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Effect of planting density on yield and architecture suitability of groundnut (*Arachis hypogaea*) varieties

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ABSTRACT

A field experiment was conducted during rainy (*kharif*) seasons of 2018 and 2019 at the research farm of Sri Venkateswara Agricultural College (Acharya N. G. Ranga Agricultural University), Tirupati, Andhra Pradesh, to study the effect of planting density on yield and architecture suitability of groundnut (*Arachis hypogaea* L.) varieties. The experiment included 4 sowing densities (D_1, 33.3 plants/m^2; D_2, 50 plants/m^2; D_3, 66.6 plants/m^2 and D_4, 100 plants/m^2) and 3 genotypes with varying architecture (G_1, Kadiri 6-erect; G_2, Kadiri 9-decumbent 2; and G_3, Dharani-decumbent 3). The results showed that across planting densities, Dharani and Kadiri 9 genotypes showed higher architectural traits, structural carbohydrates and kernel yield compared to the Kadiri 6. A significant positive correlation was detected between the lodging percentage and both plant height (r = 0.88**) and internodal length (r = 0.61*). Significant negative correlations, were identified between lodging percentage and several parameters, including leaf thickness (r = -0.92**), specific leaf weight (r = -0.93**), stem diameter (r = -0.79**), specific stem weight (r = -0.97**), number of branches (r = -0.72**), cellulose content (r = -0.80**), and lignin content (r = -0.79**). These findings indicate that the decumbent architecture is optimal for achieving groundnut lodging resistance and kernel yield in high-density planting systems.

Keywords: Architecture, Density, Lodging percentage

Groundnut (*Arachis hypogaea* L.) is an important annual legume crop, as it provides both food and cash income. Studies reported that groundnut plant density of 33.3 plant/m^2 produced higher yields (Gawas *et al.* 2020) and plant density above 33.3 plant/m^2 reduced groundnut yields (Gawas *et al.* 2020). High density planting can lead to problems like shade avoidance, lodging, reduced structural integrity, accelerated senescence, and a decline in overall crop productivity (Postma *et al.* 2021). However, crop yield under high density planting may vary according to the environmental conditions, fertilization, genotype, plant architecture, and the combination of all these factors.

Crop growth and yield depends on the ability to harness and optimal utilization of the environmental resources, viz. light, water and nutrients. Optimum plant density (spacing between plants) is among the critical crop management practices for obtaining high resource use efficiency and crop yields. The impact of different plant densities on crop yield has been extensively studied across diverse agricultural crops, viz. maize (El-aty *et al.* 2019 and Du *et al.* 2021), chickpea (Singh *et al.* 2019), dry bean (Baez-Gonzalez *et al.* 2020) and common bean (Musana *et al.* 2020). Among all the factors, plant architecture stands as a critical determinant under high density planting, as it effects light capture, resource utilization, and yield. High-density planting results in greater competition for resources and altered plant architecture. Architectural traits and carbohydrates affect structural integrity of the plant, thus increasing crop lodging rate and ultimately affects crop yields. Underutilization of diverse groundnut plant architectures and lack of suitable groundnut varieties fitting to specific sowing densities hinder its productivity potential. This study aims to identify groundnut genotypes with higher yields, lodging resistance and plant architectures well-suited for high-density planting.

MATERIALS AND METHODS

An experiment was conducted during the rainy (*kharif*) seasons of 2018 and 2019 at research farm of Sri Venkateswara Agricultural College (Acharya N. G. Ranga Agricultural University), Tirupati (13.65°N and 79.42°E). The experiment was conducted in a split plot design with

