Saudi Journal of Biological Sciences 29 (2022) 781–792

Contents lists available at ScienceDirect

Saudi Journal of Biological Sciences

journal homepage: www.sciencedirect.com

Original article

Improvement in growth and yield attributes of cluster bean through optimization of sowing time and plant spacing under climate change scenario

Ibrar Hussain [a], Muqarrab Ali [a,*], Adel M. Ghoneim [b], Khurram Shahzad [c,*], Omer Farooq [d], Shahid Iqbal [a], Fahim Nawaz [a], Shakeel Ahmad [e], Viliam Bárek [f], Marian Brestic [g], Sami Al Obaid [h], Shah Fahad [i], Subhan Danish [j,l,*], Suleyman TABAN [k], Hanife AKÇA [k], Rahul Datta [l,*]

[a] Department of Agronomy, MNS- University of Agriculture, Multan, Pakistan
[b] Department of Soil Sciences, College of Food and Agricultural Sciences, King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia
[c] Department of Soil Science, Lasbela University of Agriculture, Water and Marine Sciences, Uthal, Balochistan, Pakistan
[d] Department of Agronomy, Bahauddin Zakariya University, Multan, Pakistan
[e] Department of Soil Science, MNS- University of Agriculture, Multan, Pakistan
[f] Institute of Landscape Engineering, Slovak University of Agriculture, Nitra, Tr. A. Hlinku 2, 94901 Nitra, Slovakia
[g] Institute of Plant and Environmental Sciences, Slovak University of Agriculture, Nitra, Tr. A. Hlinku 2, 94901 Nitra, Slovakia
[h] Department of Botany and Microbiology, College of Science, King Saud University, PO Box -2455, Riyadh 11451, Saudi Arabia
[i] Hainan Key Laboratory for Sustainable Utilization of Tropical Bioresource, College of Tropical Crops, Hainan University, Haikou 570228, China
[j] Department of Soil Science, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan, Punjab 60800, Pakistan
[k] Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Ankara University, 06110 Diskapi-Ankara, Turkey
[l] Department of Geology and Pedology, Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemedelska1, 61300 Brno, Czech Republic

ARTICLE INFO

Article history:
Received 11 September 2021
Revised 26 October 2021
Accepted 11 November 2021
Available online 19 November 2021

Keywords:
Cyamopsis tetragonoloba L
Growth attributes
Planting density
Sowing time

ABSTRACT

Cluster bean (*Cyamopsis tetragonoloba* L.) yield has plateaued due to reduction in rainfall and rise in temperature. Therefore, its production cycle could not get appropriate water and temperature. It becomes important to standardize the sowing time and plant spacing of cluster beans in changing climate scenarios to get higher productivity. Therefore, a field study was conducted in 2019 at the Research area of MNS-University of Agriculture, Multan, Pakistan to evaluate the effect of four sowing times (15th May, 1st June, 15th June, and 1st July) and three plant spacings (10, 12 and 15 cm) on crop growth, yield, and physiological functions of cluster bean genotype BR-2017 under split plot arrangement under randomized complete block design (RCBD) with three replications. The sowing times (15th May, 1st June, 15th June, and 1st July) were placed in the main plot, while plant spacing (10, 12 and 15 cm) was maintained in subplots. The significant effect of sowing time and plant spacing was observed on pod plant^{-1}, pod length, grain yield, and 1000-grain weight. Results showed that 1st June sowing performed better over 15th May, 15th June, and 1st July, while plant spacing 15 cm about in all sowing times showed higher results on growth and yield parameters of cluster bean over plant spacing 10, 12, and 15 cm. The 1st June sowing time at 15 cm plant spacing showed 8.0, 22.7, and 28.5% higher grains pod^{-1} than 15th May, 15th June, and 1st July sowing, respectively. Maximum grain yield was observed on 1st June in all three spacings (10, 12, and 15 cm). The chord diagram indicates that the crop has received optimum environmental conditions when sown 1st June over other sowing times. In conclusion, 1st June sowing with 15 cm plant spacing could be a good option to achieve maximum productivity of cluster bean under changing climate scenario.

* Corresponding authors.
E-mail addresses: muqarrab.ali@mnsuam.edu.pk (M. Ali), sd96850@gmail.com (S. Danish), rahulmedcure@gmail.com (R. Datta).
Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.sjbs.2021.11.018
1319-562X/

1. Introduction

Cluster bean (*Cyamopsis tetragonoloba* L.) is mainly grown in arid and semi-arid areas of India, Pakistan, South Africa and United States (Ashraf and Iram, 2005; Punia et al., 2009a). Cluster bean pods are used as a vegetable. Galactomannans is a polysaccharide that is extracted from guar and known as guar gum (Sabahelkheir et al., 2012). Grain of cluster bean is made of germ (41–46%), endosperm (34–43%) and hull (13–18%) (Srivastava et al., 2011). In addition, cluster bean is grown as a green manuring crop in different parts of the world. The husk of cluster bean is used for cattle feed because it contains high protein contents (Rai and Dharmatti, 2013). Cluster bean is also a good source of fats, proteins, phosphorous, calcium, and mineral salts (Kumar and Rodge, 2012; Kumar and Ram, 2018). Cluster bean is a leguminous crop that helps in the fixation of atmospheric nitrogen that contributes towards soil fertility (Rai and Dharmatti, 2013).

Sowing time and planting geometry play an important role in the production of cluster bean (Punia et al., 2009b). Sowing time affects the whole plant growth cycle (Luqman et al., 2020), including seed germination, seedling emergence, vegetative plant growth, flowering, pod formation, grain filling, and crop maturity. When crop is sown early, plants make its vegetative phase prolonged compared to reproductive phase depending upon atmospheric temperature and rainfall of area (Ayaz et al., 2004). But when the crop is sown late, flowering comes earlier and plants could not complete their normal vegetative phase (Ali et al., 2004). The increase in temperature accelerates the phenological cycle of plants (Laghari et al., 2021), leading to a decline in crop yield of crop (Zimmermann et al., 2017). Therefore, cluster bean production is directly related to the annual rainfall, temperature and humidity of area (Meena et al., 2014). Sowing time plays a vital role in increasing or decreasing crop yield (Meena and Meena, 2015). Hussain et al. (2004) found that germination of mung bean crop was affected due to early sowing because of unfavorable environmental conditions during the crop cycle. Different sowing times are practiced in different parts of the world. The months of May and August are considered the best sowing time for yield purpose in Pakistan, while in the Mediterranean environment of Italy, mid-May is considered most beneficial to obtain a higher yield (Gresta et al., 2013). In the southwest of United States sowing is conducting between May to early June (Tripp et al., 2011). In the study of Meena et al. (2018), late sowing of cluster bean after 15th July caused the reduction in seed, straw, and biological yields compared to before 15th July sowing.

In addition, sowing time, planting density is also important in the production of cluster bean. Improper planting geometry of crops increases space, water, nutrients, and light competition among plants, increases weed density and creates hurdles in cultural practices. Due to wider spacing, the low plant population causes low yield and ultimately an economic loss to the farmers. Moreover, Intra crop competition enhanced due to variation in plant spacing (Sudarma et al., 2015). Experiments on plant and row spacing in the different soil and environmental conditions showed higher crop yield was achieved by maintaining proper planting density (Acikgoz et al., 2009). Stem length, and biomass and portion in the study of Blumenthal et al. (2005) are increased by increasing the plant spacing (Ball et al., 2000). Kumar and Ram (2018) found that cluster bean grown at 70 cm plant spacing showed higher yield than one grown on 75 and 100 cm spacing.

In another study of Choy et al. (2015), lower plant spacing showed higher branches, leaves and plant height than wider branches. Blumenthal et al. (2005) found maximum productivity of Indian bean with planting geometry 45 × 20 cm. Dhedhi et al. (2016) carried out an experiment in India to evaluate the response of various sowing times and planting density on cluster bean yield. The findings showed that sowing time (1st July) and planting density 30 × 10 cm^2 achieved the maximum cluster bean yield compared to other sowing times. In the controversy of sowing time and planting spacing, it becomes important to standardize the sowing time and plant spacing in changing climate scenarios. Therefore, this study was planned with main objective to optimize the sowing time and planting spacing in Multan, Pakistan to achieve maximum productivity of cluster bean.

2. Materials and methods

Experimental Site: The experiment was carried out in the Agronomic Research Station of MNS-University of Agriculture, Multan, Pakistan, located at 32.14 °N latitude and 73.65 °E longitude during the Kharif summer season 2019. A field experiment was layout in arid climatic conditions (Fig. 1). Soil texture was loamy which contains pH*s* (8.2) (McLean, 1982) organic matter (0.50%) (Nelson and Sommers, 1982), EC*e* (2.45 dS m^{-1}) (Rhoades, 1996), exchangeable potassium (215 mg kg^{-1}) (Pratt, 1965) and available phosphorus (7.15 mg kg^{-1}) (Kuo, 1996) (Table 1).

Treatments: The treatments of this study include four sowing times (15th May, 1st June, 15th June and 1st July), and variety (BR-2017), and three plant spacings (10, 12.5 and 15 cm). The sowing times were taken in the main plot, while in the subplot, plant spacing was maintained.

