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Growth, yield and quality attributes of guar (*Cyamopsis tetragonoloba* I.) genotypes grown under different planting dates in a semi-arid region of Pakistan

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Guar (*Cyamopsis tetragonoloba* L.) is grown in semi-arid regions worldwide as a forage, vegetable, and green manure crop. An experiment was conducted to evaluate growth, forage yield and nutritional quality of guar genotypes grown under different sowing dates. To this end, seven genotypes, *viz.*, Desi Punjab, Farmi Punjab, Desi Sindh, Farmi Sindh, BR-90, BR-2017 and Baluchistan were grown at three sowing times (mid-May, late-May and early-June) during the two years 2020 and 2021. Results showed that maximum leaf area and pods per plant were recorded in genotype Farmi Punjab, while maximum fresh and dry forage yield were archived in genotype 'BR-90'. Similarly, maximum crude protein in the forage and gum content in mature seeds, were also recorded in BR-90. In addition, mid-May was proved to be the best sowing time for guar genotypes studied in view of achieving maximum morphological traits, fresh and dry forage yield and forage quality, compared to later planting times. Moreover, late sowing caused reduction in yield and other related attributes. It is perceived that synthetic guar variety BR-90 and planting time at mid-May are the best for semi-arid region of Punjab, Pakistan.
Keywords: Sowing dates, morphological traits, forage yield, forage quality, guar genotypes, semi-arid regions.

INTRODUCTION

Guar (*Cyamopsis tetragonoloba* L.) is a seasonal restorative crop grown in most parts of Pakistan and India due to its ability to comply with limited water supply. Guar can be edible in green form as animal feed, as snap bean or may be utilized as green amendment (Gomaa and Mohamed, 2007). Due to its commercial importance and tolerance to various abiotic stresses, guar is grown in many world areas (Trostle, 2020). The 80% of the total production is obtained from steppe climatic regions of India, 15% from Pakistan, while the remaining 5% is mainly obtained from the US (Oklahoma and Texas) and Sudan (Sharma, 2014). It can be grown in a variety of environmental and soil conditions (Gresta *et al.*, 2014) because of its adaptability to coarse textured, saline and low fertility soils (Ashraf *et al.*, 2002; Ashraf *et al.*, 2005).
As a seed crop, guar is cultivated for its commercial utilization as source of gum, which is actually galactomannans (Miyazawa and Funazukuri, 2006). Galactomannans for industrial purposes (Jackson and Doughton, 1982) are obtained from guar as well as from carob (*Ceratonia siliqua*). Galactomannans are hetero-polysaccharides made of side-chain D-galactopyranosyl residues that have been substituted to a variable degree by (β-1,4)-linked D-mannopyranosyl residues in the main chain. The physical characteristics of the galactomannans and their complex chemical structure are determined by the ratio of galactose to mannose (Marten and Brunstedt, 2001). Between 13% and 18% of the guar seed consists of husks; 34-43% is endosperm and the remaining 41-46% is embryo (Srivastava *et al.*, 2011). Galactomannans account for 30% of the total seed weight and are present in the endosperm (Sabahelkheir*et al.*, 2012; Abidi *et al.*, 2015). Gel is produced when water is mixed with guar gum (King, 2008), which has high viscosity, thickness and bonding properties. These properties make the gel a binding and stabilizing agent in different sectors as printing, paper, paint, drilling, food, medicine, cosmetics, chemical and agrochemical industries (Lubbe and Verpoorte, 2011; Kalyani, 2012).
Depending on the quantity of this polysaccharide and other seed components, namely ash and protein, guar gum is divided into two main groups: high and low quality gum. High

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quality gum is mainly utilized in food preparations. On the other hand, low quality gum is utilized in non-edible industries (Undersander *et al.*, 1991). Guar gum is composed of various carbohydrate polymers (galactose, mannose), whose composition is almost similar to the gum of locust bean. Guar gum is water soluble and can be used in many edible products as emulsifiers, stabilizers, thickeners and soluble dietary fiber (SDF) (Kays *et al.*, 2006).