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four sowing densities (D_1, 33.3 plants/m^2; D_2, 50 plants/m^2; D_3, 66.6 plants/m^2; and D_4, 100 plants/m^2) and 3 genotypes with varying plant architecture (G_1, Kadiri 6-erect; G_2, Kadiri 9-decumbent 2; and G_3, Dharani-decumbent 3), with 3 replications. Gypsum was given as top dressing at 500 kg/ha at flowering. The inputs provided and cultural operations undertaken were consistent for the crops grown at different planting densities. To obtain plant architectural traits, five identical plants were used for analysis and calculation. Observations on various architectural traits, including plant height, internodal length (cm), and the number of branches per plant, were meticulously recorded following established standard procedures. Additionally, measurements of stem diameter on the main stem and leaf thickness were obtained using a vernier caliper.

$$\text{Specific leaf weight} = \frac{\text{Lead dry weight (g)}}{\text{Leaf area (cm}^2\text{)}}$$

$$\text{Specific stem weight} = \frac{\text{Stem dry weight (g)}}{\text{Height of stem (cm)}}$$

$$\text{Lodging percentage (\%)} = \frac{\text{Total number of lodging plants in a plot} \times 100}{\text{Total number of plants in the same plot}}$$

The stem lignin content was determined using a modified method based on the protocol (Zhang *et al.* 2017). Similarly, the cellulose content was determined following the procedure detailed by Liu *et al.* (2016). The data on yield and yield attributes, viz. total number of filled pods, 100 kernel weight and kernel yield (kg/ha) were recorded per plant using standard procedures. Statistical analysis of the data was carried out by applying a one-way ANOVA procedure with SPSS version 15 (Panse and Sukhatme 1985). Additionally, Pearson correlation analysis was carried out using R Studio.

RESULTS AND DISCUSSION

Effect of sowing density on architectural traits and lodging resistance: An increase in plant density per unit area, aimed at achieving greater productivity, but can also result in crop lodging. Recent research studies indicated that there is a strong correlation between lodging resistance and plant architectural traits like plant height, height of the center of gravity and internodal length (Shah *et al.* 2019, Liu *et al.* 2022, Wu and Ma 2022 and Zhao *et al.* 2023). In the current study, pooled data showed variations in plant height, internodal length, number of branches, leaf thickness, stem diameter, specific leaf weight and specific stem weight across groundnut genotypes and planting densities. Kadiri 6-erect sown at 100 plants/m^2 exhibited significantly greater plant height (50.73 cm) (Supplementary Fig. 1A) and internodal length (2.64 cm) (Supplementary Fig. 1B). The groundnut genotypes with erect growth pattern exhibit trait of limited lateral spread and narrower stems. Consequently, when cultivated at a density of 100 plants/m^2, these genotypes encounter restricted space for lateral expansion. As a result, they adapt by primarily adopting a vertical growth strategy to efficiently intercept incoming light. This vertical growth orientation allows them to optimize light capture and utilization within the constrained planting space. Bongers *et al.* (2019) reported the significance of high plant density on plant behaviour as a key focal point in their research. At high densities, the competition for both photosynthesis and nutrient uptake among plants increases. Thus, resulting in increased the elongation of the stem and plant height, serves as an adaptive strategy to secure access to light resources for photosynthesis. Genotype Dharani, sown at 33.3 plants/m^2 had significantly higher number of branches whereas Kadiri 6-erect sown at 100 plants/m^2 displayed lower number of branches (Supplementary Fig. 1C). Higher number of branches in Dharani-decumbent 3 may be attributed to presence of both primary and secondary branches coupled with more spreading nature at 33.3 plants/m^2. In line with these findings, Ibrahim *et al.* (2022) reported that plants exhibited increased branching due to reduced competition at lower plant densities. Genotype Dharani, sown at 33.3 plants/m^2 had significantly higher leaf thickness and Kadiri 6-erect sown at 100 plants/m^2 displayed a smaller leaf thickness (Supplementary Fig. 1D). Increased leaf thickness contributes to factors such as relative water content, photosynthetic efficiency, and growth potential. The extent of light absorption by a leaf and the path of carbon dioxide (CO_2) diffusion across its tissues are contingent upon leaf thickness (Feng *et al.* 2019). Thus, Dharani genotype with higher leaf thickness has greater potential of resource acquisition and photosynthesis.

