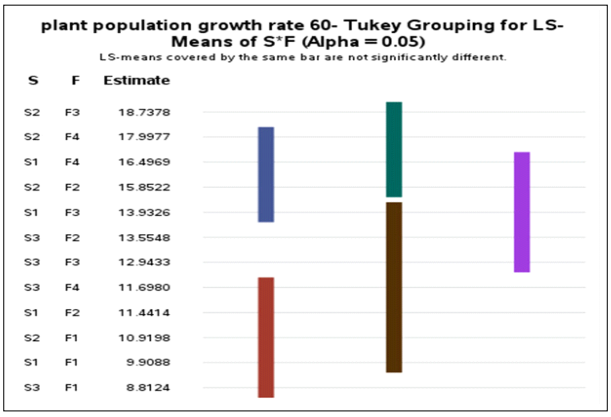



**Fig 3:** Plant population growth rate at 60-90 DAS as per Tukey grouping of geometry and fertility levels.

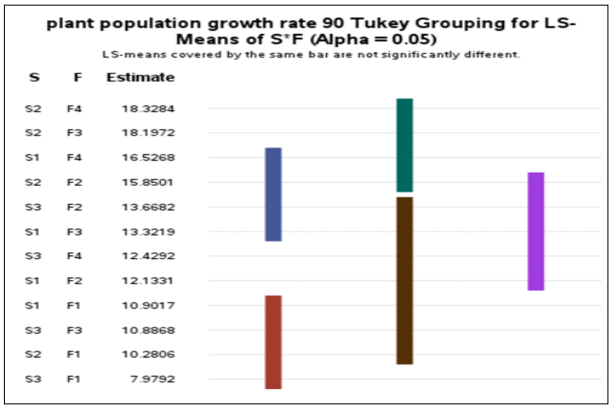



**Fig 4:** Plant population growth rate at 90 DAS-harvest as per Tukey grouping of geometry and fertility levels.

60-90 DAS except 90 DAS-harvest as per tukey grouping. The crop growth rate was obtained statistically highest in S2F4 among all the interactions between geometries with different fertility levels which was at par with S3F2 and S1F4 as per tukey grouping at 30-60 DAS (Fig 5).

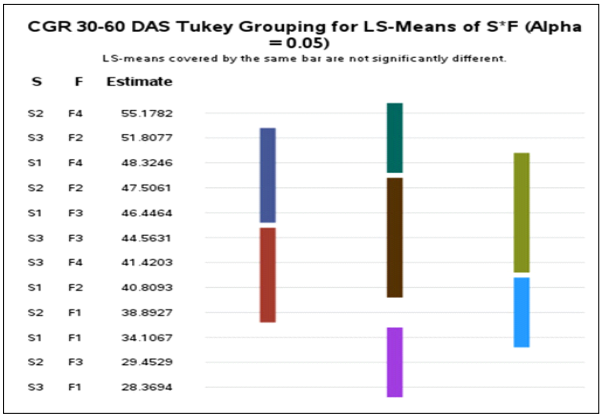



**Fig 5:** Crop growth rate at 30-60 DAS as per Tukey grouping of geometry and fertility levels.

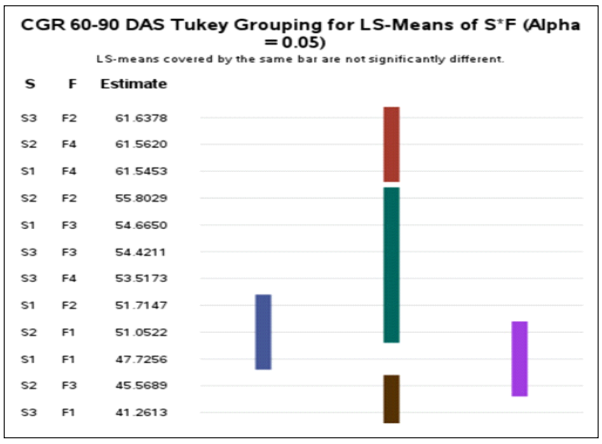



**Fig 6:** Crop growth rate at 60-90 DAS as per Tukey grouping of geometry and fertility levels.

At 60-90 DAS, it was statistically higher in S3F2 being at par with S2F4 and S1F4 (Fig 6). However, at 90 DAS-harvest, there was non-significant variations in interactive effect on crop growth rate were observed among geometries with different fertility levels (Table 1).

