Journal of Agricultural and Crop Research
Vol. 9(9), pp. 230-235, September 2021
doi: 10.33495/jacr_v9i9.21.154
ISSN: 2384-731X
Research Paper

Agro-physiological and yield attributes of common bean (*Phaseolus vulgaris* L.) genotypes as affected by planting density in Botswana

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Accepted 7th September, 2021.

Abstract. A field trial was conducted under drip irrigation over two seasons in 2019 and 2020, at the experimental station of the Department of Agricultural Research in Botswana, to evaluate the effects of planting density on yield and some agro-physiological attributes in common bean (*Phaseolus vulgaris* L). The experimental design was a split-plot with three replications, and two genotypes (DAB564 and DAB520) as main treatments and three planting densities as sub-treatments; 44,444 plants/ha (0.75 m between rows and 0.3 m between plants), 66 666 plants/ha (0.75 m between rows and 0.2 m between plants) and 133,333 plants/ha (0.75 m between rows and 0.1 m between plants). It came out from data recorded that, over both cropping seasons, common bean genotypes were significantly influenced by the planting density. The Planting density × Genotype effect was also significant which means that both genotypes responded differently to the planting density no matter the cropping season considered.

Keywords: Planting density, transpiration rate, stomatal conductance, leaf photosynthetic rate, grain yield.

INTRODUCTION

Legume crops play an important role as foodstuff for humans and animals, where they are a source of plant proteins that improve health (Tharanathan and Mahadevamma, 2003). Common seeds contain 22% protein, 2% fat and 61% carbohydrates as well as good levels of minerals and vitamins (DAFF, 2010). Legume crops are also able to fix atmospheric nitrogen that is released in the soil through crop residues as high-quality organic matter for soil fertility improvement. One of such legume crops is the common bean for which research investigations starting in Botswana in recent years (Molosiwa *et al.*, 2019). Common bean grows well under warm climates with average temperatures ranging from 18 to 24°C and requires rainfall ranging from 400 to 650 mm annually (Stephen *et al.*, 2014). Although common bean is well adapted to the warm climates of Botswana, there is limited information available about its cropping practices. Across the country, it is consumed greatly in primary schools and clinics (Molosiwa *et al.*, 2019).

Plant density is the major determinant of crop yield and is particularly important in large-seeded crops like the common bean. An increase or decrease in the planting density of common bean can either have a negative or a positive impact on yield. High plant density has been reported to result in increased plant height, alteration in leaf orientation and leaves becoming erect to intercept more light (Singh and Singh, 2002). Fasoula and Tollenaar (2005) reported increased competition between plants, which affected crop growth and development and ultimately yield of each plant under high plant density. On the other hand, Reddy (2000) observed that too narrow and too wide spacing affected grain yields through competition and due to the effect of shading. Under low density, yield reduction can occur due to inefficient utilization of growth factors (Gezahegn, 2019). Whenever a crop can tolerate high planting density, this often depends on many factors such as genotype, soil type and general environmental conditions. Therefore, plant density is an important limiting factor of crop yields. A reduced planting density may reduce total yield due to a reduced number of plants per unit area (Ramroodi *et al.*, 2008). In contrast, under higher planting densities, competition between plants for carbon dioxide, light, water and nutrients is increased to the detriment of crop yield. Under non-limiting conditions of soil moisture and nutrients, higher planting density may be necessary to utilize efficiently resources available for crops. However, it must be noted that optimum plant density of a crop variety at one location may not apply at other locations because of variation in soil type and other environmental conditions, hence there is a need to develop site-specific recommendations (Dabocha *et al.*, 2019).

Investigations on planting density as well as genotype screening on common bean, as a newly introduced crop in Botswana, were urgently needed to facilitate its adaption by farmers. That is all about the objective of the present study.

MATERIALS AND METHODS

Site characteristics

The climate in Botswana is arid to semi-arid, with daily temperatures ranging from 18.2 to 33.6°C in November and from 21.4 to 33.5°C in February. The soil texture was sandy-loam with 62% sand, 14% silt, 12% clay, pH 5.9, and 0.28 S/m of electric conductivity. Both trials were conducted at the experiment station of the Agricultural Research Department of the University of Botswana (24° 33'S, 25° 54'E, and 994 m above sea level) in the South-Eastern region of the country. The mean maximum and minimum temperatures of the areas during October to December of 2019 and 2020 growing seasons were ranges 20 to 35.4°C and 17 to 32°C, respectively.

