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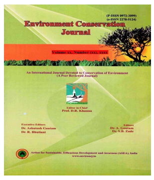

Performance of Quinoa (*Chenopodium quinoa* Willd.) under varied sowing windows and planting patterns

Jyoti Jadipujari ✉
University of Agricultural Sciences, GKVK, Bengaluru

S. R. Anand
University of Agricultural Sciences, AICRN on Potential Crops, GKVK, Bengaluru

Mahantesh B Nagangoudar
University of Agricultural Sciences, GKVK, Bengaluru

G. E. Rao
University of Agricultural Sciences, GKVK, Bengaluru

K. N. Kalyana Murthy
University of Agricultural Sciences, GKVK, Bengaluru

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ABSTRACT

The experiment on "Performance of quinoa (*Chenopodium quinoa* Willd.) under varied sowing windows and planting patterns" was carried out at Main Research Station, Hebbal, UAS, GKVK, Bengaluru, during *Kharif*-2019. The experiment constituted four sowing dates (D_1: July second fortnight, D_2: August first fortnight, D_3: August second fortnight and D_4: September first fortnight) and four planting patterns (S_1: 30 × 15 cm, S_2: 45 × 15 cm, S_3: 60 × 15 cm and S_4: 75 × 15 cm) and replicated thrice was laid out in split-plot design. The results revealed that, increase in AGR and CGR with advancement of age of quinoa and was peak at 60 DAS and showed decreasing trend towards harvest. Sowing during July second fortnight showed significantly, higher AGR and CGR between 30-60 DAS (0.367 and 5.11, respectively) and grain and stover yield (2051 and 2439 kg/ha, respectively) as compared to other sowing windows. Similarly, between 60 DAS-harvest, Absolute Growth Rate and Crop Growth Rate (0.195 and 2.65, respectively) were significantly higher under July second fortnight sowing window, yet was found to be on par with sowing on August first fortnight and August second fortnight. In contrary, September first fortnight sown crop reached days to 50 per cent flowering (43.90) and days to maturity (97.36) early, which was significantly lower compared to other sowing windows and found on par with August first fortnight sown crop (41.16 and 95.53, respectively). Among the varied planting patterns, 45 × 15 cm spacing was found to be optimum and recorded significantly higher grain and stover yield (1941 and 2346 kg/ha, respectively) as compared to other spacings.

Introduction

Food security of world in coming days relies on the sustained accomplishment of cereals production in Asia. Since 2002, production of cereals has shown a steady increase (Anon., 2019), the road to food security faces major hurdles *viz*., with increasing demand versus declining yield and area harvested; soil fertility and decline in productivity of intensive cereal-based cropping systems (Bell *et al.,* 2019); exhaustion and or limitations of natural resources for production; stabilization of yield potential of recently released varieties/hybrids; biotic stresses, abiotic stresses (low temperature, drought and salinity); low income from major cereal crops production and changing socio-economic situations (Van and Ferrero, 2006). Quinoa (*Chenopodium quinoa* Willd.), an herbaceous annual plant belongs to *Amaranthaceae* family. Quinoa cultivation is one of the main livelihoods of Andean farmers in South America where it is known to be cultivated since ages, but no longer restricted to them as it spread to