Field Experiment: Seedbed was set up by developing the field for 3–4 times with farm tractor mounted cultivar each followed by planking. The beds were set up by utilizing a bed shaper. Soaking irrigation was applied seven days before planting of cluster bean seed to keep the exploratory land soft and moist to get ready root and seedbed. The treatments were applied according to split-plot arrangement RCBD design. Cluster bean variety BR-2017 was sown in 2nd week of May using seed rate 20 kg ha^{-1} on beds. The plant × plant and row × row spacing of 10, 12 and 15 cm were maintained, respectively. Thinning of the crop was done 25 days after sowing (DAS) to maintain the plant population as per treatments. The recommended dose of NPK fertilizers for cluster bean (20, 40 and 20 kg ha^{-1}) were applied. All Phosphorus was applied at sowing, while Nitrogen was applied at sowing and flowering stages. Sources of fertilizers used were urea (46 % N), di-ammonium phosphate (18 % N: 46% P_2O_5) and SOP (50% K_2O). first irrigation was applied 3 days after sowing and 2nd irrigation was applied 10 days after first irrigation. Crop was harvested carried out manually. Weeds were controlled manually as well as the use of weedicides. Cluster bean harvesting was done when more than 80% of pods were matured. Harvesting was done at 120 days in all the sowing times.

Data Collection: Leaf area was measured at 30, 45, 60,75,90 and 105 DAS at time of harvesting for five plants using Portable leaf area meter (ICT International, CI-202). Leaf area index was find out by using equation (Watson, 1952).

$$\text{LeafAreaIndex(LAI)} = \frac{\text{Leafareaperplant}}{\text{Landareaperplant}}$$

At harvesting, the plant height, number of clusters per plant, pod length, pods per cluster and grains pod^{-1} of five randomly selected plants from each plot. Grain yield was obtained from the collected pods from each plot. Based on the net plot yield obtained from all the harvested pods, yield per hectare was found. Subsamples of 100 grains were obtained from five plants of each plot randomly chosen. On an electronic balance (KERN, ALJ-310–4 N) these samples were weighed. SPAD-502 (Spectrum Technologies:2900PDL) was used to take the leaf chlorophyll content at 90 DAS. Photosynthetic rate and transpiration rate data were taken using infrared gas analyzer [CID Bio-Science, CI-340].

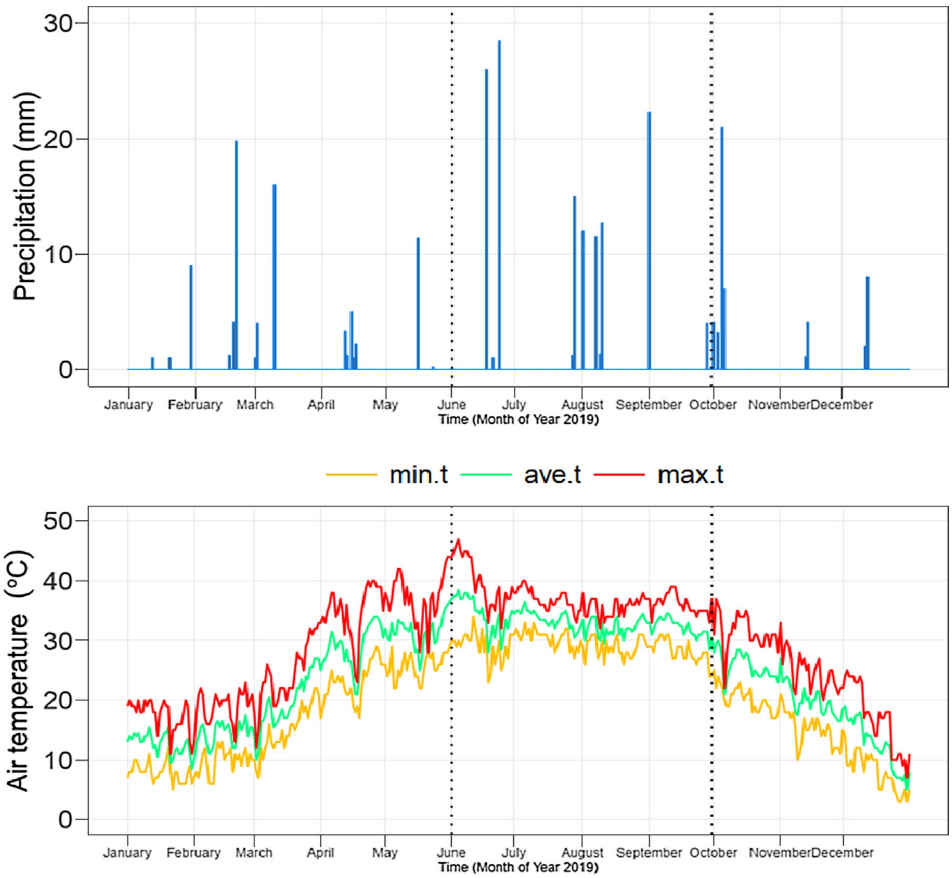

Fig. 1. The daily minimum, maximum and average temperature and rainfall in Multan, Pakistan during the year 2019. The dotted lines are showing the duration of the cluster bean crop.

Table 1
Soil properties of experimental site, Multan, Pakistan during 2019.

Depth	ECe (dS m^{-1})	pHs	Organic Matter (%)	Available Nitrogen (mg kg^{-1})	Available Phosphorus (mg kg^{-1})	Available Potassium (mg kg^{-1})	Texture
0–15 cm	2.45	8.2	0.50	100	7.15	215	Sandy loam
15–30 cm	2.54	8.00	0.46	50	5.46	180	

Statistical Analysis: Growth, yield and physiological parameters were statistically analyzed by using linear model in R software (R_Core_Team, 2020). The means were compared at $p \leq 0.05$ using adjusted Tukey multiple comparison procedure with "emmeans" package (Lenth, 2017; Steel et al., 1997). Chord diagrams were made, and Pearson correlation was done using origin 2021 to assess the average impact of each treatment factor on collected data. Probability values bar graphs were also made by using Origin 2021 (OriginLab Corporation, 2021).

3. Results

Pods Plant^{-1} and Pod Length: The main effect of sowing time and plant spacing was statistically significant at $p < 0.05$, however, the interaction effect of sowing and plant spacing was non-significant on pods plant^{-1} (Table 2).

First June sowing time performed better on pods plant^{-1} than other sowing times (15th May, 15th June and 1st July) (Table 3). The wider plant spacing 15 cm showed a higher response on pods per plant in all sowing times than 10 and 12 cm. In 15th May, plant spacing 15 cm showed 30.2 and 12.6% as compared to 10 and 12 cm, respectively (Table 3; Fig. 2A). In 1st June, plant spacing 15 cm showed 26.1 and 37.6% as compared to 10 and 12 cm respectively (Table 3). In 15th June, plant spacing 15 cm showed 26.6 and 25.4% as compared to 10 and 12 cm, respectively (Table 3). In 1st July, planting density 15 cm showed 27.5 and 37.8% as compared to 10 and 12 cm respectively (Table 3). The main effect of sowing time and plant spacing was statistically significant at

Table 2
P value of main and interaction effect of sowing time and plant spacing on growth, yield and physiological parameters of cluster bean.

Effect	Pods Plant^{-1}	Pod length	Cluster Plant^{-1}	Plant height	Pods cluster^{-1}	E	Pn	Leaf Area Index	Chlorophyll contents	Grain yield	100-grain weight	Grains pod^{-1}
Sowing time (S)	<0.01	<0.01	<0.01	<0.01	<0.01	0.23	0.02	<0.01	<0.01	<0.01	<0.01	<0.01
Plant Spacing (P)	0.01	0.01	0.02	<0.01	0.09	0.09	0.37	<0.01	0.08	<0.01	<0.01	0.25
S × P	0.29	0.77	0.84	<0.01	0.81	0.22	0.22	<0.01	0.16	<0.01	0.36	0.59

Table 3
Impact of sowing time and intra rowing spacing on pods plant^{-1} and pod length of cluster bean.

Plant Spacing (cm)	Pods plant^{-1}				Pod length (cm)			
	Sowing times				Sowing times			
	15th May	1st June	15th June	1st July	15th May	1st June	15th June	1st July
10	281.0 ± 11.0a	371.6 ± 69.2a	109.6 ± 14.5a	40.0 ± 3.46a	4.7.0 ± 0.6a	6.5 ± 0.5a	5.3 ± 0.3a	4.5 ± 0.2a
12	325.0 ± 17.0b	340.6 ± 123.5a	110.3 ± 15.7 a	37.6 ± 3.79a	5.0 ± 0.7ab	6.8 ± 0.6a	5.3 ± 0.2a	4.5 ± 0.3a
15	366.3 ± 14.0c	468.6 ± 36.9a	138.0 ± 5.2a	51.0 ± 10.82a	5.2.0 ± 0.87b	7.1 ± 1.01a	5.7 ± 0.3b	4.6 ± 0.4a

The values are the mean and standard deviation of three replications. Within plant spacing, the values with the same letter (s) are statistically non-significant at $p < 0.05$.