Experimental design and data collection

The experiment was laid out and 2019 and 2020 following a split-plot design, with three replications and two genotypes as main treatments and three planting densities as sub-treatments (2 Gen x 3 PD x 3 Rep = 18). Common bean genotypes used were DAB564 and DAB520 whereas the planting densities tested were 44,444 plants/ha (75 cm × 30 cm), 66,666 plants/ha (75 cm × 20 cm) and 133 333 plants/ha (75 cm × 10 cm). Each sub-plot size was 2.25 m × 3 m (6.75m^2), which gives a total net surface area of 121.5 m² for a single experiment.

Phenological data recorded include the number of days to emergence, number of days to anthesis and number of days to physiological maturity. Physiological traits measured include leaf area index, stomatal conductance, transpiration rate and net assimilation rate. The physiological variables were assessed at the flowering stage using a portable photosynthesis monitoring system (LI- 6400, Licor, Lincon, USA). All measurements were performed under the following conditions: airflow 500 µmol s^{-1}, leaf temperature of 25°C, Carbon dioxide concentration in the air coming into the chamber 360-380 µl^{-1}, relative humidity in the chamber from 20 and 60% and irradiance (PAR) of 1000 µmol m^{-2} s^{-1}, which represented a condition of light saturation for the plant in the field at 10 hours in the morning (Lambers *et al.*, 2008). Ten randomly tagged plants at harvesting were used to estimate the average number of pods per plant, 100 grain mass, and pod length for each treatment, while grain yield was estimated from the net plot of 4.5 m^2 and converted into kg ha^{-1} at optimum maturity. The data obtained from each variable were subjected to a two-way Analysis of variance (ANOVA) using the STATISTICA software package, version 13.1 after the normality test was checked. The significance of differences in treatments was judged by using the Least Significant Difference (LSD) method. Significance was declared as the probability calculated $P < 0.05$.

RESULTS

Table 1 shows the effect of genotypes and plant density on the phenology of common bean during the 2019 and 2020 planting seasons. The genotype had no effect on the number of days to emergence and anthesis during 2019, but the genotype significantly influenced the two phenological stages in the 2020 season. Plant density significantly affected the phenology of common bean in both years of study (Table 1). Crops grown fewer than 66,666 plants/ha took fewer days to emerge compared to those of other density treatments, and the difference in days was significant at $p \leq 0.05$ in both years. Planting crops at 66,666 plants/ha delayed their time to reach the anthesis period and the difference in the anthesis period significantly differed with that of other densities in both the 2019 and 2020 seasons. Similarly, the longest days to maturity were observed under the 66,666 plants/ha crops, significantly differing from those of other densities on which the crops matured earlier. The interaction of genotype and density was significant for all the measured phenological stages only during the 2020 season.

All the physiological attributes of the common bean under study were significantly influenced by genotype and plant density during both the 2019 and 2020 planting seasons (Table 2). Genotype DAB 564 exhibited significantly higher mean values in all the mean values of leaf area index, transpiration rate, stomatal conductance and leaf photosynthetic rate in both years. Similarly, significantly higher mean values of the measured physiological traits were obtained from the 66 666 plants/ha treatment for both 2019 and 2020. The interaction of genotype and density means was

Table 1. Effect of genotype and plant density on the phenology of common bean during the 2019 and 2020 seasons.