Corresponding author E-mail: jjadipujari@gmail.com
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different parts of the world *viz*., Bolivia, Chile, Ecuador and Peru (Jaikishun *et al.,* 2019). In recent years, North America and Europe have taken up quinoa farming in sizeable area. India has recently joined the list of countries cultivating quinoa. The quinoa life cycle is approximately 6 months, but it varies depending on the region, which determines the sowing and harvest months (Sajjad *et al.,* 2014). Being a quantitatively short-day species, quinoa has wider adaptability to varied climatic conditions (Miguel *et al.,* 2020). It can be grown well at the altitude of about 3,900 m from mean sea level, soil p^H ranging from 6 to 8.5 and temperature varying from humid to sub-tropical and tropical areas. It is a hardy plant and can thrive well under moisture stress conditions of marginal soils as well. However, the most suited soil for quinoa farming is sandy loam. September to May is the optimum period for quinoa in the Andean region *i.e*., during the austral spring–summer time, with mean temperatures between 10 to 25 ^{0}C. However, the most adequate range of mean temperature for its growth is 15-20 ^{0}C (Garcia *et al.,* 2019).Quinoa required almost 70 to 200 days to complete its entire growth period and maturity of some entries is location specific. The results reported from the experiment conducted for evaluation of quinoa entries in America, Europe and Africa were – it is observed that growing period of quinoa in Kenya was 65-98 days with 100 per cent cultivars maturity with seed yield of 4000 kg/ha. Whereas, it is varied between 70 to 200 days and some entries did not mature in some locations. But it is 120 to 160 days in countries like Denmark and Sweden, the yield observed is also lower with maturity of only few entries of quinoa. The growing period in Greece was 110-160 days and the yield was 2000 kg/ha (Jacobsen, 2017).In India, it grows naturally in Himalayan region where temperature ranges between 0-20 °C. Performance of quinoa varieties varies with the latitude and altitude of a region (Jacobsen, 2017) in terms of important phenological changes with respect to duration of the growth stages needed to complete their life cycle and differing in their canopy morphology and inflorescence levels. In Karnataka, as a part of research programme in All India Co-ordinated Research Network on Potential crops, Bangalore who initiated adoptability studies and evaluation of some quinoa germplasms for semiarid plains region. Although, growth and develo pment are vital in developing continuous information to back-up the agronomical research and breeding program, till today no/limited information is available on how and where to grow quinoa. Hence, there is a need to standardize the optimum sowing time and plant spacing, which could help the farmers to cultivate this crop for higher productivity with economic benefits. The yield is mainly dependent on the growth parameters, with increase in leaf area, photosynthesis will be augmented which in order leads to higher synthesis and partitioning of photosynthates into the economic parts of the crop. Physiological growth indicators depict the crop growth progress at various phenological stages of the plant. Hence, the growth components not only play vital role in plant's development which is a criterion of yield attributes. In this regard various growth indices (*viz.*, Leaf Area Index, Crop Growth Rate, Relative Growth Rate, Net Assimilation Rate and Leaf Area Duration) are often used in evaluating the plant productive capability and environmental efficiency (Anzoua *et al.,* 2010).

Material and Methods

The experiment was carried out at Main Research Station, Hebbal, UAS, GKVK, Bengaluru, during *Kharif*-2019. The experiment constituted four sowing dates (D_1: July second fortnight, D_2: August first fortnight, D_3: August second fortnight and D_4: September first fortnight) and four planting patterns (S_1: 30 × 15 cm, S_2: 45 × 15 cm, S_3: 60 × 15 cm and S_4: 75 × 15 cm) and replicated thrice was laid out in split-plot design. Totally there were sixteen treatments combinations with three replications. This site comes under 5th Agro-climatic zone (i.e, Eastern Dry Zone) of Karnataka at 13° 04' North latitude, 77° 58' East longitude and 904 m above mean sea level. The variety used was EC 507744. The monthly mean temperature during crop growth period was 27.7 °C (maximum) and 16.1 °C (minimum) with an average relative humidity varying between the 58.3-91.4 per cent and rainfall occurred during the crop growth period (July-December) was 786.4 mm. The soil texture was red sandy loam with acidic pH, low in organic carbon (0.25%), low in available N (254.14 kg/ha) and medium in available P_2O_5 (28.32 kg/ha) and K_2O (186.04 kg/ha). The recommended dose of fertilizer supplied was 60:40:40 kg N:P_2O_5:K_2O ha^{-1} through urea, Di-ammonium phosphate (DAP) and Muriate of Potash (MOP), respectively. Complete dose of P, K and half the dose of N was applied at the time of sowing as basal application. 50 per cent of N was top dressed later before inter cultivation at 30 DAS. Protective irrigations were given when there was no rainfall for more than 8-10 days, only two irrigations were given during the month of July and August especially during germination stage to ensure after crop establishment. July 26th, August 9th, August 26th and September 16th sown crop were harvested at 97, 95, 93 and 90 DAS, respectively. Five plants from each net plot were randomly selected to record the data on growth and yield attributes and the mean values were represented in the tabular form. Data recorded was subjected to statistical analysis by following the analysis of variance as suggested by Panse and Sukhatme, (1978). Critical difference was calculated wherever F test was found significant at 5 percent probability level and the values were furnished.