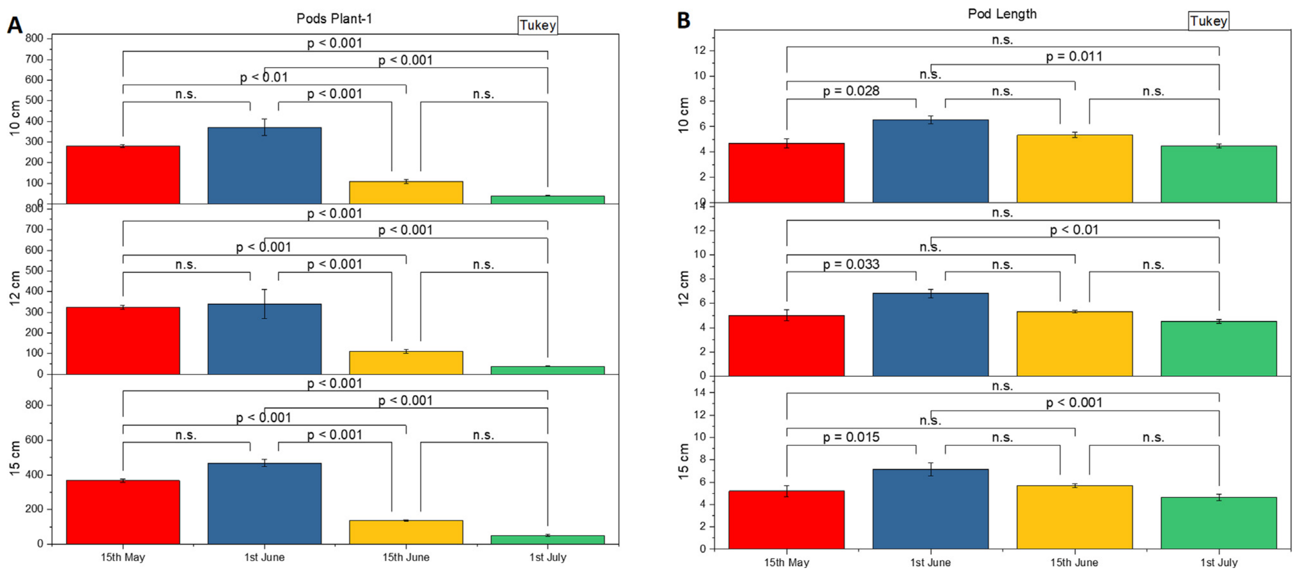

Fig. 2. Impact of sowing times and intra row spacing on pod plant^{-1} (A) and pod length (B) of cluster bean. The values are the mean of three replication. The error bars represent the standard error (n = 3). Within sowing time, the values are p values computed by Tukey test at $p < 0.05$.

$p < 0.05$, however, the interaction effect of sowing and plant spacing was non-significant on pod length (Table 2). First June sowing time showed better on pod length than other sowing times (15th May, 15th June and 1st July). The wider plant spacing 15 cm showed a higher response on pod length in all sowing times than 10 and 12 cm (Fig. 2B). In 15th May, plant spacing 15 cm showed 10.6 and 4% as compared to 10 and 12 cm, respectively (Table 3). In 1st June, plant spacing 15 cm showed 9.2 and 4.4% as compared to 10 and 12 cm respectively (Table 2). In 15th June, plant spacing 15 cm showed 7.5 and 7.5% as compared to 10 and 12 cm, respectively (Table 3). In 1st July, plant spacing 15 cm showed 2.2 and 2.2% as compared to 10 and 12 cm respectively. Pearson correlation showed that pods plant^{-1} and pod length were significantly positive in correlation with pods cluster^{-1}, leaf area index, chlorophyll contents, grains yield, 100 grains weight, plant height, grains pod^{-1}, cluster plant^{-1} and days to maturity of cluster bean (Fig. 9).

Cluster Plant^{-1}: The main effect of sowing time and plant spacing was statistically significant at $p < 0.05$, however, interaction effect of sowing and plant spacing was non-significant on cluster plant^{-1} (Table 2). First June sowing time performed better on clusters plant^{-1} than other sowing times (15th May, 15th June and 1st July) (Table 4). The wider plant spacing 15 cm showed a higher response on clusters per plant in all sowing times than 10 and 12 cm (Fig. 3). In 15th May, plant spacing 15 cm showed 6.5 and 1.8% compared to 10 and 12 cm, respectively (Table 4). In 1st June, plant spacing 15 cm showed 6.2 and 2.2% as compared to 10 and 12 cm respectively (Table 4). In 15th June, plant spacing 15 cm showed 6.9 and 2% as compared to 10 and 12 cm, respectively (Table 4). In 1st July, planting density 15 cm showed 15.1 and 15.1% as compared to 10 and 12 cm respectively (Table 4). Pearson correlation showed that cluster plant^{-1} was significantly positive in correlation with pods cluster^{-1}, leaf area index, chlorophyll contents, grains yield, 100 grains weight, plant height, grains pod^{-1}, days to maturity, pods plant^{-1} and pod length of cluster bean (Fig. 9).

Plant Height and Pods Cluster^{-1}: The main and interaction effect of sowing time and plant spacing was significant at $p < 0.05$ on plant height (Table 2). First June sowing time performed better on plant height than other sowing times (15th May, 15th June and 1st July) (Table 5). The wider plant spacing 15 cm showed a higher response on plant height in all sowing times than 10 and 12 cm (Fig. 4A). In 15th May, plant spacing 15 cm showed 5.6 and 2.7% compared to 10 and 12 cm, respectively (Table 5). In 1st June, plant spacing 15 cm showed 10.6 and 3.9% compared to 10 and 12 cm respectively (Table 5). In 15th June, plant spacing 15 cm showed 3.6 and 3.6% compared to 10 and 12 cm, respectively (Table 5). In 1st July, planting density 15 cm showed 3.4 and 0.8% compared to 10 and 12 cm respectively (Table 5). The main effect of sowing time and plant spacing was statistically significant at $p < 0.05$, however, the interaction effect of sowing and plant spacing was non-significant on pods cluster^{-1} (Table 2). First June sowing time showed a better effect on pods per cluster than other sowing times (15th May, 15th June and 1st July). The wider plant spacing 15 cm showed a higher response on pods per cluster in all sowing times than 10 and 12 cm (Fig. 4B). In 15th May, plant spacing 15 cm showed 9.5 and 4.5% compared to 10 and 12 cm, respectively (Table 5). In 1st June, plant spacing 15 cm showed 4.5 and 0% compared to 10 and 12 cm respectively (Table 5). In 15th June, plant spacing 15 cm showed 18.4 and 23.2% compared to 10 and 12 cm respectively (Table 5). In 1st July, plant

Table 4
Impact of sowing time and intra row spacing on cluster plant^{-1} of cluster bean.

Plant Spacing (cm)	Clusters plant^{-1}			
	Sowing times			
	15th May	1st June	15th June	1st July
10	15.3 ± 0.5a	16.67 ± 1.5a	14.3 ± 0.6a	6.67 ± 0.5a
12	16.0 ± 10.0ab	18.0 ± 20.0a	15.0 ± 0.01ab	6.67 ± 0.5a
15	16.3 ± 0.5b	17.6 ± 2.1a	15.3 ± 0.5b	7.67 ± 1.5a

The values are the mean and standard deviation of three replications. Within plant spacing, the values with the same letter (s) are statistically non-significant at $p < 0.05$.

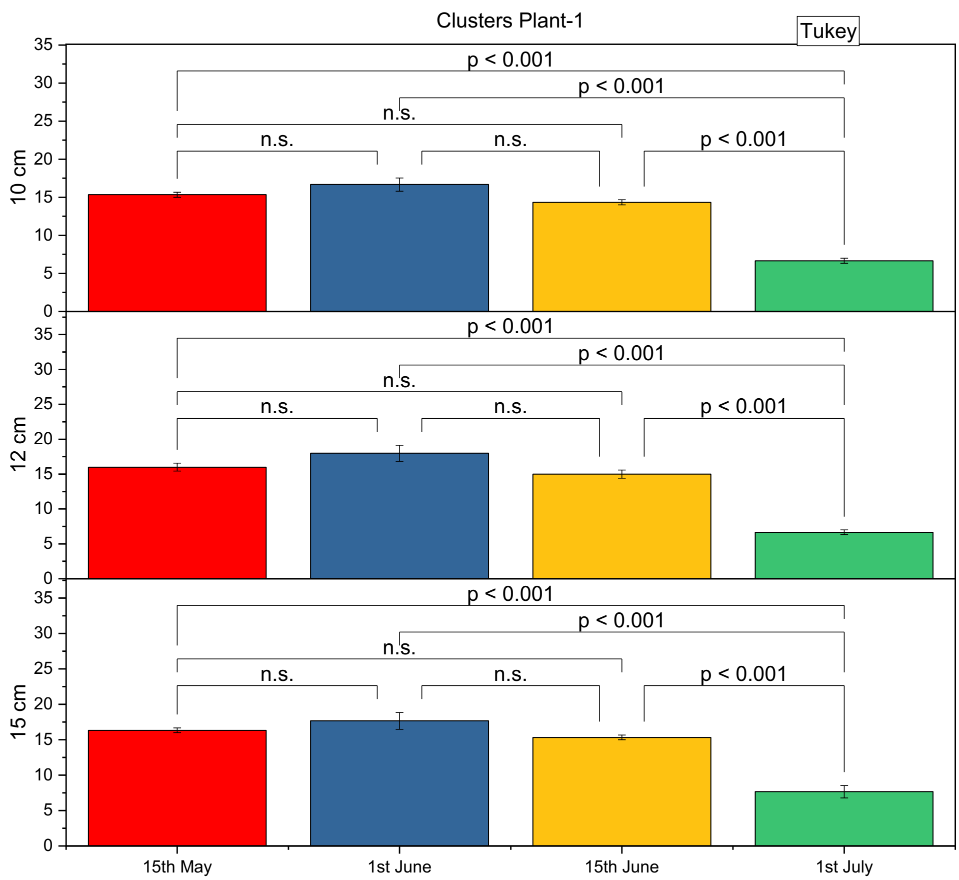

Fig. 3. Impact of sowing times and intra row spacing on cluster plant^{-1} of cluster bean. The values are the mean of three replication. The error bars represent the standard error (n = 3). Within sowing time, the values are p values computed by Tukey test at $p < 0.05$.