Treatment	Days to emergence		Days to anthesis		Days to physiological maturity	
	2019	2020	2019	2020	2019	2020
Genotype						
DAB 564	5.44[a]	5.60[a]	39.55[a]	39.7[a]	83.6[a]	82.3[a]
DAB 520	5.33[a]	5.2[b]	39.56[a]	39.1[b]	82.0[b]	81.4[b]
LSD	0.48	0.42	1.18	0.48	1.21	0.80
Planting density						
44,444 plants/ha	5.5[a]	5.6[a]	38.8[b]	37.3[b]	77.0[c]	77.5[b]
66,666 plants/ha	4.8[b]	4.8[b]	41.6[a]	43.1[a]	89.8[a]	90.7[a]
133,333 plants/ha	5.8[a]	5.8[a]	38.1[b]	37.3[b]	81.6[b]	77.5[b]
LSD	0.59	0.51	1.45	0.59	1.48	0.98
Mean	5.4	5.4	39.6	39.4	82.8	81.89
CV (%)	8.74	7.49	2.91	1.19	1.42	0.95
Genotype*Density	NS	0.0012*	NS	0.0001*	NS	0.0011*

Means in a column with the same letters are statistically not significant at $p \leq 0.05$.

significant for leaf area index, stomatal conductance and leaf photosynthetic rate in both years of study.

There were significant differences in pod length, number of pods per plant, 100 grain mass and grain yield between the two common bean genotypes during the 2019 and 2020 seasons (Table 3). In all of these parameters, genotype DAB 564 exhibited significantly higher mean values compared to genotype DAB 520.

Plant density significantly enhanced most of the measured yield components and grain yield of the common bean during the 2019 and 2020 seasons, as reflected in Table 3. The results showed that density treatment of 66,666 plants/ha produced higher mean values in the number of pods per plant, 100 grain mass and grain yield, whereas greater pod length was obtained from the density of 44,444 plants/ha in both years. Genotype by density interaction was significant for pod length, number of pods per plant and grain yield.

DISCUSSION

The results from Table 1 showed genotype significantly increased all the measured phenological stages during the 2020 planting season, while it had no effect on them during the 2019 season. In general, most measured parameters were higher during the 2020 season compared to the 2019 season. These differences might be attributed to differences in average temperatures during the season. During the 2020 growing season, the average minimum and maximum temperatures ranged from 17 to 32°C for October to December (Meteorology data 2020), which was slightly lower compared to the same period in the 2019 growing season which recorded an average of 20 to 35.4°C (Meteorology data 2019). Normally when temperatures are higher, like in the 2019 season, the common bean plant tends to quicken its growth stages, resulting in inadequate time for grain filling, hence less overall grain yield. Plants at the density of 66,666 plants/ha emerged faster than those from other densities. Crops sown at a higher density of 133,333 plants/ha took more days to emerge and this was attributed to stronger competition for food and moisture, whereas these requirements were fulfilled at a density of 66,666 plants/ha. Adverse deciding factors in seed germination include relative humidity light, water availability and temperature changes (Garcia-Parra *et al.*, 2020). Also, germination is regulated by genetic expression and the ability of cellular division and elongation in the tissues (Lemoine *et al.*, 2013). This is why factors like moisture and food presence are important. In accordance with the above, the presence of water at the vacuole is important for radical development (Garcia-Parra *et al*., 2020), hence faster emergence at an appropriate density where moisture is not limited. These findings are similar to those reported by Hameed *et al.* (2003) who reported more days to emergence at higher density while working on wheat.

Plants at higher density took lesser days to reach the anthesis period. Because of stiffer competition for limited resources under the plant tend to quicken their development stages and reach the anthesis stage faster. These results are in agreement with those of Turk *et al.* (2003) who found out that high plant density promoted phenological development with flowering occurring 14 days earlier in the high plant density on lentils. More days to physiological maturity were observed under a density of 66,666 plants/ha. Plants under this density took a longer time to develop more pods due to enough photosynthates and also more time was spent in

Table 2. Effect of genotype and plant density on physiological attributes of common bean during 2019 and 2020 seasons.

