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Growth and yield of quinoa (*Chenopodium quinoa* L) as influenced by dates of sowing and plant geometry in semi arid region

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Abstract
The field experiment was conducted during *rabi* (winter) season of 2018-19 at Agricultural Research Station, Mandor, Jodhpur. The soil of the experimental field was loamy sand in texture, slightly alkaline in reaction, poor in organic carbon (0.12%), low in available nitrogen (172 kg ha^{-1}) and phosphorus (24.2 kg ha^{-1}) but medium in available potassium (332 kg ha^{-1}). Among 8 dates of sowing, the performance of quinoa in terms of number of branches, panicle length, test weight and seed yield were significantly better when quinoa was sown on 15th November and 25th November. Among plant geometry, seed yield per hectare was significantly higher under narrow spacing (30 cm x 30 cm and 45 cm x 30 cm) when averaged on the basis of per hectare due to higher number of plants in narrow spacing. The crop took on average 140 to mature in all the dates of sowing. The crop geometry did not influence the maturity days of quinoa. It was concluded that quinoa crop can be sown between 15th November and 25th November with plant geometry of 30 cm x 30 cm for higher seed yield in western Rajasthan. The findings of the study would be helpful in crop planning for introduction and development of package of practices of quinoa for crop diversification in the State.

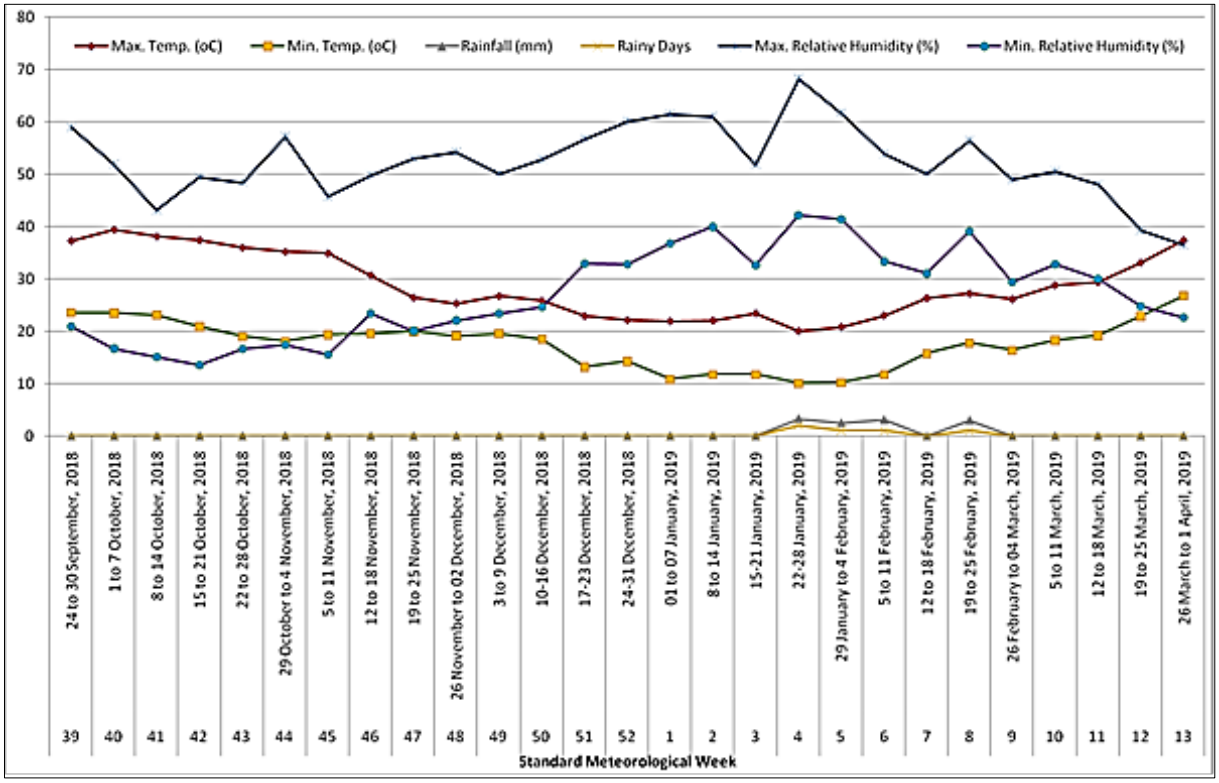
Keywords: Quinoa (*Chenopodium quinoa* L.), date of sowing, plant geometry and seed yield