Table 5
Impact of sowing time and plant spacing on plant height and pod cluster^{-1} of cluster bean.

Plant Spacing (cm)	Plant height (cm)				Pods cluster^{-1}			
	Sowing times				Sowing times			
	15th May	1st June	15th June	1st July	15th May	1st June	15th June	1st July
10	142.3 ± 7.5a	142.6 ± 8.0a	137.6 ± 4.73a	116.3 ± 6.1a	21.0 ± 1.7a	22.3 ± 2.3a	7.67 ± 1.1a	6.0 ± 0.0ab
12	146.0 ± 60.0ab	152.3 ± 5.1b	137.0 ± 8.19a	119.3 ± 4.5a	22.3 ± 2.5ab	23.0 ± 2.0a	7.33 ± 0.6a	5.6 ± 0.5a
15	150.6 ± 8.9b	157.6 ± 4.0b	142.3 ± 3.06a	120.0 ± 8.5a	23.0 ± 02.0b	23.0 ± 2.6a	9 ± 0.0a	6.6 ± 0.5b

The values are the mean and standard deviation of three replications. Within intra row spacing, the values with the same letter (s) are statistically non-significant at $p < 0.05$.

spacing 15 cm showed 11.1 and 19.1% compared to 10 and 12 cm respectively. Pearson correlation showed that plant height and pods cluster^{-1} were significantly positive in correlation with cluster plant^{-1}, leaf area index, chlorophyll contents, grains yield, 100 grains weight, grains pod^{-1}, days to maturity, pods plant^{-1} and pod length of cluster bean (Fig. 9).

Grain Yield, 100-Grain Weight, and Grains Pod^{-1}: The main and interaction effects of sowing time and plant spacing were significant at $p < 0.05$ on grain yield (Table 2). First June sowing time performed better on grain yield than other sowing times (15th May, 15th June and 1st July) (Fig. 5 and Fig. 6A). The wider plant spacing 15 cm showed a higher response on grain yield in all sow-

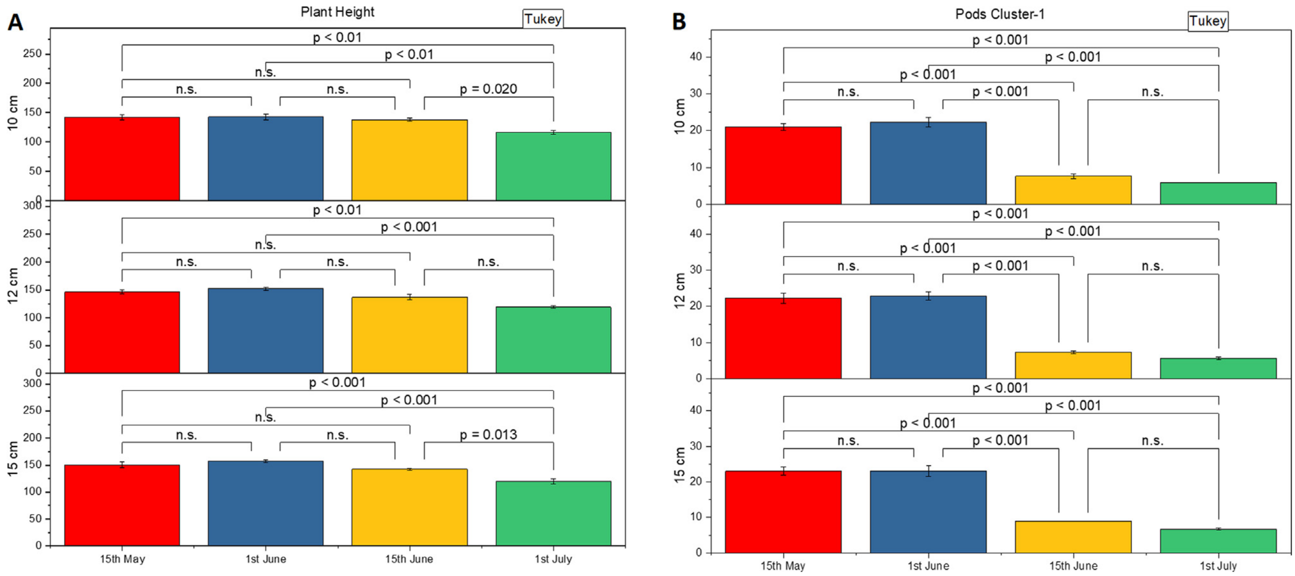

Fig. 4. Impact of sowing times and intra row spacing on plant height (A) and pods cluster^{-1} (B) of cluster bean. The values are the mean of three replication. The error bars represent the standard error (n = 3). Within sowing time, the values are p values computed by Tukey test at $p < 0.05$.

ing times than 10 and 12 cm. In 15th May, plant spacing 15 cm showed 25.6 and 4.5% compared to 10 and 12 cm, respectively (Fig. 5). In 1st June, plant spacing 15 cm showed 20.5 and 7.3% compared to 10 and 12 cm respectively (Fig. 5). In 15th June, plant spacing 15 cm showed 35.0 and 5.3% compared to 10 and 12 cm, respectively (Fig. 5). In 1st July, planting density 15 cm showed 19.1 and 10.5% compared to 10 and 12 cm respectively (Fig. 5). The main effect of sowing time and plant spacing was statistically significant at $p < 0.05$, however, the interaction effect of sowing and plant spacing was non-significant on 100-grain weight (Table 2). First June sowing time performed better on 100-grain weight than other sowing times (15th May, 15th June and 1st July). The wider plant spacing 15 cm showed a higher response on 100-grain weight in all sowing times than 10 and 12 cm. In 15th May, plant spacing 15 cm showed 20.5 and 13.8% compared to 10 and 12 cm, respectively (Fig. 5 and Fig. 6B). In 1st June, plant spacing 15 cm showed 19.1 and 9.8% compared to 10 and 12 cm respectively (Fig. 5). In 15th June, plant spacing 15 cm showed 0 and 2.7% compared to 10 and 12 cm respectively (Fig. 5). In 1st July, plant spacing 15 cm showed 29.4 and 15.7% compared to 10 and 12 cm respectively). The main effect of sowing time and plant spacing was statistically significant at $p < 0.05$, however, the interaction effect of sowing and plant spacing was non-significant on grains pod^{-1} (Table 2). First June sowing time performed better on grains pod than other sowing times (15th May, 15th June and 1st July) (Fig. 5). The wider plant spacing 15 cm showed a higher response on grains per pod in all sowing times than 10 and 12 cm. In 15th May, plant spacing 15 cm showed 15.7 and 13.6% compared to 10 and 12 cm, respectively (Fig. 5). In 1st June, plant spacing 15 cm showed 3.2 and 3.2 % compared to 10 and 12 cm respectively (Figs. 5 and 6C). In 15th June, plant spacing 15 cm showed 10.6 and 4.2% compared to 10 and 12 cm, respectively (Fig. 5). In 1st July, plant spacing 15 cm showed 6.0 and 6.0% compared to 10 and 12 cm respectively. Pearson correlation showed that grain yield, 100-grain weight and grains pod^{-1} were significantly and positively correlated with cluster plant^{-1}, leaf area index, chlorophyll contents, days to maturity, pods plant^{-1} and pod length of cluster bean (Fig. 9).

Transpiration and Photosynthetic Rates: The main and interaction effect of sowing time and plant spacing was statistically non-significant at $p < 0.01$ on transpiration rate (Table 2). The 15th May sowing time performed better on the transpiration rate than other sowing times (15th June, 15th June and 1st July) (Table 6). The wider plant spacing 15 cm showed a higher response on transpiration rate in all sowing times as compared to 10 and 12 cm (Fig. 7A). In 15th May, plant spacing 15 cm showed 16.5 and 101.1% compared to 10 and 12 cm, respectively (Table 6). In 1st June, plant spacing 15 cm showed 22.7 and 83.0% compared to 10 and 12 cm respectively (Table 6). In 15th June, plant spacing 15 cm showed 16.6 and 62.9% compared to 10 and 12 cm, respectively (Table 6). In 1st July, planting density 12 cm showed 38.2 and 81.4% compared to 10 and 15 cm respectively (Table 6). The main and interaction effect of sowing time and plant spacing was statistically non-significant at $p < 0.01$ on photosynthetic rate (Table 2). The 15th May sowing time performed better on photosynthetic rate than other sowing times (1st June, 15th June and 1st July). The lower plant spacing 15 cm showed a higher response on the photosynthetic rate in all sowing times than 10 and 12 cm (Fig. 7B). In 15th May, plant spacing 10 cm showed 53.2 and 40.4% compared to 12 and 15 cm, respectively (Table 6). In 1st June, plant spacing 15 cm showed 67.9 and 36.9% compared to 10 and 12 cm respectively (Table 6). In 15th June, plant spacing 12 cm showed 7.9 and 10.6% compared to 10 and 15 cm respectively. In 1st July, plant spacing 12 cm showed 77.3 and 81.8% compared to 10 and 12 cm respectively (Table 6).