Genotype Dharani, sown at 33.3 plants/m^2 had significantly higher specific stem weight (Fig. 1A) and stem diameter (Fig. 1B) compared to other treatments. Erect type, Kadiri 6 sown at 100 plants/m^2 displayed stem diameter, and specific stem weight. Specific leaf weight was significantly higher for the Dharani-decumbent 3, and the Kadiri 9-decumbent 2 type, sown at 33.3 plants/m^2 (60.10 g/m^2 and 59.12 g/m^2 respectively), while, Kadiri 6-erect sown at 100 plants/m^2 had a smaller specific leaf weight (48.83 g/m^2) (Fig. 1C). Across high density plantings (50, 66.6 and 100 plants/m^2) Dharani-decumbent 3 and Kadiri 9-decumbent 2, recorded higher stem diameter, specific leaf weight, specific stem weight and number of branches compared to erect type (Kadiri 6 genotype). Stem strength is considered a crucial factor in the evaluation of lodging resistance (Lui *et al.* 2022). Stem diameter and specific stem weight are closely interlinked with the anatomical characteristics responsible for determining stem strength (Muhammad *et al.* 2020).

In this study, it was evident that higher sowing density led to an increase in plant height and internodal length, coupled with a decrease in stem diameter, specific leaf weight, specific stem weight, leaf thickness, and the number of branches across all genotypes. The higher values of architectural traits in decumbent types, tissues in thicker stems are stiffer compared to erect types. Kadiri 6 genotype

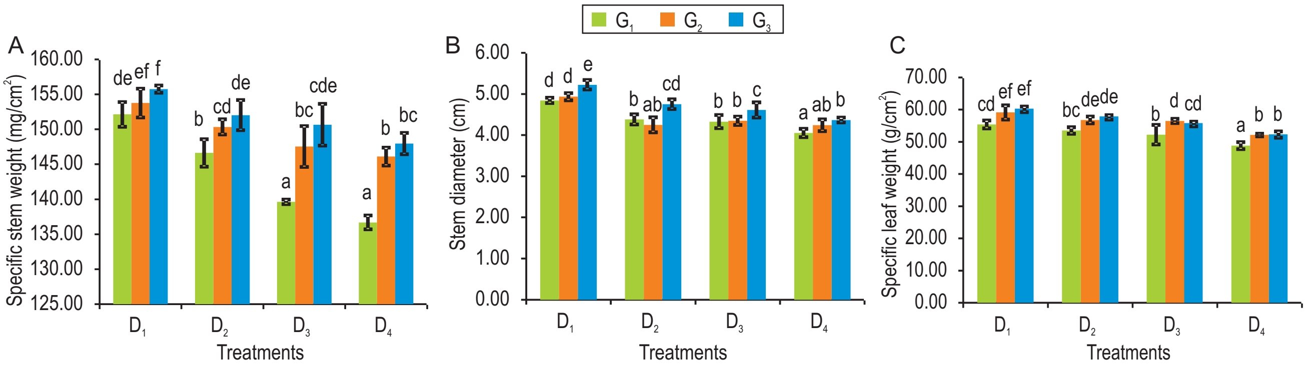

Fig. 1 Effect of sowing density and genotypes on architectural traits of groundnut.
(A) Specific stem weight (mg/cm); (B) Stem diameter (cm); (C) Specific leaf weight (g/m^2).
Treatment details are given under Materials and Methods. Values are represented in mean ± SD of 15 plants; Bars sharing the same superscripts suggest that there is no statistically significant difference among them.

with erect type has narrower stems and decumbent types have wider stems. Regarding mechanical strength, stems with narrower widths displayed reduced resistance to lodging, whereas wider stems enhanced resistance to lodging. Plants with intermediate heights and shorter internodal lengths strike a balance between providing adequate structural support and minimizing susceptibility to lodging caused by wind or rain (Li *et al.* 2021). These results are in line with Liu *et al.* (2022) and Zhao *et al.* (2023) that highlight the crucial role of plant architectural traits in enhancing lodging resistance.