Unfavorable environmental conditions along with the variation in sowing time significantly affects plant growth and development (Meftahizadeh *et al.*, 2019). Optimization of planting period is helpful in maximizing production under changing climatic condition (Hussain *et al.*, 2022).The resilience of guar to changing climate (Abidi *et al.*, 2015) and ability to survive under semi-arid environment makes this plant suited for the Egyptian environment. May-August planting time showed enhanced guar grain production under strong environmental change in Northwest India and Pakistan (Losavio*et al.*, 2002). However, sowing of guar at mid-May was shown responsible for maximizing guar output under the Mediterranean condition of Italy (Gresta *et al.*, 2013).

The most crucial elements for a good stand establishment in the field and potential production are the sowing date and plant density (Deka *et al.*, 2015). Furthermore, due to weather changes, choosing the right sowing date is essential for achieving a high yield. The date of guar sowing could change from May to August (Gresta *et al.*, 2013). According to Tiwana and Tiwana (1992), late sowing (June 30) produced noticeably taller plants than early sowing (June 15 and 17). Additionally, it was noticed that early seeding produced grain with a noticeably higher weight than late sowing (Abbas *et al.*, 2017). According to Kalyani (2012), the first and second fortnights of July and August were the best times for sowing. Semi-arid environment with an average annual rainfall of 250 mm is suitable for guar production under low nutrient and ample sunlight availability (Ashraf *et al.*,2005). However, two to three irrigations are required for the cultivation of guar in rainfed areas (Singh, 2014). Average water requirement for guar production has been estimated to be 2650 m^3 ha^{-1} (Gresta *et al.*, 2013).

Gum of guar has been newly used as a lubricant in the hydraulic fracturing of the oil industry (Abidi *et al.*, 2015; Gresta *et al.*, 2013). The process of natural gas extraction can be enhanced when guar gum is used as a fracking liquid (King, 2008). Heavy use of guar gum for the extraction of natural gas or oil pushed the demand for gum in the whole world (Gresta *et al.*, 2013).

In contrast to the experiences acquired in other world areas, a limited data is available on ideal sowing time for guar in the Punjab, Pakistan. Besides sowing time, very little information is available about guar genotypes that can be grown fruitfully in this arid region for forage purposes, owing to the intrinsic drought resistance of this crop and the prevailing uses for biomass produced in this region. Therefore, a two-year field experiment was conducted with the aim of determining the effects of sowing dates on crop stand, growth and forage yield of different guar genotypes planted in the Thal region, Punjab, Pakistan.

MATERIALS AND METHODS

***Site description*:** A two years (2020 and 2021) field experiment was conducted in the research area, Department of Agronomy, Bahauddin Zakariya University Bahadur Sub Campus Layyah (30°57’N; 70°56’E; 151m asl), Pakistan. Soil of the experiment site plays an important role for the growth and development of crop. For the determination of soil physico-chemical properties, soil samples were collected from different parts of the field with the help of an auger, mixed and sent to the laboratory. Soil physico-chemical properties were determined using standard procedure. The two years average data revealed that the soil was a sandy loam having alkaline pH (8-8.5), organic matter content of 0.65%, total nitrogen 0.15-0.19 g kg^{-1}, available phosphorus 6 mg kg^{-1}, available potassium 86 mg kg^{-1}, and electrical conductivity 1.06 dS m^{-1}. Weather data is important for any crop related scientific study, as crop growth and development strongly depends on weather. The weather data of the experimental site during the two growth seasons are shown in Table 1.

***Seed collection*:** Guar seed was collected from different provinces of Pakistan. Desi Punjab and Farmi Punjab were obtained from local farmers of Layyah, while BR-90 and BR-2017 were obtained from Regional Agriculture Research Institute (RARI), Bahawalpur; Desi Sindh and Farmi Sindh were obtained from Sindh Province, and Farmi Baluchistan from the Department of Agriculture, Baluchistan, Pakistan.

Table 1. Meteorological data of the experimental site during the 2020 and 2021 growing seasons.

Month	Rainfall (mm)			Average Temperature ˚C			Relative humidity %	
	2020	2021	Last 10 years mean	2020	2021	Last 10 years mean	2020	2021
May	9.5	0.7	15.8	30.75	31.45	30.8	60.5	54.7
June	8.5	27.9	32.4	32.75	33.40	32.6	55.5	61.3
July	58.6	48.0	72.9	33.70	34.40	33.1	71.2	80.2
August	86.5	9.0	92.4	33.40	32.60	33.2	72.9	76.1
September	28.0	6.8	24.3	30.80	31.60	31.0	79.4	77.4
October	trace	trace	25.5	25.40	26.45	25.1	76.8	79.3

Experimental materials and design**:** The seven aforementioned genotypes were tested under different sowing times (mid-May, late-May and early-June) during the years 2020 and 2021. The experiment was planned in a randomized completely block design (RCBD) in a split-plot arrangement at three replicates during both years. Planting dates and genotypes were kept in main plots and sub plots, respectively. The net plot size was 1.2 m × 4 m (4.8 m^2), meaning 4 rows 30 cm apart per 4 m length.