Leaf Area Index and Chlorophyll Contents: The main and interaction effect of sowing time and plant spacing were statistically significant at $p < 0.05$ on leaf area index. First June sowing time performed better on leaf area index than other sowing times (15th May, 15th June and 1st July) (Table 7). The wider plant spacing 15 cm showed a higher response on leaf area index in all sowing times than 10 and 12 cm (Fig. 8A). In 15th May, plant spacing 15 cm showed 25.6 and 4.5% compared to 10 and 12 cm, respectively (Table 7). In 1st June, plant spacing 15 cm showed 0 and 5.5% compared to 10 and 12 cm respectively (Table 7). In 15th June, plant spacing 15 cm showed 14.2 and 6.6% compared to 10 and 12 cm, respectively. In 1st July, planting density 15 cm showed 3.0 and 36% compared to 10 and 12 cm respectively. The main effect of sowing time was statistically significant at $P < 0.05$, however, the main effect of plant spacing and interaction effect of sowing time and plant spacing was non-significant on chlorophyll contents. First June sowing time performed better on chlorophyll

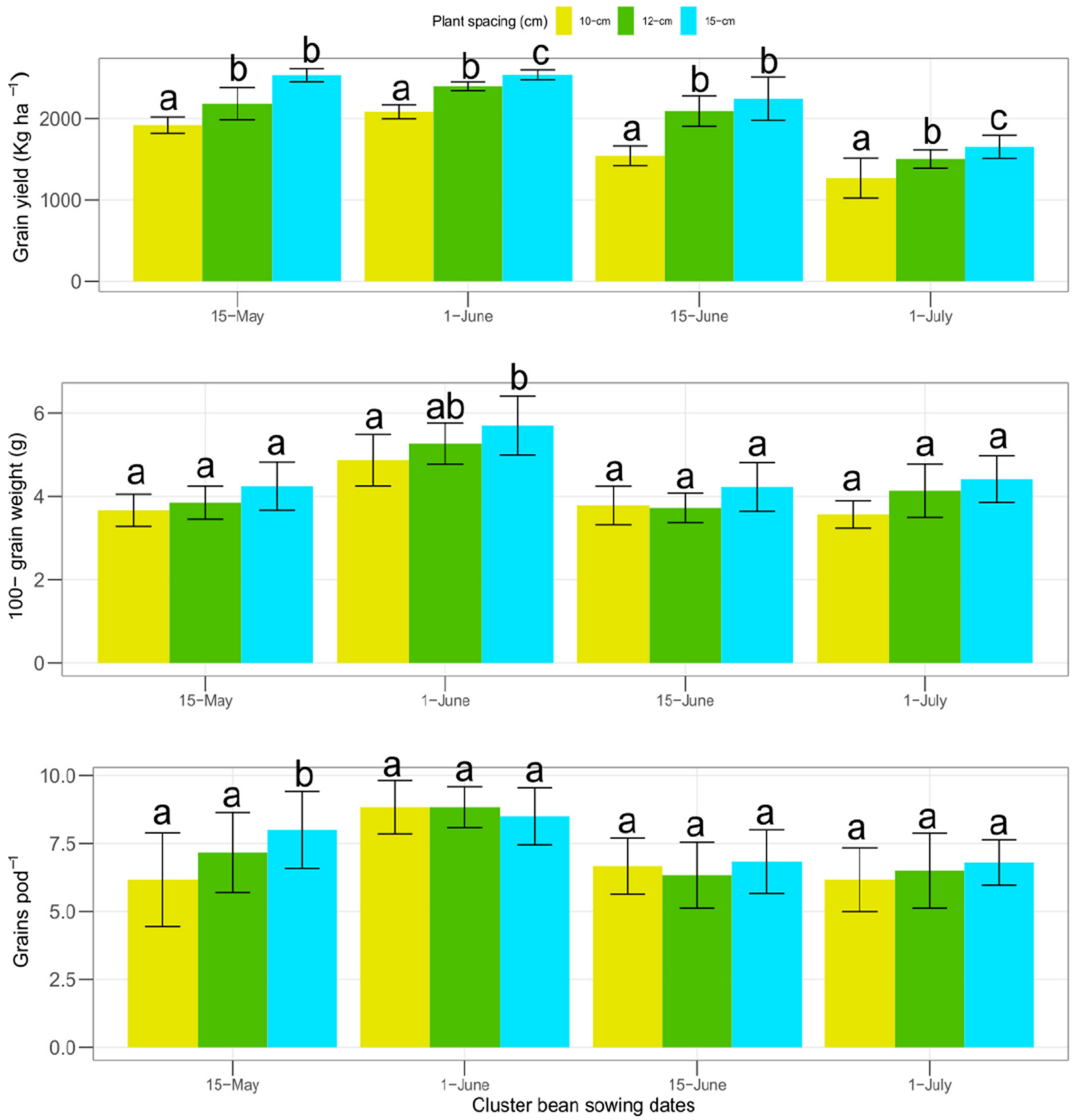

Fig. 5. Impact of sowing times and planting spacing on grain yield, 100-grain weight, and grain pod^{-1} of cluster bean. The values are the mean of three replication. The error bars represent the standard deviation (n = 3). Within sowing time, the same letter (s) values are statistically non-significant at $p < 0.05$.

contents than other sowing times (15th May, 15th June and 1st July). The wider plant spacing 15 cm showed a higher response on chlorophyll contents in all sowing times than 10 and 12 cm (Fig. 8B). In 15th May, plant spacing 15 cm showed 0.1 and 3.7% compared to 10 and 12 cm, respectively (Table 7). In 1st June, plant spacing 15 cm showed 29.2 and 9.0% compared to 10 and 12 cm respectively (Table 7). In 15th June, plant spacing 15 cm showed 7.8 and 9.52% compared to 10 and 12 cm, respectively. In 1st July, plant spacing 15 cm showed 3.4 and 1.7 % compared to 10 and 12 cm respectively.

Chord Diagram: Chord diagram also justified the significance of sowing time (Fig. 10A) and plant spacing (Fig. 10B) to improve growth and yield attributes of cluster bean. On average contribution basis, it showed that 1st June sowing time is better than 15th May, 15th June, and 1st July. Sowing of 15th May is better than 1st July and 15th June. Late sowing 1st July is not suitable for cluster bean better growth and productivity (Fig. 10A). Furthermore, plant spacing 15 cm can give better results for improving growth attributes over 10 and 12 cm spacing. Plant spacing of 12 cm is also better than 10 cm. Decreasing plant spacing up to 10 cm can decrease growth and yield attributes of cluster beans over 15 cm (Fig. 10B).

4. Discussion

The present study was carried out to evaluate the effects of different sowing times (15th May, 1st June, 15th June and 1st July) and planting spacing (10, 12 and 15 cm) on cluster bean production in Multan, Pakistan. Results revealed that cluster bean sowing at 1st June showed higher values of growth, yield, and physiological parameters than the other sowing times (15th May, 15th June and 1st July). In addition, wider plant spacing (15 cm) showed better response than narrow plant spacing (10 and 12 cm).

The sowing time 1st June with planting spacing 15 cm significantly increased the plant height, chlorophyll contents, clusters plant^{-1}, pods plant^{-1}, pods per cluster, leaf area index, transpiration rate, photosynthetic rate, grains per pod, pod length, 100-

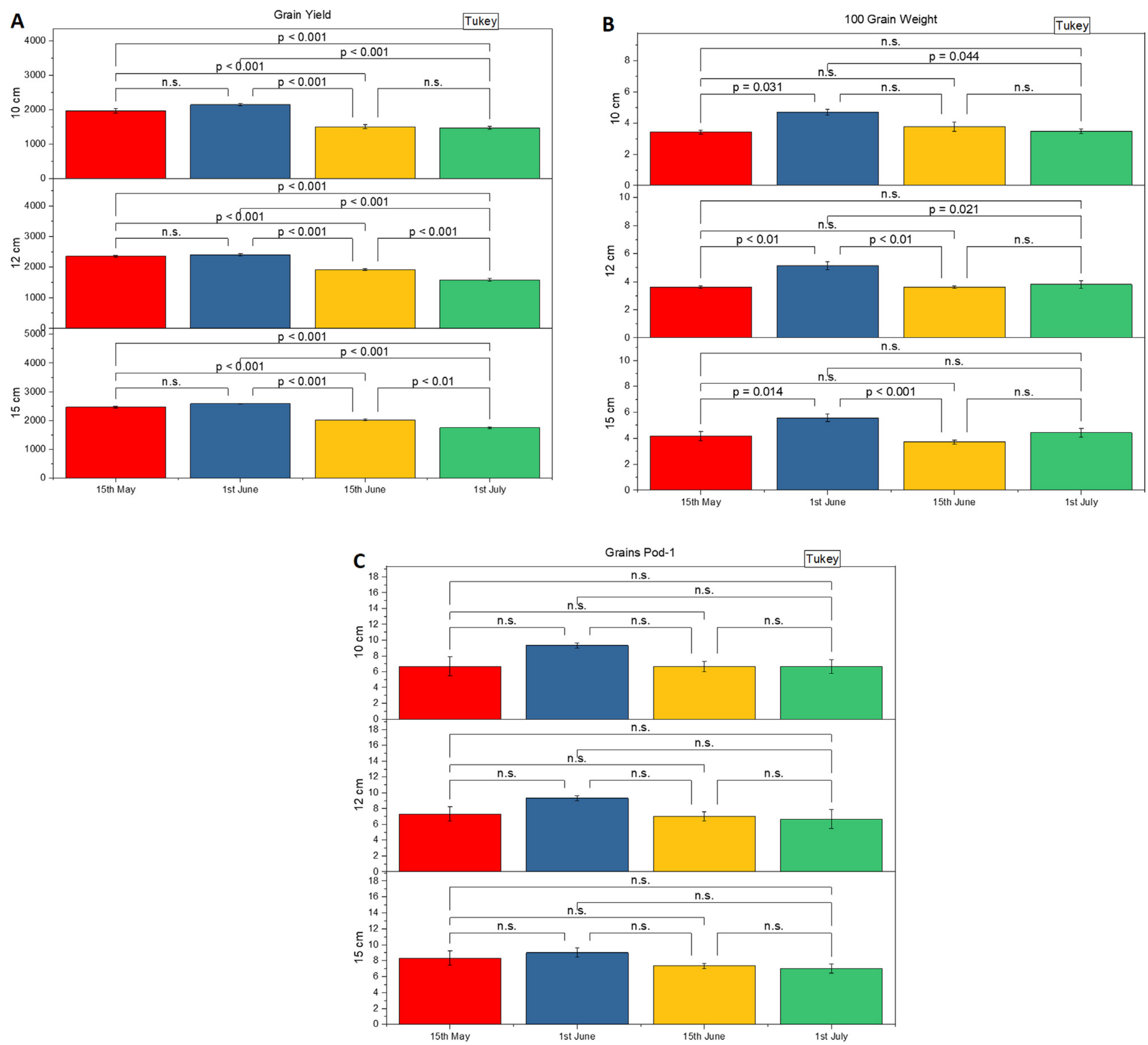

Fig. 6. Impact of sowing times and intra row spacing on grains yield (A), 100 grains weigh (B) and grains pod^{-1} (C) of cluster bean. The values are the mean of three replication. The error bars represent the standard error (n = 3). Within sowing time, the values are p values computed by Tukey test at p < 0.05.