The reduced plant height was observed in closer spacing that can be attributed to increased competition among plants for essential resources such as nutrients and light. In contrast, wider spacing decreases this competition, leading to increased plant height. These findings are in line with the research conducted by Rishi and Galwey (1991) but contradict the findings of Smitha *et al.* (2011). Additionally, it was noted that plant height exhibited a progressive increase with higher NPK levels, with the combination of the highest NPK levels resulting in the greatest plant height. The greater plant height can be ascribed to the abundant availability of nitrogen and phosphorus, facilitating improved photosynthesis and overall vigour. Phosphorous is an essential nutrient both as a part of several key plant structure compounds and also as a catalyst in conversion of numerous key biochemical reactions in plant like photosynthesis, respiration, cell elongation, cell division, activation of Amino acid for synthesis of protein and carbohydrate metabolism, also helps in formation of energy rich phosphate bonds, phospholipids and development of root system and nodulation which contributed to increase in general health and vigour of plant. Phosphorous also important for its role in capturing and converting sun's energy into useful plant compounds. Phosphorous also associated with different metabolic activities that leads to better translocation of nutrients that leads to better expression of characters like increased stem strength, increased stalk and stimulated root development. With wider row spacing helped in reducing inter and intra plant competition thus helped in efficient

**Table 1:** Effect of geometry and fertility levels on growth dynamics of quinoa.

| Treatments | Plant population growth rate | | | Crop growth rate | | | Leaves per plant growth rate | | Branches per plant growth rate | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 30-60 DAS | 60-90 DAS | 90 DAS-harvest | 30-60 DAS | 60-90 DAS | 90 DAS-harvest | 30-60 DAS | 60-90 DAS | 30-60 DAS | 60-90 DAS |
| **A. Geometry (S)** | | | | | | | | | | |
| S1- 20 cm × 10 cm | 13.2 | 12.9 | 13.2 | 42.4 | 53.9 | 72.7 | 44.2 | 34.2 | 26.8 | 26.3 |
| S2- 30 cm × 10 cm | 16.7 | 15.9 | 15.7 | 42.8 | 53.5 | 72.4 | 51.7 | 40.6 | 28.3 | 28.0 |
| S3- 40 cm × 10 cm | 12.2 | 11.8 | 11.2 | 41.5 | 52.7 | 72.2 | 41.7 | 27.8 | 25.0 | 24.7 |
| CD (0.05) | 1.7 | 1.6 | 1.5 | NS | NS | NS | 1.3 | 3.9 | 0.6 | 1.0 |
| **B. Fertility level (F)** | | | | | | | | | | |
| F1- Control | 9.9 | 9.9 | 9.7 | 33.8 | 46.7 | 69.2 | 31.4 | 21.8 | 24.0 | 23.5 |
| F2- 75% NPKS | 13.6 | 13.6 | 13.9 | 46.7 | 56.4 | 74.2 | 47.4 | 35.5 | 26.7 | 26.4 |
| F3- 100% NPKS | 16.5 | 15.2 | 14.1 | 40.2 | 51.6 | 69.5 | 52.8 | 38.7 | 28.3 | 28.1 |
| F4- 125% NPKS | 16.1 | 15.4 | 15.8 | 48.3 | 58.9 | 76.7 | 51.9 | 40.7 | 27.7 | 27.5 |
| CD (0.05) | 1.6 | 1.4 | 1.3 | 2.2 | 1.8 | NS | 2.2 | 3.0 | 1.2 | 1.2 |

utilization of solar radiation, nutrients and water which leads plants to better filling of available space by initiating branches. The study was in close conformity with Shukla *et al.* (2017). These observations are consistent with the results reported by Balliu *et al.* (2007); Abdelaziz *et al.* (2008) and Yasuor *et al.* (2013).