Cultivation practices**:** Two field cultivations followed by disc harrowing were carried out to incorporate the previous crop's residues to prepare the flat seed bed during both years. The crop was sown with the help of hand drill by keeping row to row distance of 30 cm. The crop was irrigated five times according to the need of guar crop. No herbicide was applied to guar crop during both years. Recommended fertilizer 125:125:75 NPK kg ha^{-1} was applied in the form of urea (46% N) and DAP (18% N; 46% P_2O_5) and sulphate of potash (50% K_2O), respectively. The manual weeding was done with the help of a spade. Harvesting of crop was done on 19-09-2020 and 16-09-2021 (1^{st} sowing), 02-10-2020 and 30-09-2021 (2^{nd} sowing), and 25-10-2020 and 22-10-2021 (3^{rd} sowing).

Data collection

Morphological and yield related traits**:** Ten plants were randomly selected from each plot to measure plant height, number of branches and pods per plant. Leaves and stem weight were measured from the randomly selected plants from each plot, and then samples were sun dried to obtain dry forage yield. Samples were weighed on a digital scale. Leaf area was measured with a leaf area meter (LICOR 3100, LI-COR, Inc.) after separating the leaves, and the ten-plant average was determined and expressed in cm^2.The central two rows were harvested to determine the fresh forage yield. After drying the samples at 60 ˚C to a constant weight, the dry forage yield was measured.

Crude protein and ash content**:** Whole plants in each experimental unit were ground and random samples (5 g) were collected from each, pooled samples from the two years were submitted to the laboratory for analysis of the quality traits (crude protein and ash contents). The crude protein content was calculated by using the formula of N concentration × 6.25, while nitrogen concentration was determined by the Kjeldahl procedure (AOAC, 2002) on whole plant samples. Sub-samples were combusted in a muffle oven at 550 °C for 3h to determine ash (AOAC, 2002).

Gum content**:** The assessment of gum content in mature seeds was carried out on pooled samples of the two years, as in the case of protein and ash content. Gum content was extracted by the standard procedure (Chudzikowski, 1971)

Statistical analysis**:** All data were statistically analyzed by using the software CoStat 6.3 (CoHort Software, Monterey, CA, USA). A three-way ANOVA was run for the sources (genotypes, sowing dates, years and their multiple interactions).

The homogeneity of variances was controlled by means of the Bartlett's test. Subsequently, a mixed model ANOVA was run for sowing dates and genotypes (fixed factor), and years (random factor), and their interaction. The error mean squares used in the calculations of the *F* values were based on the fixed (ST and CV) and random (year) factors, according to Steel et al. (1997). Significant treatment means were separated with the Student-Newman-Keuls (SNK) test at 5 % probability level (Steel *et al.*, 1997).

RESULTS

Morphological traits**:** The ANOVA results indicated that the guar genotypes differed significantly for leaf area and pods per plant (Table 2). Sowing dates were significantly different only for leaf area (Table 2).

Table 2. Effect of different sowing dates on plant growth traits of guar genotypes sown at different dates in 2020 and 2021.

Sources	Plant height (cm)	No. of branches $plant^{-1}$	Leaf area (cm^2)	No. of pods $plant^{-1}$
Sowing dates (SD)				
Mid-May	154.2	4.1	48.5a	9.6
Late-May	135.4	3.8	48.3a	3.8
Early-June	93.9	1.7	44.3b	1.1
Genotypes (G)				
Desi Punjab	121.1	4.5	47.3c	5.1ab
Farmi Punjab	120.8	3.9	48.1a	8.4a
Desi Sindh	121.8	2.7	47.2c	5.1ab
Farmi Sindh	128.2	3.4	47.8b	0.9b
BR-90	144.2	2.8	46.4d	1.9b
BR-2017	133.2	1.6	46.7d	4.9ab
Baluchistan	125.6	3.2	45.7e	7.7a
Year (Y)				
2020	111.9b	3.2	42.7b	2.5b
2021	143.8a	3.1	51.3a	7.2a
F-values				
Sowing dates (SD)	3.3ns	2.3ns	103.7**	7.0ns
Genotypes (G)	1.6ns	0.8ns	99.0**	6.7*
Years (Y)	803.3**	0.17ns	265.7**	11.0**
SD × G	3.0*	1.3ns	60.1**	13.3**
SD × Y	299.0**	5.7*	0.26ns	1.80ns
G × Y	20.7**	3.5*	0.01ns	0.31ns
SD × G × Y	2.4*	1.2ns	0.01ns	0.12ns
C.V. (%)	4.9	7.3	6.3	12.4