Table 6
Impact of sowing time and intra row spacing on transpiration and photosynthetic rates of cluster bean.

Plant Spacing (cm)	Transpiration rate				Photosynthetic rate			
	Sowing times				Sowing times			
	15th May	1st June	15th June	1st July	15th May	1st June	15th June	1st July
10	4.5 ± 1.5ab	3.3 ± 1.9a	4. 6 ± 1.8a	2.4 ± 0.15a	492.8 ± 78.33a	203.2 ± 15.6a	245.2 ± 3.0a	237.3 ± 20.8a
12	2.6 ± 1.6a	2.2 ± 0.6a	3.2 ± 1.2a	4.4 ± 1.12b	451.1 ± 128.2a	249.9 ± 20.2a	271.6 ± 3.11a	431.7 ± 251.2a
15	5.3 ± 1.6b	4.1 ± 1.9a	5.3 ± 1.8a	3.2 ± 0.15ab	321.6 ± 124.2a	341.9 ± 246.4a	251.2 ± 3.0a	243.4 ± 20.8a

The values are the mean and standard deviation of three replications. Within plant spacing, the values with the same letter (s) are statistically non-significant at p < 0.05

grain weight, and grain yield. Adequate temperature and supply of nutrients increased germination, growth (Kosa, and Karaguzel, 2020), physiological and yield attributes of cluster bean in the current study might be the possible reasons for the increase of cluster bean productivity. These findings are in line with the literature. Nikam et al. (2018) showed maximum plant height when cluster bean was sown late (1st February) compared to other early sowing times (1st January and 15th January).

In February, the cluster bean sown obtained the longer duration of growth period with suitable climatic conditions compared to other sowing times. Another study conducted by Meena et al. [12] early sowings of cluster bean increase the crop growth rate and yield parameters compared to late sowing. Meen et al. (2014) found that sowing time (1st July) obtained higher cluster bean yield than 11th July and 21st July, which was due to an increase in the number of clusters plant^{-1}, pods r plant^{-1}, 100 grain weight

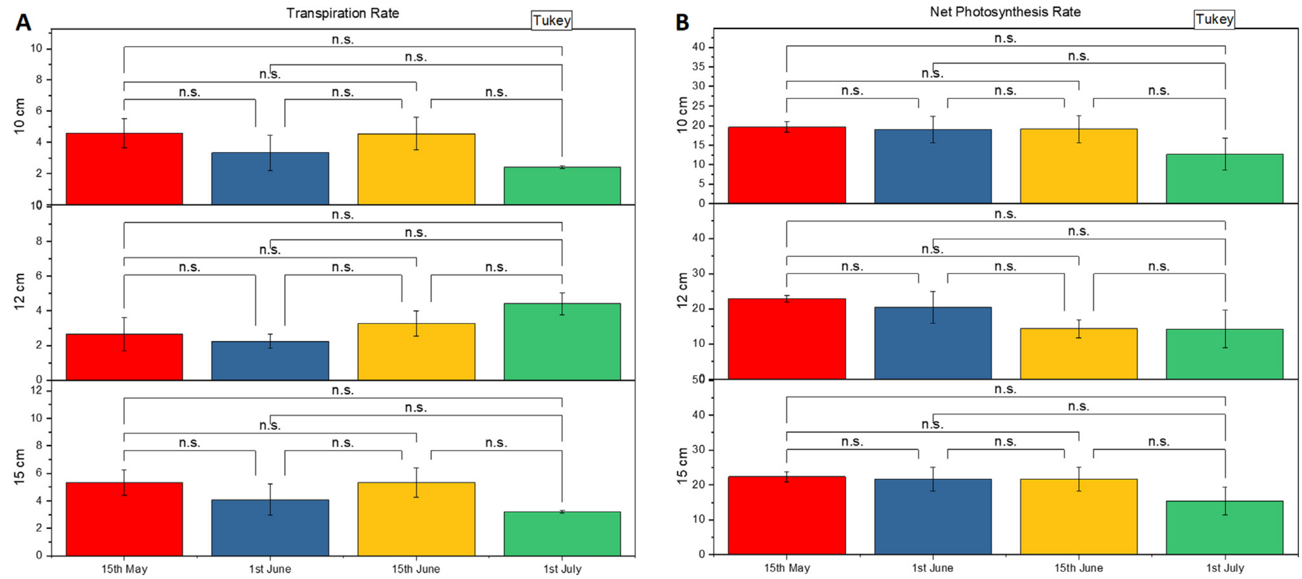

Fig. 7. Impact of sowing times and intra row spacing on transpiration rate (A) and photosynthetic rate (B) of cluster bean. The values are the mean of three replication. The error bars represent the standard error (n = 3). Within sowing time, the values are p values computed by tukey test at p < 0.05.

Table 7
Impact of sowing time and intra spacing on leaf area index and chlorophyll contents of cluster bean.

Plant Spacing (cm)	Leaf area index				Chlorophyll contents			
	Sowing times				Sowing times			
	15th May	1st June	15th June	1st July	15th May	1st June	15th June	1st July
10	0.3 ± 0.06a	0.38 ± 0.03b	0.28 ± 0.05a	0.33 ± 0.04b	62.9 ± 5.85a	65.4 ± 7.7a	64.97 ± 7.5a	38.02 ± 7.2a
12	0.3 ± 0.05a	0.36 ± 0.04a	0.3 ± 0.05ab	0.25 ± 0.04a	60.78 ± 8.48a	77.3 ± 8.2b	63.77 ± 12.3a	40.81 ± 7.1a
15	0.4 ± 0.04a	0.39 ± 0.04b	0.32 ± 0.05b	0.34 ± 0.04b	62.38 ± 11.34a	84.1 ± 5.9c	69.25 ± 5.1a	39.32 ± 1.0a

The values are the mean and standard deviation of three replications. Within plant spacing, the same letter (s) values are statistically non-significant at p < 0.05.

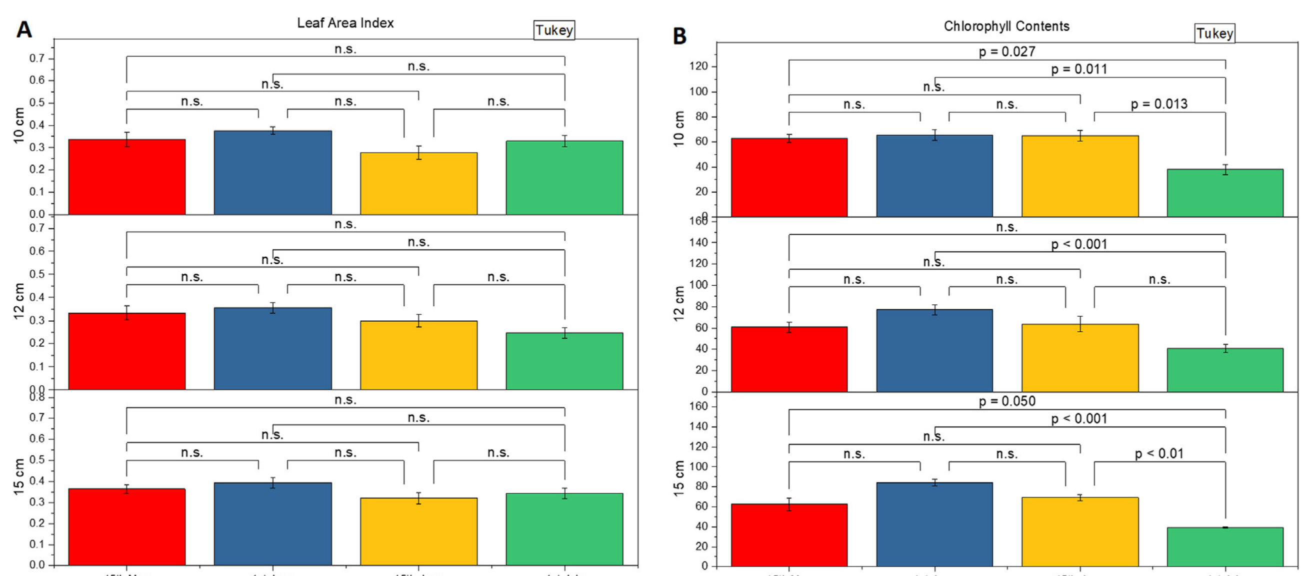

Fig. 8. Impact of sowing times and intra row spacing on leaf area index (A) chlorophyll contents (B) of cluster bean. The values are the mean of three replication. The error bars represent the standard error (n = 3). Within sowing time, the values are p values computed by Tukey test at p < 0.05.

and optimum environmental conditions during the crop period (Dhedhi et al., 2016). Ayoub and Hussein (2014) reported that unfavorable environmental conditions due to improper sowing time greatly influence cluster bean yield attributes like clusters per plant^{-1}, pods cluster^{-1}, and clusters pod^{-1}.