Introduction
Quinoa (*Chenopodium quinoa* Willd) is a pseudo-cereal and discovered as a healthy food by North Americans and Europeans in the year 1970. Quinoa mainly cultivated in Bolivia and Peru, and these countries are major producers and exporters of quinoa. It is now grown in several European countries including France, England, Sweden, Denmark, Holland, and Italy, as well as in China, India, Pakistan, New Zealand, Australia, Canada, and the United States. It is cultivated in the world with an area of 126 thousand hectares with a production of 103 thousand tonnes. Bolivia in South America is the biggest producer of quinoa with 46 per cent of world production followed by Peru with 42 per cent and United States of America with 6.3 per cent. It can be successfully grown where environmental conditions are similar to those of the Andean region. Quinoa has been observed to have high salt tolerance, frost tolerance and can grow under extremely dry conditions including drought prone areas of the world. Therefore, it can successfully be grown in diverse climatic conditions of India.
Quinoa has been identified as a highly nutritious crop in developed countries. The seed of quinoa is high in protein, possesses a gluten free balanced amino acid profile compared to common cereal grains. The increasing popularity of quinoa has triggered intensive breeding and agronomic and food science research and to promote its production and meet the growing market demand, including investigations of processing characteristics and market class opportunities. As per United Nations Organisation for Agriculture and Food, the quinoa grain is the only food that provides all amino acids essential to the life of humans in optimum quantities and is comparable with milk. The protein and oil content ranges from 7.47 to 22.08 per cent and 1.8 to 9.5 per cent respectively (Ramesh *et al.* 2017) [15].
The objective of the present study was to find out suitable sowing time and optimize plant geometry so as to introduce quinoa cultivation in arid and semi regions of western Rajasthan and hence, experiments were conducted on date of sowing and crop geometry of quinoa.

Material and methods
The experiment was conducted during *rabi* 2018-19 at Agricultural Research Station, Mandor-Jodhpur. Geographically, Jodhpur is situated between 26^{o} 15' N to 26 ^{0} 45' North latitude and 73^{o} 00' E to latitude 73^{o} 29' East longitude at an altitude of 231 meter above mean sea level.

This region falls under agro-climatic zone Ia (Arid Western Plains plain Zone) of Rajasthan.

Weather acts as an input that influencing the growth, yield and quality of crop as well as biotic phase of soil during season. Hence, it is necessary to illustrate climatic variables and their relation in this context. The periodical mean weekly temperature and relative humidity parameters for the period of the experimentation recorded from the meteorological observatory of ARS, Mandor, Jodhpur, are presented in Graph 1. The mean daily maximum and minimum temperature fluctuated between 21.9 to 39.1 ^{0}C and 10.3 to 24.2 ^{0}C, respectively during the crop growing season. The average daily relative humidity fluctuated between 12.75 to 76.6% during the experimental season. The rainfall was not received during *rabi* seasons of the study.



Graph 1: Mean weekly air temperature and relative humidity for the period of the experimentation (SMW 39 to SMW 13) recorded during 2018-19

The soil of the experimental field was loamy sand in texture, slightly alkaline in reaction, poor in organic carbon (0.12%), low in available nitrogen (172 kg ha^{-1}) and phosphorus (24.2 kg ha^{-1}) but medium in available potassium (332 kg ha^{-1}).

The field was deep ploughed with tractor drawn disc plough followed by one harrowing and planking. The plot was properly leveled before preparation of layout. The experimental field was demarcated in the plots of 3.6 m x 4.5 m as per plan of layout.

A basal dose of 30 kg N and 40 kg P_2O_5 ha^{-1} were drilled uniformly before sowing through urea and diammonium phosphate, respectively in individual plot at the depth of 5-7 cm below seed.

The seeds were treated with carbendazim at 2 g kg^{-1} seed before sowing. Since there were varying crop geometry in different date of sowing, the seed rate was different as per treatment. Sowing was done at a depth of 2-3 cm by '*kera*' method. Thinning of crop was done at 15 DAS to maintain required plant population as per treatment. Intercultural operations were done as and when necessary as to ensure normal growth of the crops. Three hand weedings were done during the period of experimentation at 30 DAS, 60 DAS and 90 DAS in every treatment. After sowing of the crop, five irrigations were applied at emergence, branching, pre-flowering and seed formation and seed hardening stages for proper growth and development during the growing season.

Prophylactic measures use taken by spraying of acephate (750 g/ha) and thiamethoxam (0.04%) at pre-flowering and pod filling stages.

Harvesting was done by sickle and threshing was done manually by beating and trampling the plants of each plot separately and cleaned seeds were collected in numbered bags and weighted to record seed yield.