Effect of planting density on stem lignin, cellulose content and lodging percentage: Carbohydrate accumulation in stems is generally recognized as the primary determinant of mechanical strength (Zhang *et al.* 2017, Hussain *et al.* 2019) besides morphological characteristics. In this study, the structural carbohydrate contents like cellulose and lignin also decreased in groundnut plants with increase in density along with growth limitations across all the genotypes. Stem lignin content (Supplementary Fig. 2A), cellulose content (Supplementary Fig. 2B) and lodging percentage (Supplementary Fig. 2C) of decumbent-3 type, Dharani (116.95 OD 280 ml/g/FW, 42.23 mg/cm W and 1%) and decumbent-2 type, Kadiri 9 (114.25 OD 280 ml/g/FW, 43.30 mg/cm W and 1.33%) sown at 33.3 plants/m^2 were significantly higher than erect type, Kadiri 6 sown at 100 plants/m^2 (89.42 OD 280 ml/g/FW, 34.62 mg/cm W and 23.66% respectively). Under high density planting (50, 66.6 and 100 plants/m^2), decumbent types recorded higher structural carbohydrates (cellulose and lignin content) over erect type (Kadiri 6). According to Tobimatsu and Schuetz (2019), lignin plays a crucial role as a phenolic compound found within the secondary cell walls. This improves the transport of water and solutes within the vascular system and enhances stem stiffness and strength, ultimately reducing lodging percentage (Reyt *et al.* 2021). Previous studies conducted by Hussain *et al.* (2019) reported similar results i.e. increase in sowing density resulted in decreased mechanical strength of plant by decreasing cellulose and lignin content and associated enzyme activities. The present study highlights that higher sowing density when combined with decumbent genotypes characterized by moderate internodes and heightened lignin/cellulose levels, increases the mechanical strength of groundnut plants, consequently reducing the incidence of lodging.

Effect of planting density on yield and yield traits: Significant interaction between the genotype and sowing density was observed for total number of pods/plant, 100 kernel weight (g) and kernel yield (kg/ha) (Table 1). Decumbent-3 type, Dharani and decumbent 2 type, Kadiri 9 genotypes recorded higher kernel yield (1829 kg/ha and 1822 kg/ha) sown at 100 plants/m^2 across planting densities, Dharani and Kadiri 9 genotypes showed higher architectural traits, structural carbohydrates, lodging percentage and kernel yield compared to the Kadiri 6 genotype. The increase in planting density, led to a greater plant population per unit area, was associated with an increase in kernel yield per hectare. 100 kernel weight and total number of pods per plant were significantly higher at 33.3 plants/m^2 in Kadiri 6 genotype, lesser competition and efficient utilization of growth resources between plants increased 100 kernel weight and total number of pods. At higher planting densities (50, 66.6 and 100 plants/m^2), an observed decrease in translocation efficiency to pods from vegetative organs can be attributed to increased competition for resources per unit area. Under high density planting (50, 66.6 and 100 plants/m^2), Dharani-decumbent 3 and Kadiri 9-decumbent-2 genotypes recorded significantly higher total number of pods and 100 kernel weight. The outcomes align with those from studies on peanuts conducted by Haro *et al.* (2007) and Zhao *et al.* (2017). Similar observations were reported by Zhao *et al.* (2020) in maize and Rajput *et al.* (2023) in rice.

