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Management of soil surface roughness and plant density affecting harvest losses of common bean cultivars

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The management of soil surface roughness, sowing density, and cultivar characteristics can impact productivity and grain losses in common bean harvests. This study aimed to determine the effect of soil rolling immediately after planting and seeding density on grain yield and harvest losses of two common bean cultivars. A field experiment was conducted using a randomized complete block design with a 4×2×2 factorial scheme and four replications. The treatments consisted of combining four plant densities (6, 9, 12, and 15 plants per meter) with two soil rolling conditions (with and without a soil roller) and two common bean cultivars (BRS FC 414 and BRS FC 415). The results showed that BRS FC 414 plants had higher internodes, a greater insertion angle of the first internode, larger hypocotyl diameter, greater pod height, and lower harvest losses compared to BRS FC 415. However, soil rolling had no effect on reducing harvest losses. Increasing plant density resulted in a reduction in the height of the tallest pods, a decrease in the percentage of pods in the upper third, and an increase in the percentage of shorter pods, ultimately leading to greater harvest losses.

Key words: *Phaseolus vulgaris*, plant architecture, shredding roller, plant harvester.

INTRODUCTION

Despite the great technological advances in common bean cultivation and the availability of high-performance harvesting machines to farmers, grain loss during harvesting operations is still excessive, with grain losses exceeding 300 kg ha^{-1} being common (Silva et al., 2021). The inadequate architecture of common bean plants, with many pods positioned close to the ground, has been the main cause of high grain losses during mechanized harvesting (Pereira Filho et al., 2021; Silva et al., 2023). In the process of managing common bean crops, a combination of good agricultural practices is necessary, which involves identifying the best cultivars with the most suitable harvesting equipment and proper soil management to achieve success in the harvesting operation and reduce grain losses (Chicati et al., 2018; Pereira Filho et al., 2021).

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Therefore, all the care taken in crop management aimed at high productivity is useless if the same care is not taken to carry out efficient harvests with fewer losses (Silva et al., 2021). Among the practices that provide increased productivity and reduced harvest losses is the management of soil roughness, which needs to be well balanced, since it is directly related to the quality of planting, harvesting, and crop productivity (Soares et al., 2020). Rough soil contains elevations and depressions. In this environment, the common beans have many pods close to the ground or touching the ground. The harvester machine would have to harvest closer to the ground and, in this case, would harvest pods and soil, resulting in a large loss of grains. Therefore, the smoother the surface of the ground, that is, the less rough it is, the harvester platform will harvest at a greater distance from the ground, resulting in less loss of grains (Silva et al., 2023).

In addition, there is the choice of cultivar, which must be adapted to the edaphoclimatic conditions of the region and have a plant architecture that favors mechanical harvesting (Ribeiro et al., 2018). However, in general, the architecture of common bean plants has negatively interfered with the mechanization of harvesting, as many cultivars do not have characteristics that are favorable to the operation of harvesting machines, such as erect growth and adequate height of pods in relation to the ground, which could contribute to reducing grain loss (Silva et al., 2020). Hence it is important to evaluate new cultivars for adaptability to mechanical harvesting.

The plant population directly affects the incidence of light and photosynthesis, diseases and weeds, harvesting, lodging, water and fertilizer use, and seed costs for most agricultural crops (Silva et al., 2021). In addition, it is important to determine the ideal plant population per area of the new common bean cultivars in order to obtain the maximum productive potential of each genetic material (Mondo and Nascente, 2018) and greater insertion of taller pods to result in lower harvest losses (Donato et al., 2021).

However, there are still few research studies evaluating management techniques affecting grain harvest losses of common beans. The hypothesis is that shredding roller immediately after sowing with cultivar and plant density has a great impact on the harvesting losses of common beans. The objective of this study was to determine the effect of superficial soil rolling immediately after planting and seeding density on grain yield and harvest losses of common bean cultivars.

MATERIALS AND METHODS

The experiment was conducted with common bean crops during the 2023 winter agricultural harvest in the municipality of Santo Antônio de Goiás, GO, located at 16º28'00" S and 49º17'00" W, and 823 m above sea level. The region's climate is classified as tropical Savannah (Aw) according to the Köppen classification, with two distinct seasons: a dry season from May to September (autumn/ winter) and a rainy season from October to April (spring/ summer). The average annual precipitation ranges from 1,500 to 1,700 mm, and the average annual temperature is 22.7°C, with annual temperature fluctuations between 14.2 and 34.8°C. The experimental area was cultivated using a direct seeding system, with a rotation of corn/soybean in the summer and common beans in the winter. The soil was classified as Acrylic Red Latosol according to the Brazilian classification (Santos et al., 2018). The experiment was designed as a randomized complete block with a 4×2×2 factorial scheme and four replicates. The treatments consisted of combining four plant populations (6, 9, 12, and 15 plants per meter) with two soil management conditions (with and without the use of a soil roller) and two common bean cultivars (BRS FC 414 and BRS FC 415). The soil roller, composed of toothed washers, was used to eliminate clods that could hinder harvesting. Both cultivars, BRS FC 414 and BRS FC 415, belong to the carioca bean group and exhibit erect and semi-erect growth habits, respectively. They are shrubs with an indeterminate type II growth habit and a normal production cycle of 85 to 94 days from emergence to physiological maturity.