ns, , *, ** mean non-significant, significant at $P \leq 0.10$, $P \leq 0.05$ and at $P \leq 0.01$, respectively. In each source, means sharing the same letters do not differ significantly (SNK test; $P \leq 0.05$).

Year was significantly different for all morphological traits except the number of branches. Similarly, the two-way interaction of sowing dates with genotypes had significant differences for plant height, leaf area and pods per plant (Table 2).

Among guar genotypes, highest leaf area and pods per plant were recorded in Farmi Punjab that was statistical at par with genotype Baluchistan, as compared to the other genotypes. The mid-May planting resulted in the highest leaf area which was statistically similar with that produced by late-May and early-June (Table 2). The year 2021 was more favorable due to optimum rainfall and favorable temperature for plant height, leaf area and pods per plant of guar.

***Dry biomass traits*:** Sowing dates were non-significant ($P \leq 0.05$) for stem dry weight and leaf dry weight (Table 3). Similarly, genotypes were non-significant for stem and leaf dry weight. The year effect was also significant for these traits. Two-way interactions of sowing dates with genotypes were non-significant for dry biomass traits (Table 3). Maximum stem dry weight was recorded in mid-May planting date as compared to early June. The year 2021 was more favorable for stem and leaf dry weight.

Table 3. Effect of different sowing dates on biomass traits and yield related components of guar genotypes sown at different dates in 2020 and 2021.

Sources	Stem dry weight (g plant^{-1})	Leaf dry weight (g plant^{-1})	Fresh forage yield (t ha^{-1})	Dry forage yield (t ha^{-1})
Sowing dates (SD)				
Mid-May	14.7	20.5	34.3a	17.8
Late-May	12.5	16.1	26.7a	13.9
Early-June	8.9	13.4	10.9b	5.4
Genotypes (G)				
Desi Punjab	14.7	18.8	18.8b	9.8b
Farmi Punjab	11.3	16.2	24.6ab	12.1ab
Desi Sindh	11.8	16.2	24.8ab	12.9ab
Farmi Sindh	12.6	17.8	26.6ab	14.0ab
BR-90	12.7	15.6	30.3a	15.8a
BR-2017	11.9	16.8	23.4ab	12.1ab
Baluchistan	9.2	15.3	19.6b	10.0b
Year (Y)				
2020	10.1b	7.3b	21.5b	9.1b
2021	13.9a	26.1a	26.5a	15.7a
F-values				
Sowing dates (SD)	13.7$^{(+)}$	1.8ns	36.2*	10.8$^{(+)}$
Genotypes (G)	2.3ns	2.5ns	7.2*	6.3*
Years (Y)	752.0**	8245.9**	90.7**	342.5**
SD × G	1.0ns	1.7ns	3.9*	2.1ns
SD × Y	43.2**	218.6**	19.01**	39.5**
G × Y	35.4**	8.5**	4.59**	3.2*
SD × G × Y	4.9**	2.4*	1.71ns	2.0*
C.V. (%)	6.5	7.0	12.3	16.1

ns, , *, ** mean non-significant, significant at $P \leq 0.10$, $P \leq 0.05$ and at $P \leq 0.01$, respectively.In each source, means sharing the same letters do not differ significantly (SNK test; $P \leq 0.05$).

***Forage yield related traits*:** Sowing dates and genotypes significantly influenced fresh and dry forage yield (Table 3). The year effect was significant for fresh forage and dry forage yield; indicating approximately a 23% and 72% advantage in 2021 vs. 2020, respectively (Table 3). Two-way interaction of sowing dates with genotypes was significant for only fresh forage yield (Figure 1). The mid May sowing date had significantly higher fresh and dry forage yield than both late May and early June. Among the guar genotypes, BR-90 produced the highest fresh yield (30.3 t ha^{-1}) and dry forage yield (15.8 t ha^{-1}) as compared to the other tested genotypes, while the lowest values were found in genotype Desi Punjab which was statistically similar with Baluchistan.