The treatments comprised combination of eight dates of sowing and four plant geometries. The experiment was laid–out in factorial randomized block design. The treatments were replicated three times. Detail of treatment combinations along with the symbols used are as under:

Date of sowing (D)	**Plant Geometry (P)**
D1: 25 September	P1: 30 cm. × 30 cm (111111 plants/ha)
D2: 05 October	
D3: 15 October	P2: 45 cm. × 30 cm (74074 plants/ha)
D4: 25 October	P3: 60 cm. × 45 cm (37037 plants/ha)
D5: 05 November	P4: 90 cm. × 45 cm (24691 plants/ha)
D6: 15 November	
D7: 25 November	
D8: 05 December	

Results and Discussion

Quinoa sowing at 25th November recorded significantly higher plant height i.e. 124.3 cm. Early sowing resulted in significant reduction in plant height. The minimum plant height was recorded when crop was sown on 25th September

i.e. 93.3 cm. Plant height is one of the most important growth contributing characters for any crop which varies depending upon plant genetic makeup and environmental conditions. The variation in plant height of quinoa was observed in present study due to different sowing time indicated that plant height of quinoa may be influenced by temperature or other environmental conditions. These results confirm the earlier finding of by Ramesh *et al.* (2017) [15] in quinoa and Yarnia (2010) [28] in Amaranth. Among different spacings, the maximum plant height was observed in 60 cm x 45 cm (37037 plants ha^{-1}) plant geometry i.e. 105.8 cm. However, minimum plant height was observed in 30 cm x 30 cm (111111 plants ha^{-1}) plant geometry i.e. 101.9 cm. These results are found similar to findings of Pourfarid *et al.* (2014) [21] that close spacing increase plant height of quinoa.

Early sowing resulted in significant reduction in number of branches of quinoa. Among the different date of sowing, 15th November sowing recorded significantly higher number of branches i.e. 23.5 and it was found at par with sowing date 25th November (23.2) followed by 5th December (23.1). The plants grown in wider spacing grew broader with more number of branches, number of panicles and increased panicle length due to availability of light, space, nutrients for single plant (Chaudhari *et al.*, 2009) [6].

Number of branches significantly influenced by various plant geometry. The maximum number of branches (17.4) was recorded under 60 cm x 45 cm (37037) plants ha^{-1}) which was found at par with in 90 cm × 45 cm (24691 plants/ha) plant geometry (17.1).

There was significant improvement in number of panicle per plant of quinoa with late sown crop i.e. 15th November and 25th November with maximum number of panicle per plant of 13.1 and 12.7, respectively. Whereas, minimum number of panicle (5.8) was recorded under 25 September date of sowing. It may be due to more number of branches recorded in above treatments and were supported by Ramesh *et al.* (2017) [16] and Hakan *et al.* (2014) [11] in quinoa and Yarnia (2010) [28] in amaranth.

On the contrary, lower number of panicle was found in case of sowing on 25th September and 5th October which may be due to less number of branches due to decreased favorable environmental conditions. Wider spacing produced significantly higher number of panicle per plant than narrow spacing. The maximum number of panicle per plant was 11.4 in 90 cm × 45 cm (24691 plants/ha) followed by 11.0 in 60 cm x 45 cm (37037 plants ha^{-1}), 10.1 in 45 x 30 cm (74074 plants/ha) and 9.9 in 30 cm x 30 cm (111111 plants ha^{-1}). These results confirmed the findings of Freitas *et al.* (2016) [10], Abbas (2014) [21] and Umesha (1988) [25] who argued the fact that lesser number of plants per unit area could get adequate nutrients, moisture and space to produce more number of panicle per plant per plant.