**Leaves per plant growth rate**

Leaves per plant growth rate of quinoa were significantly influenced by geometry and fertility levels at different stages of crop growth *i.e.* 30-60 DAS and 60-90 DAS. Among different geometry the leaves per plant growth rate were significantly highest in S2 at different stages of crop growth. Among different fertility levels, leaves per plant growth rate were significantly higher in F3 that was at par with F4 and vice-versa at various crop growth stages (Table 1). Leaves per plant growth rate showed significant variations in interactive effect among geometries with different fertility levels at various stages of crop growth *i.e.* 30-60 DAS and 60-90 DAS as per tukey grouping. The significantly superior leaves per plant growth rate was found in S2F3 among all the interactions between geometries with different fertility levels which was at par with S2F4 at 30-60 DAS (Fig 7). At 60-90 DAS, it was statistically higher in S1F4 being at par with S2F3, S2F4 and S2F2 (Fig 8). The results obtained are likely due to the augmented level of fertilizer, which stimulates the synthesis of chlorophyll and fosters vegetative growth, resulting in an increase in the number of leaves and branches in the plants. These findings are in corroboration with the results reported by Kumar and Sudhavani (2004).

**Branches per plant growth rate**

Branches per plant growth rate of quinoa were significantly influenced by geometry and fertility levels at different stages of crop growth *i.e.* 30-60 DAS and 60-90 DAS. Among different geometry, significantly higher branches per plant growth rate were attained in S2 at different stages of crop growth. Among different fertility levels, branches per plant growth rate were significantly higher in F3 which was statistically at par with F4 at different crop growth stages (Table 1). Branches per plant growth rate showed significant variations in interaction effect among geometries with different fertility levels at various stages of crop growth *i.e.* 30-60 DAS and 60-90 DAS as per tukey grouping. The significantly higher branches per plant growth rate was found in S2F3 among all the interactions between geometries with different fertility levels which was at par with S1F4, S2F4 and S2F2 as per tukey grouping at 30-60 DAS (Fig 9).