Dhedhi et al. (2016) reported adverse environmental effects on cluster bean yield due to late sowing. The reduction in photosynthetic rate in the study of Dhedhi et al. (2016) was found the main reason behind the low yield of cluster bean. In another study, Hunt et al. (2019) found that an early sowing system combined with

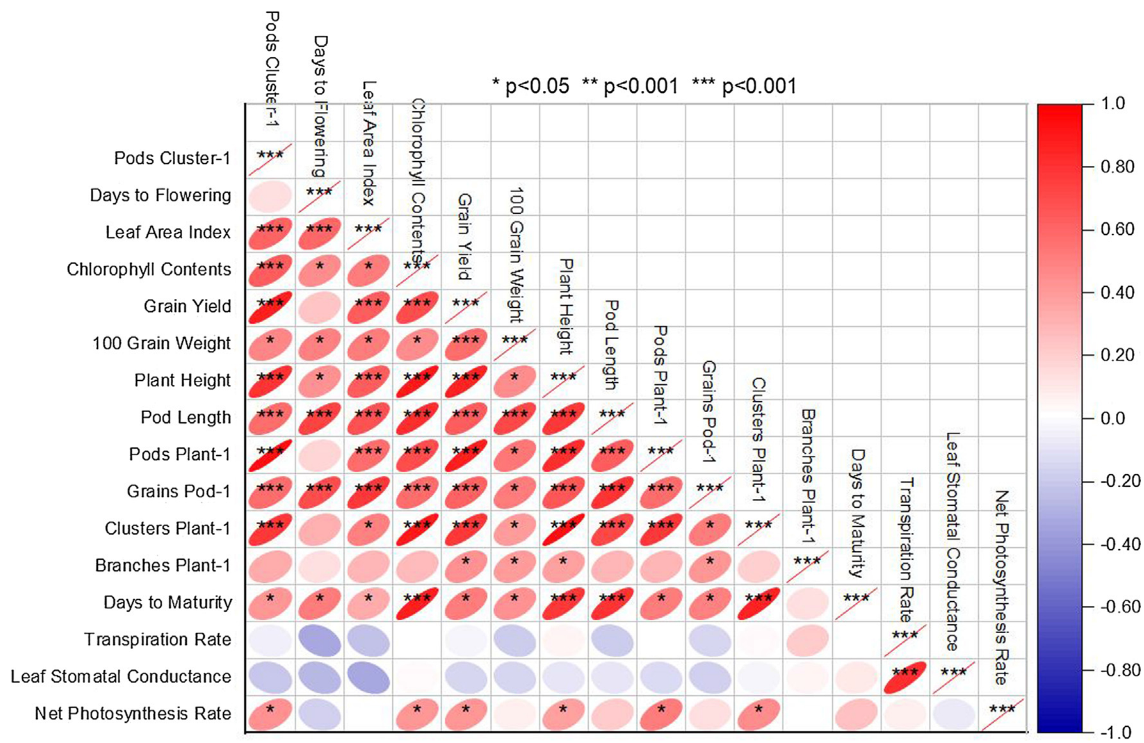

Fig. 9. Pearson correlation for different growth and yield attributes.

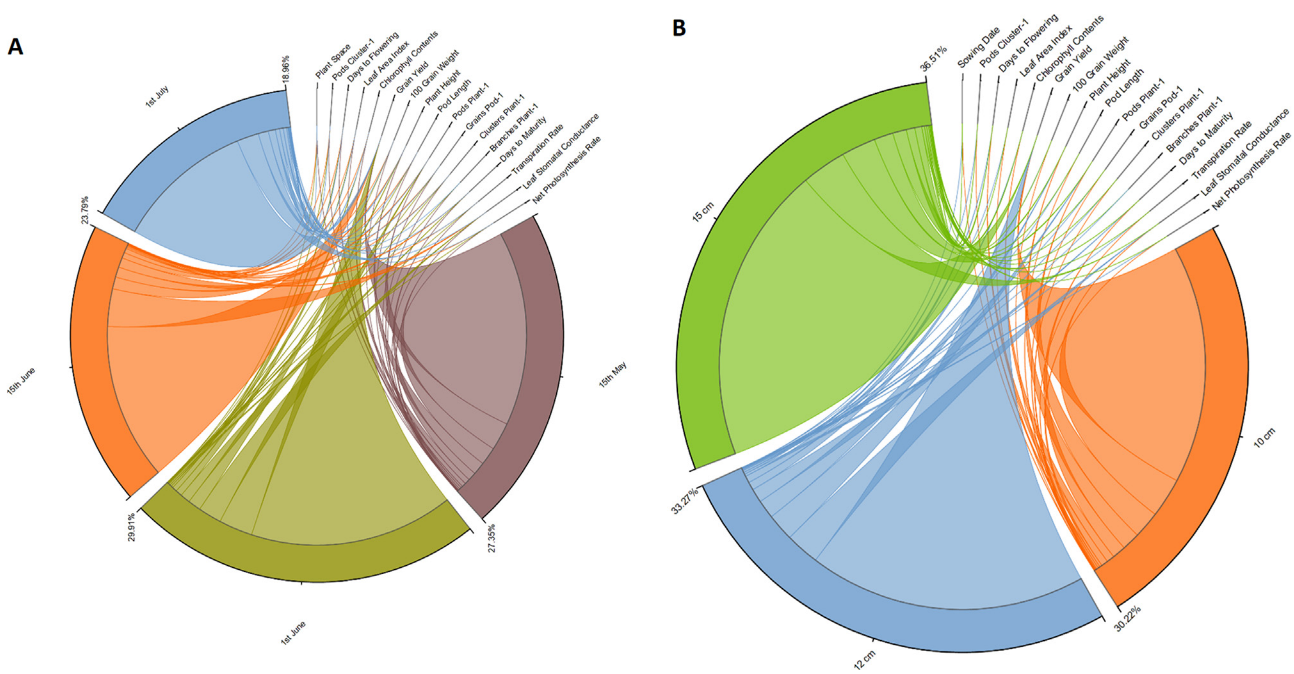

Fig. 10. Chord diagram showing contribution of sowing date (A) plant spacing (B) in improvement of growth and yield attributes of cluster bean.

slower developing wheat genotypes could be exposed to longer season and 0.54 t ha^{-1} increased in yield is possible under reduced rainfall and increasing temperature regimes. Early sowing also allows deeper root growth, more water access, and less water loss through evapotranspiration (Hunt et al., 2019). Therefore, management of sowing time is highly important under changing climatic conditions to provide plants optimal environmental conditions to flourish up to their maximum pick in respect of growth, physiological and yield development.

Zimmermann et al. (2017) studied a crop, economic and environmental model for six important crops, for 27 countries of the European Union (EU27) to assess climate change impact to 2050. Zimmermann et al. (2017) found that sowing times and thermal time requirements greatly impact crop yields, production, land use, and environmental quality. The sowing time and selection of appropriate cultivars proved helpful in optimizing yields and yield changes compared to other management practices under changing climate scenarios.

The wider plant spacing (15 cm) showed a better effect on growth, yield, and physiological parameters of cluster bean in the current study as compared to 10 and 12 cm. This might be due to less competition between plants for space, nutrients, and light. The plants might have suitable space for the extension of roots and uptake of nutrients from a large area compared to 10 and 12 cm plant spacing plants. These findings are in line with the studies reported in the literature. In the study of Nandini et al. (2017), higher plant height and number of leaves plant^{-1} were recorded with wider planting density (45 × 15 cm) as compared to lower planting density (30 × 15 cm and 45 × 10 cm) (Masa et al., 2017).

5. Conclusions

The 1st June sowing time performed better than other sowing time 15th May, 15th June, and 1st July, while plant spacing 15 cm performed best as 10 and 12 cm spacing. This might be due to prevailing suitable environmental conditions when the crop was sown on 15th June. Therefore, the combination of 1st June sowing time with 15 cm plant space could be recommended for better growth and cluster bean productivity under current climatic conditions in Multan, Pakistan. However, long-term studies are suggested with different ecological zones to revalidate the finding of this study.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This project was supported by Researchers Supporting Project number (RSP-2021/315) King Saud University, Riyadh, Saudi Arabia. This work was supported by the project APVV-20-0071.

References

Acikgoz, E., Sincik, M., Karasu, A., Tongel, O., Wietgrefe, G., Bilgili, U., Oz, M., Albayrak, S., Turan, Z.M., Goksoy, A.T., 2009. Forage soybean production for seed in mediterranean environments. F. Crop. Res. 110 (3), 213–218. https://doi.org/10.1016/j.fcr.2008.08.006.

Ali, Z., Zahul, S., Hussain, M.Z. ul, Bashu., M., 2004. Sowing dates effects on growth, development and yield of guar (Cyamopsis tetragonoloba L.) under rainfed conditions of pothowar region. J. Agric Res 42, 33–40.