***Crude protein and ash content*:** Sowing dates and genotypes significantly influenced whole plant crude protein and ash contents. The two-way interaction of sowing dates with genotypes was significant for ash contents (Figure 1) and remained non-significant for crude protein (Table 4). Among guar genotypes, maximum crude protein and ash contents were recorded in BR-90 as compared to the other tested genotypes. The mid-May sowing date resulted in the maximum crude protein and ash content with respect to the late-May and early-June planting (Table 4).

Table 4. Effect of different sowing dates on whole plant crude protein and ash contents, and seed gum content of guar genotypes sown at different dates (data on pooled samples of the two experimental years).

Sources	Crude protein (g kg^{-1})	Ash content (g kg^{-1})	Gum content (g kg^{-1})
Sowing dates (SD)			
Mid-May	275.6a	71.5a	289.9a
Late-May	257.5b	57.8b	270.0b
Early-June	238.3c	49.7c	251.2c
Genotypes (G)			
Desi Punjab	237.8e	49.6f	246.0f
Farmi Punjab	228.2f	46.9g	225.3g
Desi Sindh	269.3b	69.9b	284.8b
Farmi Sindh	256.5c	57.3d	268.1d
BR-90	295.1a	80.9a	335.4a
BR-2017	267.7b	61.4c	276.1c
Baluchistan	245.3d	51.7e	256.8e
F-values			
Sowing dates (SD)	305.5**	712.7**	300.5**
Genotypes (G)	188.2**	373.8**	417.5**
SD × G	0.13ns	11.0**	0.04ns
C.V. (%)	1.9	3.2	1.9

ns, , *, ** mean non-significant, significant at $P \leq 0.10$, $P \leq 0.05$ and at $P \leq 0.01$, respectively.In each source, means sharing the same letters do not differ significantly (SNK test; $P \leq 0.05$).

***Gum content*:** Gum content in guar seeds at maturity indicated significant differences among genotypes and planting dates. Two-way interaction of sowing dates with genotypes was non-significant for gum content (Table 4). Among genotypes, maximum guar gum content was recorded in BR-90 as compared to the other tested genotypes. The mid-May sowing date had significantly the maximum guar content than late-May and early-June.

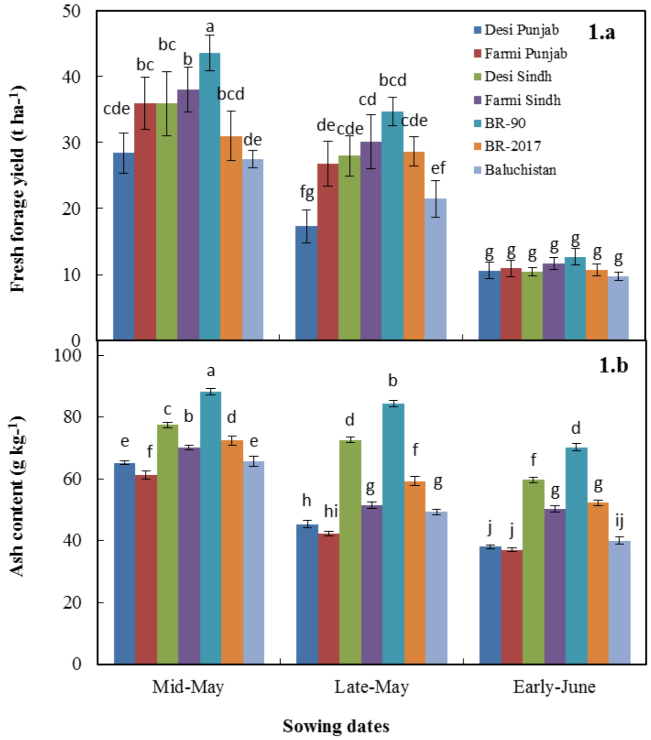

Figure 1. Interactive effect of sowing dates and genotypes of guar crop grown under field condition. 1.a, fresh forage yield; 1.b, ash content. In each source, means sharing the same letters do not differ significantly (SNK test; $P \leq 0.05$).