Absolute growth rate (AGR): It is the dry matter produced per plant per unit time. It is expressed in g/day was worked out from the below mentioned formula (Watson, 1952).

$$AGR = \frac{W_2 - W_1}{t_2 - t_1}$$

Where, AGR = Absolute growth rate expressed (g/day), W_1= Dry weight of hill at time t_1 and W_2= Dry weight of hill at time t_2

Relative growth rate (RGR): It is expressed as the gram of dry weight increased per gram of initial dry matter per unit time and expressed as g/g/day.

$$RGR = \frac{(\log_e W_2 - \log_e W_1)}{(t_2 - t_1)}$$

Where, W_1 and W_2- plant dry weigh at time t_1 and t_2, respectively.

Crop growth rate (CGR): Is the amount of dry matter produced per unit land area per unit time and expressed in g/m^2/day (Watson, 1952).

$$CGR = \left(\frac{1}{P}\right) \times \frac{W_2 - W_1}{t_2 - t_1}$$

Where, W_1 = Dry weight of hill at time t_1, W_2 = Dry weight of hill at time t_2 & P = Land area in cm^2

Net Assimilation Rate (NAR): The rate of increase in dry weight per unit leaf area of the plant over a period of time. It is expressed in g/dm^2/day and worked out from the below formula (Gregory, 1926).

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\log_e L_2 - \log_e L_1}{L_2 - L_1}$$

Where, W_1 and W_2 = total plant dry weight at the time t_1 and t_2, respectively

L_1 and L_2 = leaf area at time t_1 and t_2, respectively

Results and Discussion

Crop Growth Rate (CGR, g/m^2/day)

The crop growth rate of quinoa increased with the increasing age of the crop and it is maximum at 60 DAS, later slightly declined during harvest without considering sowing date and spacing. Sowing during July second fortnight showed significantly higher CGR between 30-60 DAS (5.11 g/m^2/day) and 60 DAS-harvest (2.65 g/m^2/day) which was found on par with August first fortnight and August second fortnight date of sowing during the 60 DAS-harvest. However, sowing during September first fortnight recorded significantly lower CGR at all the crop growth phases of quinoa. This difference in CGR is due to availability of sufficient solar radiation during early sowing date (July second fortnight) that accelerated the rate of photosynthesis and higher translocation of photosynthates to various sinks. Whereas, insufficient solar radiation and scarcity of water observed under later dates of sowing which leads to lower crop growth rate of quinoa at all growth stages as reflected in the varied dry matter per unit area. Christiansen *et al*. (2010), Hirich *et al.* (2014) and Ramesh *et al.* (2017) also reported that sowing during October 15th showed higher CGR between 30-60 DAS (5.4), 60-90 DAS (11.3) and 90 DAS-harvest (7.0) and at par with sowing during first fortnight of November at all crop growth stages of quinoa. Among the varied crop geometry, narrow spacing (30 × 15 cm) produced significantly higher CGR (g/m^2/day) between 30-60 DAS (6.07) and 60 DAS-harvest (3.17). However, lower CGR was recorded with 75 × 15 cm spacing. Higher CGR values can be ascribed to more plants and higher

Table 1: Effect of different sowing windows and varied crop geometry on absolute growth rate (g/day) and crop growth rate (g/m^2/day) of quinoa