Treatment	Leaf area index		Transpiration rate (mol H_2O/ m^2S)		Stomatal conductance (mol H_2O/ m^2S)		Leaf photosynthetic rate (µmol $CO_2/m^2/S$)	
	2019	2020	2019	2020	2019	2020	2019	2020
Genotype								
DAB 564	2.48ᵃ	2.63ᵃ	1.78ᵃ	1.87ᵃ	0.15ᵃ	0.17ᵃ	12.53ᵃ	12.05ᵃ
DAB 520	2.12ᵇ	2.16ᵇ	1.63ᵇ	1.65ᵇ	0.10ᵇ	0.12ᵇ	11.69ᵇ	11.35ᵇ
LSD	0.13	0.11	0.09	0.05	0.02	0.0057	0.36	0.14
Planting density								
44,444 plants/ha	2.28b	2.23ᵇ	1.79ᵃ	1.79ᵇ	0.09ᵇ	0.09ᵇ	11.85ᵇ	11.05ᵇ
66,666 plants/ha	2.71a	3.03ᵃ	1.89ᵃ	1.98ᵃ	0.18ᵃ	0.25ᵃ	12.96ᵃ	13.54ᵃ
133,333 plants/ha	1.91c	1.93ᶜ	1.43ᵇ	1.51ᶜ	0.10ᵇ	0.08ᶜ	11.53ᵇ	10.51ᶜ
LSD	0.16	0.14	0.12	0.07	0.03	0.007	0.44	0.17
Mean	2.31	2.40	1.71	1.76	0.13	0.15	12.12	11.69
CV (%)	5.69	4.50	5.55	3.27	15.28	3.79	2.86	1.15
Genotype*Density	0.002*	0.0001*	NS	NS	0.0004*	0.0001*	0.0036*	0.0001*

Means in a column with the same letters are statistically not significant at $p \leq 0.05$

Table 3. Effect of genotype and plant density on yield-related parameters of the common bean during 2019 and 2020 seasons.

Treatment	Pod length (cm)		No. of pods/plant		100 grain mass (g)		Grain yield (kg/ha)	
	2019	2020	2019	2020	2019	2020	2019	2020
Genotype								
DAB 564	9.6ᵃ	10.24ᵃ	9.6ᵃ	10.2ᵃ	37.86ᵃ	38.73ᵃ	1695.75ᵃ	1862.18ᵃ
DAB 520	8.6ᵃ	8.9ᵇ	8.5ᵇ	9.02ᵇ	38.02ᵃ	35.58ᵇ	1328.20ᵇ	1515.68ᵇ
LSD	0.31	0.20	0.35	0.24	1.19	0.77	5.55	60.81
Planting density								
44 444 plants/ha	9.8ᵃ	9.9ᵃ	8.9ᵇ	9.7ᵇ	38.1ᵃ	37.8ᵇ	1342.83ᵇ	1448.95ᵇ
66 666 plants/ha	8.9ᵇ	9.7ᵃ	10.1ᵃ	10.4ᵃ	39.4ᵃ	39.7ᵃ	1898.83ᵃ	2192.14ᵃ
133 333 plants/ha	8.9ᵇ	9.2ᵇ	8.2ᶜ	8.7ᶜ	36.2ᵇ	36.9ᵇ	1294.27ᵇ	1425.70ᵇ
LSD	0.38	0.24	0.43	0.30	1.47	0.94	92.53	74.48
Mean	9.2	9.6	9.1	9.6	37.9	38.2	1511.97	1688.93
CV (%)	3.31	2.07	3.74	2.48	3.07	1.96	4.86	3.50
Genotype*Density	NS	0.002*	0.007*	0.0002*	NS	NS	0.0001*	0.001*

Means in a column with the same letters are statistically not significant at $p \leq 0.05$

resource allocation which was abundant due to greater leaf area, hence the longer time taken to reach physiological maturity. It was further emphasised that the late flowering of common bean genotypes produced higher yields than earlier flowering ones (Yohannes *et al.*, 2020).

According to the results denoted in Table 2, genotype DAB 564 and density of 66,666 plants/ha exhibited significantly highest leaf area index, transpiration rate, stomatal conductance and leaf photosynthetic rate mean values during the 2019 and 2020 seasons.

At the plant density of 66,666 plants/ha, the plants had more leave area which aided in a more light interception during the critical period for grain set. As a result stomatal response was adequate to maximize gases exchange resulting in increased photosynthetic rate. In addition, the higher transpiration rate in both seasons of the study was enough to help in more absorption and upward movement of water and minerals from source to sink hence increased photosynthates (Table 2). Similar results of the increased stomatal index due to enough light resulting in increased leaf photosynthetic rate was observed by Casson and Gray (2008) and Lake *et al*. (2001).