Correlation analysis: As depicted in Fig. 2, the lodging rate of the groundnut genotypes under high density lodging percentage has significant positive correlations with plant height (r = 0.88**) and internodal length (r = 0.61*). These findings imply that taller plants with longer internodes, reduced stem stiffness of elongated internodes, making them susceptible to bending and breakage are more prone to lodging. Lodging percentage has significant negative

Table 1 Effect of sowing density and genotypes on yield and yield attributes of groundnut

Treatment	Total no. of pods/plant (No.)			100 Kernel weight (g)			Kernel yield (Kg/ha)		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
G_1D_1	22.42±1.67^{de}	23.53±1.86^{f}	22.98±1.76^{e}	44.42±0.99^{g}	37.18±1.05^{f}	40.80±0.85^{g}	1,766±44.56^{a}	1750±45.63^{a}	1,758±44.78^{a}
G_1D_2	16.40±4.08^{bc}	17.33±4.16^{bc}	16.87±4.12^{bcd}	37.83±1.48^{de}	35.22±2.41^{ef}	36.53±0.52^{de}	1,774±8.96^{ab}	1766±15.37^{ab}	1,771±6.87^{ab}
G_1D_3	14.07±3.59^{ab}	15.00±1.00^{ab}	14.54±2.24^{ab}	34.20±3.30^{c}	34.67±2.52^{def}	34.43±2.72^{c}	1,785±3.61^{abc}	1785±15.28^{bc}	1,785±6.25^{bc}
G_1D_4	11.33±1.15^{a}	13.00±1.00^{a}	12.17±1.04^{a}	36.71±1.63^{d}	33.46±1.37^{de}	35.09±0.33^{cd}	1,791±3.51^{abcd}	1790±5.033^{bc}	1,791±3.90^{bc}
G_2D_1	23.00±2.65^{de}	22.33±2.52^{de}	22.67±2.47^{e}	28.33±0.76^{b}	28.08±1.01^{b}	28.20±0.83^{b}	1,793±3.79^{abcd}	1789±7.81^{bc}	1,791±5.20^{bc}
G_2D_2	18.67±3.06^{bcd}	19.00±1.00^{cd}	18.83±2.02^{cd}	24.29±1.19^{a}	25.00±1.00^{a}	24.64±1.09^{a}	1,800±4.16^{bcdef}	1785±13.2^{bc}	1,793±8.41^{bc}
G_2D_3	16.00±2.00^{ab}	16.33±1.53^{abc}	16.17±1.44^{abc}	26.28±1.12^{ab}	29.77±1.96^{bc}	28.03±0.46^{b}	1,808±7.64^{cde}	1791±6.083^{bc}	1,800±2.25^{cd}
G_2D_4	11.67±0.58^{a}	13.00±1.00^{a}	12.33±0.76^{a}	24.35±0.13^{a}	23.75±1.63^{a}	24.05±0.82^{a}	1,831±2.52^{ef}	1812±12.12^{c}	1,822±5.85^{de}
G_3D_1	23.67±2.52^{e}	22.00±2.00^{de}	22.83±2.25^{e}	41.29±0.84^{g}	36.34±1.52^{ef}	38.82±0.38^{f}	1,798±10.69^{abcd}	1787±6.807^{bc}	1,793±8.43^{bc}
G_3D_2	20.67±1.53^{cde}	19.67±1.53^{cd}	20.17±1.53^{de}	38.19±1.66^{de}	32.14±1.21^{cd}	35.16±1.42^{cd}	1,812±10.02^{cdef}	1791±7.234^{bc}	1,802±6.53^{cde}
G_3D_3	15.00±3.00^{ab}	14.33±1.53^{ab}	14.67±2.25^{ab}	40.04±1.37^{ef}	34.96±1.00^{def}	37.50±0.43^{ef}	1,821±18.03^{def}	1806±8.505^{c}	1,813±5.53^{cde}
G_3D_4	14.67±1.53^{ab}	13.00±1.73^{a}	13.83±1.53^{ab}	38.37±0.86^{de}	38.01±1.52^{de}	35.87±0.58^{cde}	1,843±29.87^{f}	1815±5^{c}	1,829±15.54^{e}
Analysis of variance		Total No. of pods/plant (No.)			100 Kernel weight (g)			Kernel yield (Kg/ha)	
Year (Y)		*			*			*	
Density (D)		*			*			*	
Genotypes (G)		*			*			*	
YXD		*			*			*	
YXG		*			*			*	
YXDXG		*			*			*	

Treatment details are given under Materials and Methods. Values are represented in mean ± standard deviation; n = 15. Values sharing same alphabet as superscript do not vary significantly from each other.