Treatments	AGR		CGR	
	30-60 DAS	60- harvest	30-60 DAS	60-harvest
Main: Sowing windows				
D_1: Second fortnight of July (July 26)	0.367	0.195	5.116	2.65
D_2: First fortnight of August (August 09)	0.323	0.192	4.501	2.63
D_3: Second fortnight of August (August 26)	0.293	0.169	4.038	2.31
D_4: First fortnight of September (September 16)	0.262	0.117	3.660	1.59
F – test	*	*	*	*
S.Em.±	**0.012**	**0.009**	**0.149**	**0.11**
C.D. (p=0.05)	**0.043**	**0.027**	**0.517**	**0.37**
Sub: Crop geometry				
S_1: 30 × 15 cm	0.273	0.143	6.078	3.17
S_2: 45 × 15 cm	0.317	0.173	4.700	2.56
S_3: 60 × 15 cm	0.322	0.175	3.579	1.95
S_4: 75 × 15 cm	0.333	0.183	2.957	1.51
F – test	*	*	*	*
S.Em.±	**0.009**	**0.008**	**0.107**	**0.16**
C.D. (p=0.05)	**0.026**	**0.024**	**0.312**	**0.47**
Interaction (D × S)				
D_1S_1	0.329	0.200	7.308	4.45
D_1S_2	0.367	0.180	5.432	2.67
D_1S_3	0.380	0.177	4.222	1.96
D_1S_4	0.394	0.223	3.500	1.54
D_2S_1	0.284	0.155	6.302	3.44
D_2S_2	0.339	0.198	5.021	2.93
D_2S_3	0.329	0.207	3.659	2.30
D_2S_4	0.340	0.210	3.022	1.87
D_3S_1	0.249	0.129	5.533	2.86
D_3S_2	0.297	0.187	4.395	2.77
D_3S_3	0.296	0.190	3.284	2.11
D_3S_4	0.331	0.169	2.939	1.50
D_4S_1	0.233	0.088	5.168	1.95
D_4S_2	0.267	0.127	3.951	1.88
D_4S_3	0.284	0.127	3.153	1.41
D_4S_4	0.266	0.128	2.367	1.14
F - test	**NS**	**NS**	**NS**	**NS**
S.Em.±	**0.018**	**0.017**	**0.214**	**0.32**
C.D. (p=0.05)	-	-	-	-

dry matter output per unit area under close spacing. As a result, during all growth phases, wider spacing resulted in significantly decreased CGR. Despite the fact that the individual plant canopy was raised in these spacings, CGR was reduced because the plant population and dry matter production per unit area were lesser. These results are in accordance with the findings of Ramesh *et al*. (2017), that at different crop growth stages, narrow spacing (15 × 10 cm) resulted considerably greater CGR (g/m^2/day) during 30-60 DAS (6.7), 60-90 DAS (14.9) and 90 DAS - harvest (11.1), followed by 30 × 10 cm spacing (3.9, 10.2, and 8.0, respectively). The interaction effect on crop growth rate as influenced by date of sowing and varied crop geometry was found non-significant with respect to CGR.

Absolute Growth Rate (AGR, g/day)

Among different sowing dates, at 30-60 DAS (0.36) and 60 DAS-harvest (0.19) the absolute growth rate (AGR g/day) was substantially higher when sown during second fortnight of July which was on par with the August first fortnight sown crop at all growth stages. Lower AGR was recorded in September first fortnight sown crop. Among the varied crop geometry, wider spacing of 75 × 15 cm recorded substantially higher AGR during 30-60 DAS (0.33) and 60 DAS-harvest (0.18) which was on par with 60 × 15 cm and 45 × 15 cm, while lower AGR was recorded with 30 × 15 cm spacing. This could be due to greater availability of growth resources in widely spaced plants as compared to narrow spaced ones which lead to greater expansion of leaves *i.e.*, increased leaf area per unit area causing increased photosynthetic efficiency of plants reflecting in increased dry matter accumulation and in-turn the crop growth. The above findings were in line with the results of Hirich *et al.* (2014) and Ramesh *et al.* (2017). The interaction effect of sowing date and different spacings was found non-significant with respect to AGR.