The plots consisted of ten rows of 8 m long plants, sown and fertilized using a direct planting seeder-fertilizer with five planting rows, spaced 0.5 m apart, and regulated to distribute seeds according to the sowing density treatments. The seeder-fertilizer was equipped with stem furrowers for fertilization and double offset discs for sowing, and it operated in the same direction at a speed of 4 km h^{-1}. The experiments were installed in the second half of June 2023. Planting fertilization was carried out according to soil analysis, using 300 kg ha^{-1} of the formula 5-30-15 (N-P_2O_5-K_2O).

Topdressing fertilization was carried out with nitrogen in the amount of 100 kg of N ha^{-1} with the use of urea in the "V4" vegetative period (third trifoliate) of common bean. A sprinkler irrigation system was used via a central pivot, with water management being carried out according to the crop's needs. Phytosanitary management of the crop was carried out according to the needs to keep the plants free of pests, diseases, and weeds. In the experimental plots, parameters related to plant architecture, positioning of pods on the plants; formatting of the stem and branches; yield components and grain yield and mechanized harvesting operation were evaluated. The parameters were evaluated during the grain harvest phase, in the central rows of plants in each plot. By recording six height measurements to the ground, the height of the tallest pods of the plants (HTP) and the height of the lowest pods (HLP) were determined using a millimeter ruler.

The plants in each plot were then photographed to check the distribution of pods, following the methodology proposed by Silva et al. (2023). The images were collected using a camera positioned on the ground, perpendicularly, 50 cm from the target plants. The plants were kept in their natural state and some leaves were removed to expose the pods. The camera was adjusted to capture images of the entire plants. Using the PowerPoint application, each image was processed to contain only the plants, from the base to the highest pod. Horizontal lines were projected onto the image to divide it into 15 equal sections (Figure 1). Section 11 to 15 were classified as pods in the lower third (PLT).

The readings of the presence of pods or fractions of pods were taken in each of the 15 sections. Thus, the pods or fraction of pods counted in sections 1 to 5 were classified as pods in the upper third (PUT) of the common bean plants, those in sections 6 to 10 as pods in the middle third (PMT) and those in sections 11 to 15 as pods in the lower third (PLT). The percentage of pods or fraction of pods in each third of the plant was obtained in relation to the total verified in the image. With the information about the average height of the tallest pods (HTP) and the percentage distribution of all pods in each section of the plant (PUT, PMT and PLT), the percentage of pods positioned above 100 mm from the ground (P100) was calculated.

In the stage following the collection of images, six plants were

Figure 1. Example of distribution of bean pods in the upper, middle and lower thirds of the plant.
Source: Silva et al. (2023).

harvested per plot, to obtain the average value of hypocotyl diameter, internode length, branch insertion angle in the plant stem and components productivity. The diameter of the hypocotyl of the plants (DHP) was measured at its intersection with the epicotyl, using a caliper. The lengths of the first four internodes of the plants (L4I) were also evaluated using the caliper. The angle of insertion of the first branch to the stem of the plants (ANG) was measured with a 0-180º angle protractor, following the methodology proposed by Silva et al. (2023).

The yield components number of grains per pod (NGP), number of pods per plant (NPP) and mass of 100 grains (M100) were evaluated in the six plants harvested in the useful plot. Productivity (PROD) was determined by weighing the mass of all grains from plant rows 7, 8 and 9, in an area of 3.0 m². The mass of 100 grains and grain productivity were expressed in grams and kg ha^{-1}, respectively, after the water content had been corrected to 130 g kg^{-1}.

The harvest was carried out when the seeds of the BRS FC 414 and BRS FC 415 cultivars had a moisture content between 18.2% and 22.3%. The operation was carried out by a 3000 mm wide serrated blade windrower coupled to the hydraulic system and driven by the PTO of a tractor with approximately 100 hp. After the harvester operation, the harvesting height of the plants (HHP) was evaluated in six locations of the plot and the grain losses resulting from the harvesting operation with the harvester (GL) in an area of 2 m².

The data obtained were subjected to analysis of variance and when significance was detected, the means were compared by the LSD test for $p<0.05$. Regression analyses were performed with plant density data. Additionally, a multivariate principal component analysis was performed to describe the correlation between response variables (pods in the upper third, pods in the middle third, pods in the lower third, average height of the tallest pods, percentage of pods positioned above 100 mm from the ground, hypocotyl diameter, internode lengths, angle of insertion of the first branch to the stem of the plants, number of grains per pod, number of pods per plant, weight of 100 grains and grain yield) with cultivar, rolling operation and plant density. Principal components (PCs) were loaded with response variables when the correlation test produced $r > 0.50$. The first two PCs responsible for > 71% of the data variation were maintained. Biplots (two-dimensional graph) using these two PCs that correlate the studied factors and response variables were constructed with the "FactoExtra" package in the R platform (R Core Team, 2005).