During both years of study genotype and plant density significantly increased pod length, number of pods/plant, 100 grain mass and grain yield of common bean (Table 3). Genotype DAB 564 consistently produced more grain yield and yield-related components than genotype DAB 520, and this might be due to its improved genetic characters (genetic superiority over DAB 520) and better adaptation to the prevailing environment. According to Gasim *et al.* (2015), the values of yield and yield components in faba bean inbred lines are different. These differences could be caused by genetic or genetic and environmental factors (Gasim *et al*., 2013). In Al-Suhaibani *et al.* (2013), a significant difference between the two varieties in yield has been observed. Similar results were found in our research, where genotype DAB 564 was characterized by a higher seed yield compared to DAB 520 in all years of the experiment. Furthermore, Yohannes *et al.* (2020) found similar results while studying common bean genotypes. The superior genotype produced a high leaf area index, pods per plant and pod yield. From the results, a high genetic heritability was exhibited in biological yield, pods per plant and grain yield, and the genetic advance was attributed to addictive gene action and non-additive gene action (Yohannes *et al*., 2020).

The lower density of 44,444 plants/ha also gave a smaller yield than the 66,666 plants/ha density since in low density each plant may perform at its maximum capacity, but there may be insufficient total plants to reach the optimum yield (Al-Suhaibam *et al.*, 2013). The results of this study are supported by those of Dobocha *et al.* (2019), who reported the lowest yield of 1998.4 and 3105.7 kg/ha for lower densities of 10 and 30 plants/m^2, respectively.

Maximum grain yield of fewer than 66,666 plants/ha density was attributed to improvement in the number of pods/plant and 100 grain mass, since these components add to grain yield. The 66,666 populated plants utilized nutrients better, and photosynthates for grain filling because of more absorption of photosynthetically active radiation due to larger leaf surface area (as reflected by higher leaf area index in Table 2), hence greater light was intercepted, resulting in increased pod development hence more grain yield. Results of the current study are in agreement with those of Musana *et al.* (2020) who reported significantly more 100 grain mass, grain yield and pods/plant at an appropriately lower density (250,000 plants/ha) compared to higher density (350,000 plants/ha). Increased number of pods under lower plant densities (66,666 plants/ha) compared to the higher density of 133,333 plants/ha could be attributed to greater light capture coupled with less interplant competition, and this allows efficient utilization and partitioning of photosynthates into seed production (Bakry *et al*., 2011; Khalil *et al.*, 2010). Furthermore, in the current study, a higher density of 133,333 plants/ha crops might have been exposed to more induced stress by more shading, resulting in more flower drops, hence reduced photosynthesis (Leech *et al.*, 1998). The reduction in yield caused by high plant density (133,333 plants/ha) could be due to the competition between plants for this treatment which began during early vegetative growth. This competition increases shading between leaves, leading to insufficient carbon fixation, increases respiration rate and increases intra-plant competition between vegetative and reproductive structures for assimilates (Dabocha *et al.*, 2019). The results conform to those of Al-Suhaibani *et al.* (2013), who reported the seed yield per hectare was significantly increased with densities up to certain plant population/m^2.

CONCLUSIONS AND RECOMMENDATIONS

Plant density significantly affected both genotype and yield of beans. It significantly influenced the measured physiological traits of the common bean. The results also showed that Genotype DAB 564 produced significantly more grain yield (21.67%) than DAB 520. Plant density of 66,666 plants/ha increased grain yield by 31.84 and 34.96% for 2019 and 2020 years, respectively. The interaction of 66,666 plants/ha density and genotype DAB 564 gave the highest mean grain yield of 2314.18 kg/ha. It is recommended that the trial be replicated to other agro-ecological zones of Botswana for adaptability comparisons.

ACKNOWLEDGEMENTS

The authors greatly acknowledge the financial support from the PABRA-CIAT and the Department of Agricultural Research under the Ministry of Agriculture and Food Security. Our sincere appreciation and thanks go to the Technical Officer of the Cereal breeding Program, Mr. Honest Morapedi, for assisting in data collection.

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