Relative Growth Rate (RGR, g/g/day)

The rate of dry matter increase per unit dry matter over a unit time period is measured by relative growth rate. Relatively lower RGR was observed during early growth phase and increased between 30-60 DAS. Effect of sowing windows and varied crop geometry on RGR was non-significant. In general, among different sowing windows, July second fortnight sowing date recorded higher RGR at 30-60 DAS and 60 DAS-harvest (0.0146 and 0.0046 g/g/day, respectively). However, lower RGR recorded in September first fortnight sowing. The per cent increase in RGR under July second fortnight sown crop was up to 20.61 and 53.33 per cent during 30-60 DAS and 60 DAS-harvest, respectively over delayed sowings. This is attributed to the environmental conditions *viz.*, sufficient rainfall, solar radiation and optimum temperature which favours better crop growth and development finally resulting in increased dry matter production per unit area within the given time period. Similar results were also recorded by Ramesh *et al.* (2017).Among the varied crop geometry, plant spacing of 75 × 15 cm recorded higher relative growth rate during 30-60 DAS (0.0134 g/g/day) and 60 DAS-harvest (0.0045 g/g/day) as compared to other plant spacings. However, narrow spacing of 30 × 15 cm recorded lower RGR. This could be due to individual plant performance in terms of dry matter production being better under wider spacing due to better utilization of available resources such as sunlight, water, nutrients, and space which improved physiological activities of the plants resulting in a higher RGR. The higher inter-plant competition in closed spaced crops due to higher plant population per unit area causing reduced access to resources in sufficient quantity to individual plants hindering the potential growth and development of the crop. Ramesh *et al.* (2017) also found that wider spacing of 60 × 15 cm resulted in higher RGR than closer spacing of 15 × 10 cm however, the difference between the geometries was non-significant during 90 DAS-harvest growth phase of the crop. In comparison to other crop geometries, greater RGR was reported during 30-60 DAS under 15 × 10 cm spacing and during 60-90 DAS with wider spacing of 60 × 10 cm.

Net Assimilation Rate (NAR, g/dm^2/day)

The net gain of assimilates per unit of leaf area and over a unit time period is known as the NAR or unit leaf rate. The capacity of a crop's net assimilation rate (NAR) and leaf area determine its yield. NAR as influenced by different sowing windows was found significant only during 60 DAS-harvest. Whereas, varied crop geometry could not produce significant difference. Among the different sowing windows, higher NAR was recorded in July second fortnight sowing during 30-60 DAS and 60 DAS-harvest (0.090 and 0.0233 g/dm^2/day, respectively). However, lower NAR was recorded during September first fortnight sowing. The above findings were in line with the results of Ramesh *et al.* (2017). The interaction effect of different date of sowing and varied spacing on net assimilation rate was found non-significant.

Days to 50 % blooming and days to maturity

Data pertaining to days to 50% blooming as influenced by different planting windows and crop geometry presented in table 3. Significant results were observed with respect to different dates of sowing of quinoa in case of days to attain 50 per cent flowering and maturity. Among the dates of sowing, sowing during July second fortnight had taken more days to attain 50 per cent blooming (43.90) which was on par with sowing during August first fortnight (41.16) as compared to other sowing dates. Significantly, early flowering was observed in September first fortnight sowing. However, July second fortnight sowing had taken more days to maturity (97.36) which was superior over other dates of sowing. Whereas, early maturity was observed under crop sown in September first fortnight. Quinoa is a cool season crop and with decrease in temperature from July second fortnight to September first fortnight, number of days to 50 per cent blooming and days taken to maturity reduced significantly. The above results were similar with the findings of Sajjad *et al*. (2014) who reported that quinoa is a short-day plant and exhibited a positive relation with photoperiodism and it is a function of sowing dates and time taken to complete its phenology and its development phases. As the temperature and photoperiod limits the plant life cycle which depicts the late planting is responsible for yield reduction which was stated by Parvin *et al.* (2013). Days taken to 50 per cent blooming and for maturity of quinoa were found non-significant to different inter row spacings. This was similar to findings of Belmonte *et al.* (2018) and Rishi and Galwey (1991). Interaction effect for above traits was found non-significant in quinoa with respect to different sowing windows and varied spacings.