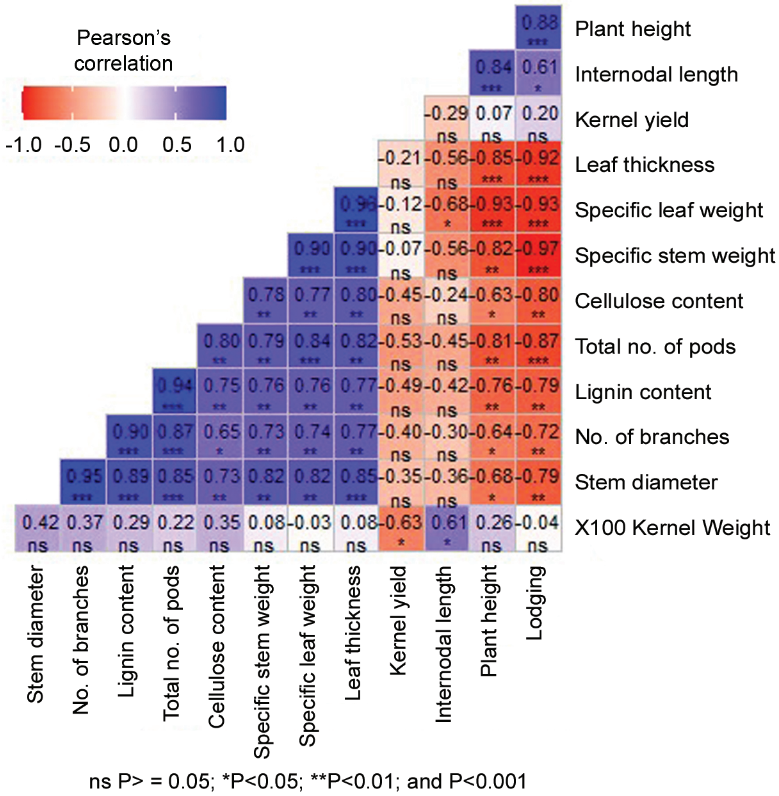

Fig. 2 Pearson correlation coefficients of physiological and yield traits of groundnut.

correlations with leaf thickness (r = -0.92**), specific leaf weight (r = -0.93**), stem diameter (r = -0.79**), specific stem weight (r = -0.97**), number of branches (r = -0.72**), cellulose content (r = -0.80**) and lignin content (r = -0.79**) of groundnut. Structural carbohydrates (cellulose and lignin content) have strong positive correlation with architectural traits, viz. stem diameter, specific stem weight, specific leaf weight, leaf thickness, no. of branches except intermodal length and plant height. Higher presence of cellulose and lignin, which are components of plant cell walls, contributes to the reinforcement of plant tissues. This reinforcement is particularly advantageous for traits associated with lodging resistance. Similar outcomes were reported by Grégoire *et al.* (2010) and Dadheech *et al.* (2020).

The planting density, 33.3 plants/m^2 is most appropriate as plant can optimize resource utilization, develop better and higher yield for all the three genotypes. Decumbent-3 type (Dharani genotype) and Decumbent-2 type (Kadiri 9 genotype) of plant architectures with moderate plant height, internodal length, higher stem diameter, specific stem weight, cellulose and lignin accumulation, with reduced lodging is suitable for high density planting. Increase in sowing density in combination with genotype specific plant architecture (decumbent type) prevents lodging rate and increases kernel yield.

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