DISCUSSION

The planting date is a key factor that affects vegetative and reproductive stages as well as the duration of the growing season, all of which affect fresh forage yield, quality and seed gum content. The purpose of this study was to investigate how different sowing times (mid-May, late-May, and early-June) and genotypes affect cluster bean (guar) production in Layyah, Pakistan. The results showed that cluster bean sowing at the middle of May produced higher growth, yield, and physiological attributes than the other sowing times. Higher value of morphological attributes may be due to more suitable temperature and other favorable ambient conditions plants experience during early stages of growth (Sing *et al.*, 2021; Singla *et al.*, 2016).

Meftahizadeh and Hatami (2022) evaluated the performance of guar genotypes under different sowing dates and reported that guar attributes as plant height, crop cycle length, and number of pods/plant were all significantly influenced by three factors (planting time, genotypes and year) and their multiple interactions, which was also observed in the current study. Increase in these attributes leads to increase in seed and biological yield due to their positive correlation with the yield. The reduction in harvest index at late plantings may be due to the shrinking of the growth period and its influence on the reproductive stage, which resulted in a reduction in the number of pods per plant and ultimately reduced biological and seed yield (Hussain *et al.*, 2022; Heydarzade *et al.*, 2022). Guar seed contains high quality fibre, protein and galactomannan. Since its protein is comparable to some other vegetable protein sources as oilseed cake used commercially in poultry diets. Seed of guar is suitable for galactomannan extraction and can also be used in future breeding programs for two-fold-use production, *i.e.*, gum and guar meal for feed uses. According to Chiofalo et al. (2018), it is one of the imperative nutritional qualities of guar seed that it contains the highest level of protein which is considered to be a most effective protein supplement for livestock. In our study, the genotype BR-90 produced maximum protein content in all sowing dates, which might to due to its better genetic makeup (Ton, 2021; Gresta *et al.*, 2018). Punia *et al.* (2009) reported that protein contents and other quality traits of guar is the product of environmental and genotypic interaction, and genotypes with better genetic make up for protein content produce higher protein contents and other quality attributes over variable environments. Maximum gum content in guar seeds was alsoobserved in genotype BR-90, which may be the result of better genetic makeup. Guar gum was produced maximum when genotypes were sown in mid-May, and minimum was produced when they were sown in mid-June in both years. The substantial variation in seed gum content associated with genotypes and, to a lesser extent, sowing date (Table 4; Honnaiah *et al.*, 2021; Meftahizadeh *et al.*, 2019) is the best premise for the choice of cultivars suited for biomass (forage) as well as seed (gum extraction) purposes. However, for the latter use also the seed yield per hectare is a relevant trait in view of determining the gum yield per hectare, which in the present experiment was not assessed.

Rasheed *et al.* (2015) reported genetic diversity in genotypes for growth and quality traits. Regarding sowing dates, maximum crude protein level was observed in early sowing and minimum level was found in late sowing (Table 4). Differences in the sowing dates may be attributed to suitable temperature and humidity at flowering and seed formation stage for the early sown crop. In turn, this circumstance favored maximum accumulation of protein and galactomannan content (Meftahizadeh *et al.*, 2019).

***Conclusion*:** It is concluded that sowing dates and guar genotypes showed significant effects on morphological, dry biomass and forage related traits of guar in the arid climate of Thal region, Punjab, Pakistan. The present experiment revealed that mid-May sowing was best with the tested genotypes in terms of morphological/biomass traits, dry biomass yield and forage quality. Further studies with earlier planting dates (in April and early May) and more diverse genotypes of guar could better define the ideal planting period in the arid climate of the Thal region of southern Punjab, Pakistan. More favorable weather conditions prevailed during the growth period starting with mid-May planting. At this sowing date genotype BR-90 achieved better morphological traits, dry biomass yield and forage quality over the other plating dates and genotypes.

***Author Contributions*:** A.Sh. (Ahmad Sher) and A.Sa. (Abdul Sattar) conceived of the idea; B.S. conducted the experiment; A.Q. and M.I. carried out the literature review; S.U.A. and L.B. worked on statistical analysis; A.Sh. and L.B. proof read and provided intellectual guidance. All authors read the first draft, helped in revision, and approved the article. All authors have read and agreed to the published version of the manuscript.

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***Data Availability Statement*:** All relevant data are included within the paper in the form of tables and figure.

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