Table 2: Effect of different sowing windows and varied crop geometry on relative growth rate (g/g/day) and net assimilation rate (g/dm^2/day) of quinoa

Treatments	RGR		NAR	
	30-60 DAS	60- Harvest	30-60 DAS	60- Harvest
Main: Sowing windows				
D_1: Second fortnight of July (July 26)	0.0146	0.0046	0.090	0.0233
D_2: First fortnight of August (August 09)	0.0133	0.0044	0.077	0.0230
D_3: Second fortnight of August (August 26)	0.0129	0.0042	0.074	0.0218
D_4: First fortnight of September (September 16)	0.0121	0.0033	0.073	0.0119
F - test	**NS**	**NS**	**NS**	*
S.Em.±	**0.0006**	**0.0003**	**0.010**	**0.0021**
C.D. (p=0.05)	-	-	-	**0.0072**
Sub: Crop geometry				
S_1: 30 × 15 cm	0.0128	0.0039	0.070	0.0172
S_2: 45 × 15 cm	0.0134	0.0041	0.076	0.0206
S_3: 60 × 15 cm	0.0133	0.0042	0.078	0.0209
S_4: 75 × 15 cm	0.0134	0.0045	0.090	0.0212
F - test	**NS**	**NS**	**NS**	**NS**
S.Em.±	**0.0005**	**0.0002**	**0.008**	**0.0018**
C.D. (p=0.05)	-	-	-	-
Interaction (D × S)				
D_1S_1	0.0151	0.0049	0.092	0.0295
D_1S_2	0.0142	0.0039	0.086	0.0216
D_1S_3	0.0143	0.0037	0.088	0.0204
D_1S_4	0.0147	0.0036	0.093	0.0217
D_2S_1	0.0127	0.0040	0.067	0.0177
D_2S_2	0.0137	0.0045	0.082	0.0204
D_2S_3	0.0134	0.0046	0.078	0.0243
D_2S_4	0.0134	0.0046	0.082	0.0297
D_3S_1	0.0119	0.0037	0.063	0.0142
D_3S_2	0.0132	0.0046	0.074	0.0264
D_3S_3	0.0127	0.0046	0.072	0.0262
D_3S_4	0.0139	0.0039	0.085	0.0202
D_4S_1	0.0114	0.0029	0.058	0.0076
D_4S_2	0.0125	0.0035	0.063	0.0140
D_4S_3	0.0129	0.0034	0.075	0.0129
D_4S_4	0.0116	0.0034	0.101	0.0132
F - test	**NS**	**NS**	**NS**	**NS**
S.Em.±	**0.0010**	**0.0004**	**0.015**	**0.0037**
C.D. (p=0.05)	-	-	-	-

Table 3: Effect of different sowing windows and spacings on days to 50 % flowering and days to maturity of quinoa

Treatments	Days to 50% flowering	Days to maturity
Main: Sowing windows		
D_1: Second fortnight of July (July 26)	43.90	97.36
D_2: First fortnight of August (August 09)	41.16	95.53
D_3: Second fortnight of August (August 26)	40.72	93.56
D_4: First fortnight of September (September 16)	38.38	90.34
F - test	*	*
S.Em.±	**0.81**	**0.52**
C.D. (p=0.05)	**2.79**	**1.80**
Sub: Crop geometry		
S_1: 30 × 15 cm	41.68	95.11
S_2: 45 × 15 cm	41.28	94.46
S_3: 60 × 15 cm	40.52	93.92
S_4: 75 × 15 cm	40.69	93.30
F - test	**NS**	**NS**
S.Em.±	**0.62**	**0.58**
C.D. (p=0.05)	-	-
Interaction (D × S)		
D_1S_1	45.35	98.31
D_1S_2	44.55	97.45
D_1S_3	42.56	97.15
D_1S_4	43.15	96.52
D_2S_1	43.25	96.23
D_2S_2	39.69	95.98
D_2S_3	40.47	95.24
D_2S_4	41.25	94.68
D_3S_1	40.85	94.25
D_3S_2	41.30	93.85
D_3S_3	40.52	93.26
D_3S_4	40.23	92.87
D_4S_1	37.29	91.65
D_4S_2	39.58	90.56
D_4S_3	38.52	90.03
D_4S_4	38.12	89.12
F - test	**NS**	**NS**
S.Em.±	**1.24**	**1.15**
C.D. (p=0.05)	-	-