Ashraf, M., Iram, A., 2005. Drought stress induced changes in some organic substances in nodules and other plant parts of two potential legumes differing in salt tolerance. Flora Morphol. Distrib. Funct. Ecol. Plants 200 (6), 535–546. https://doi.org/10.1016/j.flora.2005.06.005.

Ayaz, S., McKenzie, B.A., Hill, G.D., McNeil, D.L., 2004. Variability in yield of four grain legume species in a subhumid temperate environment. II. Yield components. J. Agric. Sci. 142, 21–28. https://doi.org/10.1017/S0021859604004113.

Ayoub, E.Z., Hussein, A.M., 2014. Effects of sowing date and plant population on snap bean (Phaseolus vulgaris L.) growth and pod yield in Khartoum State. Univers. J. Agric. Res. 3, 115–118.

Ball, R.A., Purcell, L.C., Vories, E.D., 2000. Short-season soybean yield compensation in response to population and water regime. Crop Sci. 40 (4), 1070–1078.

Blumenthal, M., Quach, J.V.P., Searle, P.G.E., 2005. Effect of soybean population density on soybean yield, nitrogen accumulation and residual nitrogen. Aust. J. Exp. Agric 28 (1), 99. https://doi.org/10.1071/EA9880099.

Choy, S., Prasad, K.M.N., Wu, T.Y., Ramanan, R.N., 2015. A review on common vegetables and legumes as promising plant-based natural coagulants in water clarification. Int. J. Environ. Sci. Technol. 12, 367–390. https://doi.org/10.1007/s13762-013-0446-2.

Dhedhi, K.K., Chaudhari, N.N., Juneja, R.P., Sorathiya, J.S., 2016. Effect of date of sowing and crop geometry on growth and production potential of cluster bean under rainfed condition of Gujarat. Int. J. Bio-resource Stress Manag. 7, 851–854. https://doi.org/10.23910/ijbsm/2016.7.4.1633.

Gresta, F., Sortino, O., Santonoceto, C., Issi, L., Formantici, C., Galante, Y.M., 2013. Effects of sowing times on seed yield, protein and galactomannans content of four varieties of guar (Cyamopsis tetragonoloba L.) in a Mediterranean environment. Ind. Crops Prod. 41, 46–52. https://doi.org/10.1016/j.indcrop.2012.04.007.

Hunt, J.R., Lilley, J.M., Trevaskis, B., Flohr, B.M., Peake, A., Fletcher, A., Zwart, A.B., Gobbett, D., Kirkegaard, J.A., 2019. Early sowing systems can boost Australian wheat yields despite recent climate change. Nat. Clim. Chang. 9 (3), 244–247. https://doi.org/10.1038/s41558-019-0417-9.

Hussain, A., Khalil, S.K., Khan, S., Khan, H., 2004. Effect of sowing time and variety on grain yield of mungbean. Sarhad J. Agric 20, 481–484.

Kumar, D., Rodge, A., 2012. Status, scope and strategies of arid legumes research in India-A review. J. Food Legum. 25, 255–272.

Kosa,, S., Karaguzel,, O., 2020. Effects of seed age, germination temperature, gibberellic acid and stratification on germination of silene compacta. Pakistan J. Bot. 52 (3), 901–908.

Kumar, M.N., Ram, A., 2018. Tree age affects postharvest attributes and mineral content in amrapali mango (Mangifera indica) fruits. Hortic. Plant J. 4 (2), 55–61. https://doi.org/10.1016/j.hpj.2018.01.005.

Kuo, S., 1996. Phosphorus, in: Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P.N., Tabatabai, M.A., Johnston, C.T., Sumner, M.E. (Eds.), Methods of Soil Analysis Part 3: Chemical Methods. John Wiley & Sons, Ltd, SSSA, Madison, Wisconsin, pp. 869–919. https://doi.org/10.2136/sssabookser5.3.c32.

Laghari, K.A., Pirzada, A.J., Sial, M.A., Khan, M.A., Mangi, J.U., 2021. Assessment of wheat (*Triticum aestivum* L.) genotypes for high temperature stress tolerance using physico-chemical analysis. Pakistan J. Bot. 53 (2), 379–385.

Lenth, R., 2017. Emmeans: Estimated marginal means, aka least-squares means. R Packag.

Masa, M., Tana, T., Ahmad, A., 2017. Effect of plant spacing on yield and yield related traits of common bean (Phaseolus vulgaris L.) varieties at Areka, Southern Ethiopia. J. Plant Biol. Soil Heal. 4, 1–13. https://doi.org/10.13188/2331-8996.1000020.

McLean, E.O., 1982. Soil pH and lime requirement, in: Page, A.L. (Ed.), Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, pp. 199–224.

Meena, H., Meena, R.S., Lal, R., Yadav, G.S., Mitran, T., Layek, J., Patil, S.B., Kumar, S., Verma, T., 2018. Response of sowing dates and bio regulators on yield of clusterbean under current climate in alley cropping system in eastern U.P., India. Legum. Res. 41, 563–571. https://doi.org/10.18805/LR-3759.

Luqman, Hussain, Z., Ilyas, M., Ahmad Khan, I., Bakht, T., 2020. Influence of sowing orientation and intercropping of chilies on onion yield and its associated weeds in Peshawar, Pakistan. Pakistan J. Bot. 52 (1), 95–100.

Meena, H.N., Meena, R.S., 2015. Role of bio-regulators in clusterbean (Cyamopsis tetragonoloba L.) productivity. Ann. Agri Bio Res. 20, 37–39.

Meena, R., Yadav, R., Meena, V., 2014. Respose of groundnut (arachis hyogaea L.) varieties to sowing dates and NP fertilizers under western dry zone of India 43, 169–173.

Nandini, K.M., Sridhara, S., Hivanand, P., Kiran, K., 2017. Effect of planting density and different genotypes on growth, yield and quality of guar. Int. J. Pure Appl. Biosci. 5, 320–328. https://doi.org/10.18782/2320-7051.2499.

Nelson, D.W., Sommers, L.E., 1982. Total Carbon, Organic Carbon, and Organic Matter, in: Page, A.L. (Ed.), Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI, USA, pp. 539–579.

Nikam, C., Nagre, P.K., Gawande, S., 2018. Effect of different dates of sowing and nitrogen levels on growth, seed yield and quality of gum cluster bean. Int. J. Curr. Microbiol. Appl. Sci. Special Is, 2043–2049. https://doi.org/10.18805/ag.D-4715

OriginLab Corporation, 2021. OriginPro. OriginLab, Northampton, MA, USA.

Pratt, P.F., 1965. Potassium, in: Norman, A.G. (Ed.), Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties, 9.2. John Wiley & Sons, Ltd, pp. 1022–1030. https://doi.org/10.2134/agronmonogr9.2.c20.

Punia, A., Yadav, R., Arora, P., Chaudhury, A., 2009a. Molecular and morphophysiological characterization of superior cluster bean (Cymopsis tetragonoloba) varieties. J. Crop Sci. Biotechnol. 12 (3), 143–148. https://doi.org/10.1007/s12892-009-0106-8.

Punia, A., Yadav, R., Arora, P., Chaudhury, A., 2009b. Molecular and morphophysiological characterization of superior cluster bean (Cymopsis tetragonoloba) varieties. J. Crop Sci. Biotechnol. 12 (3), 143–148. https://doi.org/10.1007/s12892-009-0106-8.

R_Core_Team, 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria [WWW Document].

Rai, P.S., Dharmatti, P., 2013. Genetic divergence studies in cluster bean (Cyamopsis tetragonoloba L). J. Sci. Front. Res. Agric 13, 1–5.

Rhoades, J.D., 1996. Salinity: Electrical Conductivity and Total Dissolved Solids, in: D.L. Sparks, A.L. Page, P.A. Helmke, R.H. Loeppert, P. N. Soltanpour, M. A. Tabatabai, C. T. Johnston, M. E. Sumner (Eds.), Methods of Soil Analysis, Part 3, Chemical Methods. Soil Science Society of America, Madison, WI, USA, pp. 417–435. https://doi.org/10.2136/sssabookser5.3.c14.

Sabahelkheir, M.K., Abdalla, A.H., Nouri, S.H., 2012. Quality assessment of guar gum (Endosperm) of guar (Cyamopsis tetragonoloba). ISCA J. Biol. Sci. 1, 67–70.

Srivastava, S.K., Anees, Ramani, R., 2011. . Promise of Guar Meal. Sci. Report. 38–39.

Steel, R.G., Torrie, J.H., Dickey, D.A., 1997. Principles and Procedures of Statistics: A Biometrical Approach. McGraw Hill Book International Co., Singapore.

Sudarma, K., Aini, N., Wicaksosno, K.P., 2015. Improving of kidney bean production by plant spacing in two different altitudes at south central timor regency Indonesia. Online J. Biol. Sci. 15 (4), 268–273.

Tripp, L.D., Lovelace, D.A., Boring, E., 2011. Keys to profitable guar production. Texas Agric. Exp. Stn. Bull., 7–11
Watson, D.J., 1952. The Physiological Basis of Variation in Yield, in: Norman, A.G. (Ed.), Advances in Agronomy. Academic Press, pp. 101–145. https://doi.org/10.1016/S0065-2113(08)60307-7.
Zimmermann, A., Webber, H., Zhao, G., Ewert, F., Kros, J., Wolf, J., Britz, W., Vries, W. D., 2017. Climate change impacts on crop yields, land use and environment in response to crop sowing dates and thermal time requirements. Agric. Syst. 157, 81–92. https://doi.org/10.1016/j.agsy.2017.07.007.