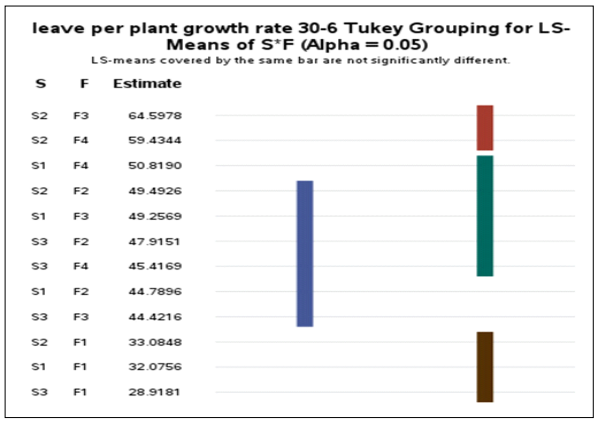



**Fig 7:** Leaves per plant growth rate at 30-60 DAS as per Tukey grouping of geometry and fertility levels.

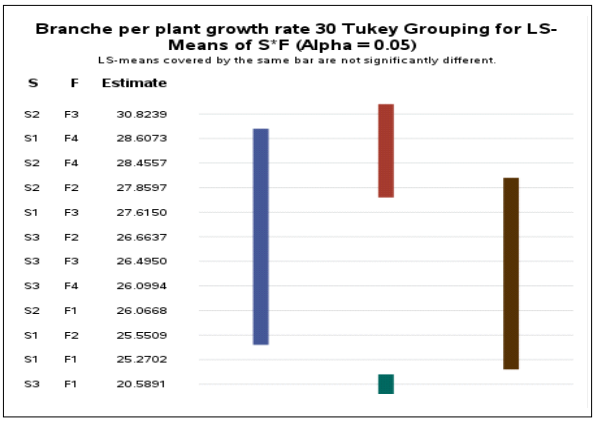



**Fig 9:** Branches per plant growth rate at 30-60 DAS as per Tukey grouping of geometry and fertility levels.

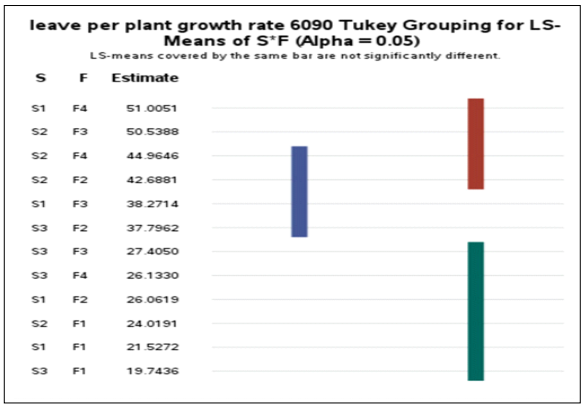



**Fig 8:** Leaves per plant growth rate at 60-90 DAS as per Tukey grouping of geometry and fertility levels.

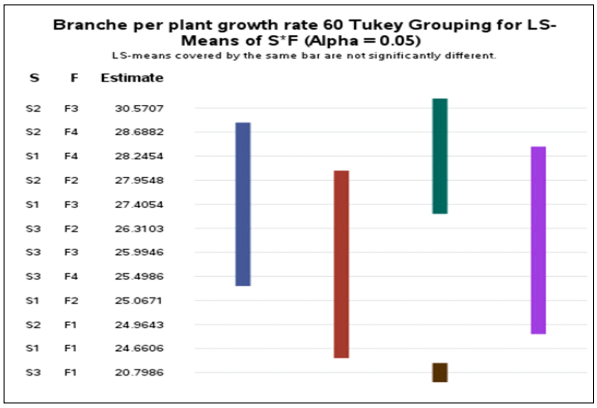



**Fig 10:** Branches per plant growth rate at 60-90 DAS as per Tukey grouping of geometry and fertility levels.

At 60-90 DAS, it was statistically higher in S2F3 being at par with S2F4, S1F4, S2F2 and S1F3 (Fig 10).

In closely spaced crops, the intense competition for light, space, moisture and nutrients leads to reduced branching and a lower leaf count. These conclusions align with the findings reported by Yeboah *et al.* (2014). More number of branches/plant at 100% RDF may be due to the availability of optimum phosphorous content which may have attributed to the fact that phosphorus helped in producing a higher nodulation count, which resulted in higher nitrogen fixation which led to the production of more branches for higher photosynthetic ability (Ndor, 2012).

**Yield attributes and yield**

**Panicle fresh weight (g)**

Panicle fresh weight of quinoa was significantly influenced by geometry and fertility levels. Among different geometry, significantly higher panicle fresh weight was attained in S2. Among different fertility levels, panicle fresh weight was significantly higher in F4 being at par with F3 (Table 2). Significant variations in interactive effect on panicle fresh weight were observed among geometries with different fertility levels as per tukey grouping. The significantly higher panicle fresh weight was recorded in S2F3 which was statistically at par with S2F4 and S1F4 among all the interactions between geometries with different fertility levels as per tukey grouping (Fig 11). This could possibly be attributed to the availability of nutrients to the plants and the improved uptake of elements, especially nitrogen, resulting from the application of fertilizers. Consequently, plants exhibited enhanced nutrient absorption, leading to growth and an increase in the yield attributes and yield.