Grain and stover yield (kg/ha)

The effect of sowing windows and spacings on grain yield, stover yield and interaction effect was found significant. Among sowing windows, July second fortnight recorded significantly higher grain yield (2051 kg/ha). Nevertheless, sowing during August first fortnight and August second fortnight were found on par with each other. However significantly lower grain yield was recorded in September first fortnight sown crop. The superiority of July second fortnight sowing date with respect to grain and stover yield might be due to the higher vegetative growth with optimum plant population made it maximum utilization of natural resources very effectively and efficiently. The increased leaf area helps in more absorption of carbon dioxide causing accelerated photosynthetic activity and effective translocation of photosynthates from source to all plant parts that reflected in the higher growth (plant height, number of tillers, leaf area and dry matter production) and yield attributes (number of panicles, panicle length, panicle weight and grain yield per plant etc). Similar results were also noticed by Hakan *et al*. (2014) in quinoa, Parvin *et al*. (2013)

and Sajjad *et al*. (2014) in grain amaranth. Thus, lower yield observed under late planted crop largely suffered limitation of temperature and photoperiod throughout the plant life cycle. Among varied spacings, grain and stover yield obtained with the spacing of 45 × 15 cm (1941 and 2346 kg/ha) was significantly higher compared to narrow spacing (30×15 cm) (1695 and 2065 kg/ha) and 60 × 15 cm (1648 and 2049 kg/ha) of wider spacing. The grain yield and stover yield are on par in spacing of 30 × 15 cm (1695 and 2065 kg/ha) and 60 × 15 cm (1648 and 2049 kg/ha) and both were superior over the wider spacing of 75 × 15 cm. The per cent increase in grain yield in 45 x 15 cm was to the tune of 14.5 per cent. Further increase in the row spacing to 60 x 15 cm and 75 x 15 cm shows negative to the tune of 16 and 17 per cent, respectively as compared to 30 x 15 cm narrow spacing. This clearly indicates that wider spacing could not compensate in the grain yield mainly due to lesser plant density and more density in narrow spacing could compensate with grain yield due to higher growth and yield parameters. Hence, 45 x 15 cm is found to be optimum for higher grain yield of quinoa crop. This could be due to lesser competition in wider spacing which results in improved growth and development in all phases of crop in higher row spacing compared to lesser row spacing. Though, more vegetative growth per plant was observed under wider spacing, stover yield was more in narrow spacing due to higher plant density per unit area. The results of Pourfarid *et al*. (2014), Olofintoye *et al.* (2015) and Sangul *et al*. (2020) also support the present findings. Row spacing greatly influence the grain and stover yield and hence, optimum row spacing is crucial for achieving higher yield levels as reported by Yarnia *et al*. (2010), Prommarak (2014) and Malligawad and Patil (2015). The interaction effect of sowing date and spacing on grain and stover yield was found significant. Interaction of date of sowing and spacing showed that July second fortnight date of sowing at a spacing of 45 × 15 cm recorded significantly higher grain yield (2392 kg/ha) followed by sowing during July second fortnight at a spacing of 30 × 15 cm (2083 kg/ha). Significantly lower grain yield was attained by September first fortnight date of sowing with 75 × 15 cm spacing. This increased grain and stover yield in combination of early sowing and optimum spacing (45 × 15 cm) might be due to higher growth of crop during early sown crop due to favorable environment conditions coupled with lesser competition for various natural resources in wider spacing due to optimum plant stand which enhanced the grain and stover yield. These results are in line with the findings of Parvin *et al*. (2013) and Sajjad *et al*. (2014).