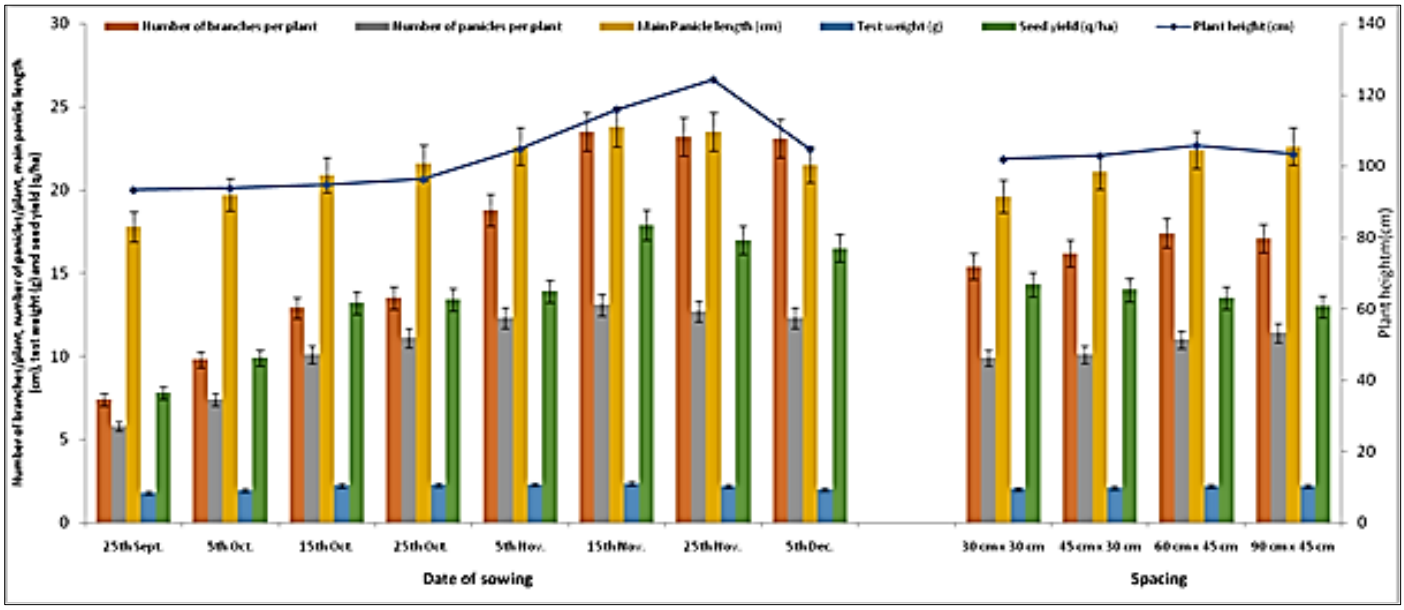
The maximum panicle length was observed under 15 November date of sowing and it was found at par with 25 November and 5 November. Whereas, minimum panicle length was observed under 25 September. It may be due to more number of branches recorded in above treatments. These results were supported by Yarnia (2010) [28] and Hakan *et al.* (2014) [11].

Panicle length significantly influenced by plant geometry. The maximum panicle length (22.6) was observed under 90 cm x 45 cm and it was found at par with 60 cm x 45 cm whereas minimum panicle length (19.6 cm) was recorded in 30 cm x 30 cm plant geometry. Wider spacing (60 × 45 cm or 60 × 45 cm) produced more number of branches $plant^{-1}$ and hence the number of panicles $plant^{-1}$ were found higher at wider spacing as compared to narrow spacing.

The test weight of quinoa seed was significantly influenced by dates of sowing. The maximum test weight of quinoa seed was recorded under 15 November (2.37 g), it was found at par with 5 November (2.31 g) date of sowing while minimum test weight of quinoa seed was recorded in earlier sowing date i.e. 25 September (1.80).

The maximum test weight (2.22 g) was recorded under wider plant geometry 90 cm x 45 cm and it was found at par with 60 cm x 45 cm while minimum plant geometry was recorded under narrow plant geometry 30 cm x 30 cm (2.03g).

Sowing on 15th November produced significantly higher seed yield per hectare (17.9 quintal ha^{-1}) and it was found at par with 25th November (17.9 kg ha^{-1}) whereas minimum yield per hectare (17.9 kg $quintal^{-1}$) was recorded under 25 September date of sowing. Yield attributes and yield may be due to efficient utilization of natural resources (water and nutrients) with optimum vegetative growth and higher translocation of photosynthates from source to sink. Similar results were reported by Hakan *et al.* (2014) [11] and Sajjad *et al.* (2014) [22] in quinoa and Chaudhari *et al.*, (2009) [6] in amaranth crop. Plant geometry of 30 cm × 30 cm (1.11 lakh ha^{-1}) recorded significantly higher seed yield per hectare (14 quintal ha^{-1}) compared to 45 cm × 30 cm (14.0 quintal ha^{-1}), 60 cm × 45 cm (13.5 quintal ha^{-1}) and 90 cm × 45 cm (13.0 ha^{-1}) inter and intra row. The minimum seed yield per hectare was recorded by the crop sown at 90 cm × 45 cm (13.0 quintal ha^{-1}). It may be due to lower plant population. There is in general direct correlation between seed yield per hectare and plant population per hectare. These results are in agreement with the findings of Freitas *et al.* (2016) [10], Bekhordi *et al.* (2014) [4], Yeboag *et al.* (2014) [29] and Daneshian *et al.* (2011) [7].



Graph 1: Effect of Date of Sowing and Plant Geometry on Growth and Yield of Quinoa (*Chenopodium quinoa* L.)

Conclusion

Quinoa crop can be sown between 15th November to 25th November with plant geometry of 30 cm x 30 cm for higher seed yields in western Rajasthan. The findings of the study would be helpful in crop planning for introduction and development of package of practices of quinoa for the crop diversification in the State.

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