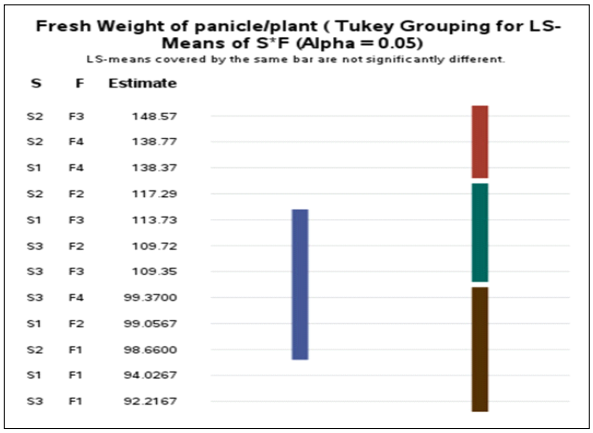



**Fig 11:** Panicle fresh weight of quinoa as per Tukey grouping of geometry and fertility levels.

The application of phosphorus may have led to an accumulation of carbohydrates, which were subsequently mobilized to the reproductive parts of the plants. The significance of potassium, a highly mobile nutrient in plants, should not be overlooked, as it plays a vital role in the elongation and division of young tissues and contributes to maintaining turgor pressure. Moreover, it improves both the quality and yield of the plants. These findings are consistent with the research conducted by Nath *et al.* (2008) in ajwain and Mehta *et al.* (2011) in fennel.

**Number of fingers**

Number of fingers of quinoa was significantly influenced by geometry and fertility levels. Among different geometry, significantly higher number of fingers was significantly attained in S2. Among different fertility levels, number of fingers was significantly higher in F3 which was found equal to F4 (Table 2). Significant variations in interactive effect on number of fingers were observed among geometries with different fertility levels with significantly higher in S2F3 among all the interactions between geometries with different fertility levels being at par with S2F4 as per tukey grouping (Fig 12). These findings are consistent with the research conducted by Nath *et al.* (2008) in ajwain and Mehta *et al.* (2011) in fennel.

**Finger length (cm)**

Finger length of quinoa was significantly influenced by geometry and fertility levels. Among different geometry, higher finger length was significantly attained in S2. Among

**Table 2:** Effect of geometry and fertility levels on yield attributes and yield of quinoa.

| Treatments | Panicle fresh weight | Number of fingers | Finger length | Seed yield | Biological yield |
|---|---|---|---|---|---|
| **A. Geometry (S)** | | | | | |
| S1- 20 cm × 10 cm | 111.3 | 21.8 | 22.8 | 483.8 | 1863.6 |
| S2- 30 cm × 10 cm | 125.8 | 27.5 | 26.9 | 600.0 | 2111.2 |
| S3- 40 cm × 10 cm | 102.7 | 20.4 | 20.3 | 600.0 | 1647.2 |
| CD (0.05) | 9.5 | 1.7 | 1.8 | 32.2 | 148.3 |
| **B. Fertility level (F)** | | | | | |
| F1- Control | 95.0 | 19.0 | 18.7 | 289.4 | 1308.2 |
| F2- 75% NPKS | 108.7 | 22.6 | 21.6 | 538.9 | 1769.2 |
| F3- 100% NPKS | 123.9 | 25.7 | 28.2 | 646.5 | 2149.1 |
| F4- 125% NPKS | 125.5 | 25.7 | 24.8 | 605.2 | 2269.4 |
| CD (0.05) | 4.4 | 2.0 | 1.7 | 59.2 | 195.3 |

different fertility levels, finger length was significantly higher in F3 (Table 2).