Harvest index

Effective partitioning of assimilates from source to sink portion is represented by harvest index. Harvest index of quinoa is high and at par with most of the cereal crop (like Finger millet, Bajra, sorghum). Among different sowing windows, significantly higher harvest index was recorded in July second fortnight (46.03%) sowing, which was superior over other sowing dates. Significantly lower harvest index was recorded in September first fortnight sowing. Among varied crop geometry, significantly higher harvest index was recorded with the spacing 45 × 15 cm (45.59 %), which was superior over other spacings. 75 × 15 cm spacing recorded significantly lower harvest index. These results are in line with the findings of Olofintoye *et al*. (2015). On the contrary, Carlos and Juliana (2008) who reported non-significant harvest index between plant densities of 1,00,000 to 6,00,000 plants ha^{-1}. Interaction effect of sowing windows and spacing on harvest index of quinoa was found significant. Among different combinations, July second fortnight date of sowing with 45 × 15 cm spacing recorded significantly higher harvest index (47.83 %) which was significantly superior over other treatment combinations. Significantly lower harvest index was recorded in September first fortnight sowing with 75 × 15 cm spacing.

Conclusion

As per the results obtained, it can be concluded that July second fortnight is the optimum date of sowing for quinoa during *Kharif* season under eastern dry zone of Karnataka. It is due to the fact that, the July sown crop was in synchrony with the onset of monsoon in the present study zone. Thus, leisure availability of soil moisture coupled with sufficient solar energy have accelerated the physiological processes reflecting in higher yield level as compared to delayed crop wherein, crop suffered moisture shortages at the grain filling stages as the

Table 4: Effect of different sowing windows and spacings on grain yield, stover yield and harvest index (%) of quinoa

Treatments	Grain yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)
Main: Sowing windows			
D_1: Second fortnight of July (July 26)	2051	2439	4.60
D_2: First fortnight of August (August 09)	1688	2098	4.45
D_3: Second fortnight of August (August 26)	1517	1916	4.41
D_4: First fortnight of September (September 16)	1398	1799	4.36
F - test	*	*	*
S.Em.±	**31.34**	**45.22**	**0.16**
C.D. (p=0.05)	**108.46**	**156.49**	**0.56**
Sub: Crop geometry			
S_1: 30 × 15 cm	1695	2065	4.49
S_2: 45 × 15 cm	1941	2346	4.55
S_3: 60 × 15 cm	1647	2049	4.45
S_4: 75 × 15 cm	1371	1791	4.32
F - test	*	*	*
S.Em.±	**19.18**	**38.64**	**0.12**
C.D. (p=0.05)	**55.99**	**112.79**	**0.35**
Interaction (D × S)			
D_1S_1	2083	2389	4.65
D_1S_2	2392	2789	4.78
D_1S_3	1985	2389	4.53
D_1S_4	1744	2189	4.43
D_2S_1	1620	2029	4.44
D_2S_2	2064	2476	4.54
D_2S_3	1710	2119	4.46
D_2S_4	1361	1768	4.35
D_3S_1	1587	1978	4.45
D_3S_2	1755	2165	4.47
D_3S_3	1498	1879	4.43
D_3S_4	1230	1645	4.27
D_4S_1	1492	1867	4.44
D_4S_2	1554	1954	4.43
D_4S_3	1398	1810	4.35
D_4S_4	1150	1565	4.23
F - test	*	-	*
S.Em.±	**38.36**	**77.28**	**0.24**
C.D. (p=0.05)	**111.97**	**NS**	**0.70**

rains were withdrawing with simultaneous aging of crop. Among plant geometry, spacing of 45× 15 cm is optimum for quinoa as it is evidenced with higher grain yield and higher monitory returns of quinoa as compared to other spacing. It is found that July second fortnight sowing with the spacing of 45 × 15 cm is ideal for higher grain yield of quinoa during *Kharif* season under eastern dry zone of Karnataka.

Conflict of interest

The authors declare that they have no conflict of interest.

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