Significant variations in interactive effect on finger length were observed among geometries with different fertility levels with significantly higher in S2F3 which was statistically at par with S2F4 and S1F3 among all the interactions between geometries with different fertility levels as per tukey grouping (Fig 13). This was might be due to the application of phosphorus may have led to an accumulation of carbohydrates, which were subsequently mobilized to the reproductive parts of the plants. Potassium plays a vital role in the elongation and division of young tissues and contributes to maintaining turgor pressure.

**Test weight (g)**

Test weight of quinoa was non-significantly influenced by geometry, while it was significantly influenced by fertility levels. Among different geometry, higher test weight was attained in S2 followed by S1 and S3. Among different fertility levels, test weight was significantly higher in F3 which was found equal to F4 being statistically at par with F2. Non-significant variations in interaction effect on test weight were observed among geometries with different fertility levels (Table 2). Increase in weight of 100 seeds with spacing might be due to better availability of nutrients and less competition between plants for nutrients, water and sunlight which may have enhanced photosynthetic activities and resulted in more weight of 100 seeds.

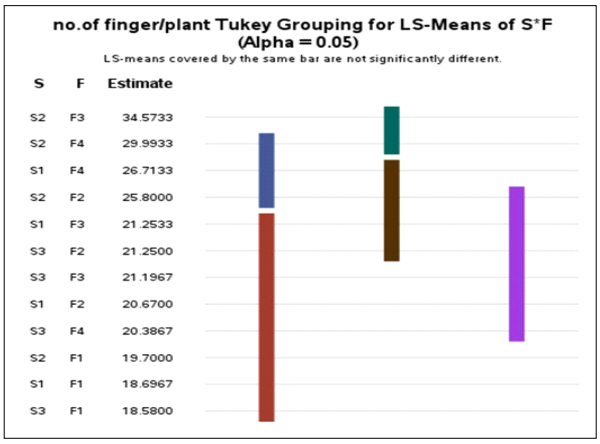



**Fig 12:** Number of fingers of quinoa as per Tukey grouping of geometry and fertility levels.

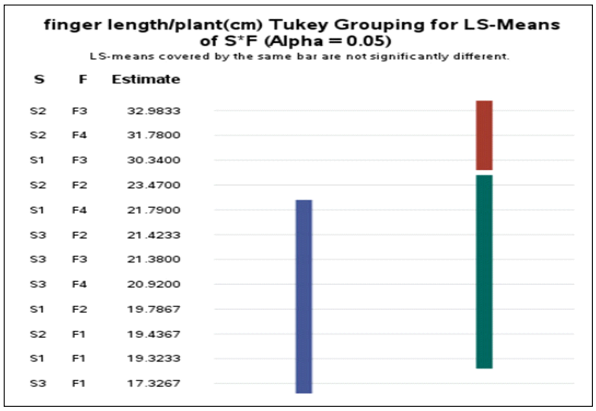



**Fig 13:** Finger length of quinoa as per Tukey grouping of geometry and fertility levels.

**Seed yield (kg/ha)**

Seed yield of quinoa was significantly influenced by geometry and fertility levels. Among different geometry, higher seed yield was attained in S2 which was significantly equal to S3. Among different fertility levels, seed yield was significantly higher in F3 which was statistically at par with F4 (Table 2).

Significant variations in interactive effect on seed yield were observed among geometries with different fertility levels as per tukey grouping. The significantly higher seed yield was found S2F3 which was statistically at par with S2F4 among all the interactions between geometries with different fertility levels as per tukey grouping (Fig 14). The maximum yield attributes under widest spacing may be owing to maximum increase in the growth parameters (height, branches, leaves, stem diameter and plant spread) which means adequate photosynthates production and greater partitioning of metabolites and nutrients towards the reproductive organs. This eventually happened because of reduced competition between widely spaced plants for space, light, nutrients and moisture. These favourable conditions increased the growth parameters up to maximum extents. These results are in close agreement with those Bajpai *et al.* (2004); Singh *et al*. (2005); Ram *et al.* (2013) and Loria *et al.* (2022). The application of an increased fertilizer dosage resulted in enhanced growth and yield-related traits, leading to seed yield, crop residue and biological yield. These consistent outcomes correspond to the findings of Okeleye and Okelana (1997).

The lowest values of plant growth parameters were recorded in control with narrower spacing. This might be due to the fact that non-availability of nutrient at early growth period reduced the plant growth significantly.

**Biological yield (kg/ha)**

Biological yield of quinoa was significantly influenced by geometry and fertility levels. Among different geometry, higher biological yield was attained in S2. Among different fertility levels, biological yield was significantly higher in F4 which was statistically at par with F3 (Table 2).

Significant variations in interactive effect on biological yield were observed among geometries with different fertility levels as per tukey grouping. The significantly higher biological yield was found S2F4 which was statistically at par with S2F3 and S1F4 among all the interactions between geometries with different fertility levels as per tukey grouping (Fig 15). The enhanced reproductive growth allowed for an expanded gap between plants, facilitating enhanced sun exposure and increased nourishment. These outcomes correspond to the findings of Patel *et al.* (2008).

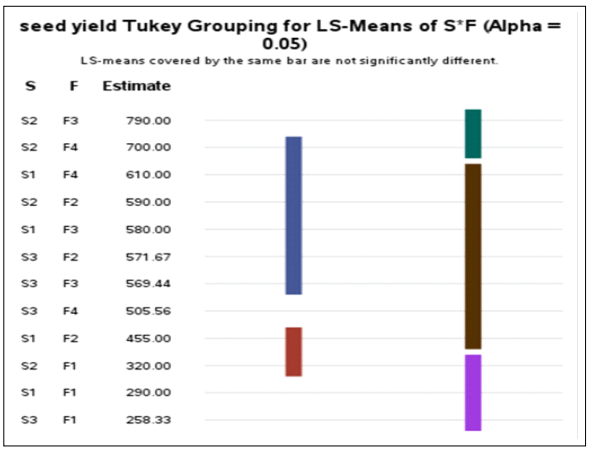



**Fig 14:** Seed yield of quinoa as per Tukey grouping of geometry and fertility levels.

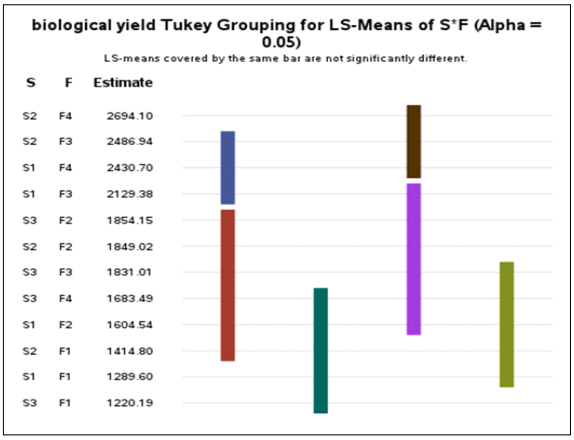



**Fig 15:** Biological yield of quinoa as per Tukey grouping of geometry and fertility levels.

## CONCLUSION

Based on the experimental findings it can be concluded from the investigation that under mid-hills of Uttarakhand, optimal plant geometry of 30 cm × 10 cm with balanced fertilization of 100% NPKS is highly efficient and can be preferred for maximum growth and yield of quinoa.

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### Authors' contributions

Pratiksha Raj: Data curation, formal analysis, writing-original draft, investigation. Arunima Paliwal: Supervision, methodology, resources, validation, writing-review and editing. Ravishankar Dubey and Aditya Raj Bisht: Data curation, writing-original draft. Ajay Kumar: Methodology, resources, data curation, writing-review and editing. Gargi Goswami: Methodology, writing-review and editing. Shalini: Validation, writing-review and editing.

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All data generated and analysed are included in the research article.

### Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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