RESULTS AND DISCUSSION

Plants of the BRS FC 414 cultivar had higher distance from the soil to the tallest pods and to the shortest pods in relation to the cultivar BRS FC 415 (Table 1). Besides, had a higher percentage of pods in the upper third and in the middle third of common bean plants compared to the BRS FC 415 cultivar. On the other hand, the BRS FC 415 cultivar showed a higher percentage of pods in the lower third of common bean plants. There was no effect of rolling operation on the variables evaluated. A higher concentration of pods positioned higher from the soil favors the mechanized harvesting process, since the cutter bar operates slightly above the soil surface (Silva et al., 2020). Thus, fewer pods will be cut by the cutter bar and may result in lower grain losses.

The height of the tallest pods, the percentage of pods in the upper third of the common bean plants, and the

Table 1. Height of the tallest pod of the plant (HTP), height of the lowest pod (HLP), percentage of pods in the upper third (PUT), percentage of pods in the middle third (PMT), percentage of pods in the lower third (PLT) of the common bean plants, percentage of pods positioned above 100 mm from the ground (P100) in common bean plants affected by soil rolling and seeding density in two cultivars. Santo Antônio de Goiás, GO, 2023.

Cultivar	HTP	HLP	PUT	PMT	PLT	P100
	mm	mm	%	%	%	%
BRS FC 414	578[a]	68[a]	29.5[a]	56.8[a]	13.7[b]	97.8
BRS FC 415	443[b]	53[b]	21.2[b]	52.2[b]	26.6[a]	87.6
Rolling						
With	513	60	25.4	56.2	18.4	93.2
Without	508	60	25.7	53.1	21.3	92.2
Plant density						
6	504	50	22.9	54.4	22.5	91.1
9	531	65	26.4	54.9	18.6	93.1
12	517	57	24.8	55.2	20.1	93.4
15	489	68	28.0	54.1	18.1	93.2

*Mean values followed by the same letter do not differ from each other using the LSD test for p<0.05.

percentage of pods in the lower third conformed to quadratic equations, with a tendency for values to decrease with increasing plant density (Figure 2A, C, and E). Conversely, the height of the lowest pods, the percentage of pods in the middle third, and the percentage of pods positioned above 100 mm from the ground tended to increase with increasing plant density (Figure 2B, D, and F). For the height of the tallest pods, an increase was observed up to a density of around 9 plants per meter (Figure 2A). However, densities above 9 plants per meter resulted in a reduction in the height of the tallest pods, likely due to natural plant lodging. Mondo and Nascente (2018) reported that increased plant density leads to greater plant height and lodging due to competition for light. A similar pattern was observed for the percentage of pods in the upper third of the plant (Figure 2C). In contrast, increasing plant density led to increases in the height of the shortest pods, the percentage of pods in the middle third, and the percentage of pods above 100 mm from the soil (Figure 2B, D, and F). This is likely due to greater plant etiolation, which is supported by the increased internode length with higher plant densities (Figure 3), as reported by Mondo and Nascente (2018).

The cultivar BRS FC 414 presented greater internode length, hypocotyl diameter and the angle of insertion of the first branch in the stem in relation to the cultivar BRS FC 415 (Table 2). There was no effect of rolling on the variables evaluated. A greater hypocotyl diameter may result in greater support of the plant upright, causing less lodging of the plants, allowing more upright plants at the time of harvest (Figure 3) (Silva et al., 2023). Greater internode length probably results in greater pod height, as observed in the present experiment, as reported by Silva et al. (2021). With a greater insertion angle, the plants have more open lateral guides that facilitate intertwining between them. This results in pods that are higher in relation to the ground (Table 1).

The diameter of the hypocotyl (quadratic equation) and the angle of insertion of the first node (linear) had reduced values with the increase in plant density (Figure 3A and C). The length of the internodes conformed to the quadratic equation in which the increase in values occurred with the increase in plant density (Figure 3B).

The increase in plant density provided increases in the length of the internodes, which is desirable, as it results in greater pod height (Table 2). On the other hand, it can cause a reduction in the diameter of the hypocotyl and the angle of the lateral guides, which is unfavorable from the point of view of supporting the plant upright. Therefore, a balance should be sought, that is, defining a plant density that provides adequate architecture. According to Moura et al. (2013), the angle of insertion of the branches, the height of the plants at harvest and the diameter of the hypocotyl were the main determining characteristics of the plant architecture of the common bean.

It was observed that the cultivars had differences in terms of yield production and grain productivity (Table 3). The cultivar BRS FC 414 had a higher number of pods per plant, grains per pod, mass of 100 grains and grain yield compared to the cultivar BRS FC 415. The grain yield of the common bean crop is a function of its yield components, such as number of pods per plant, number of seeds per pod and weight of 100 grains (Nascente et al., 2016). Based on the results of all production components for the cultivar BRS FC 414, the higher values in grain productivity are explained. There were no

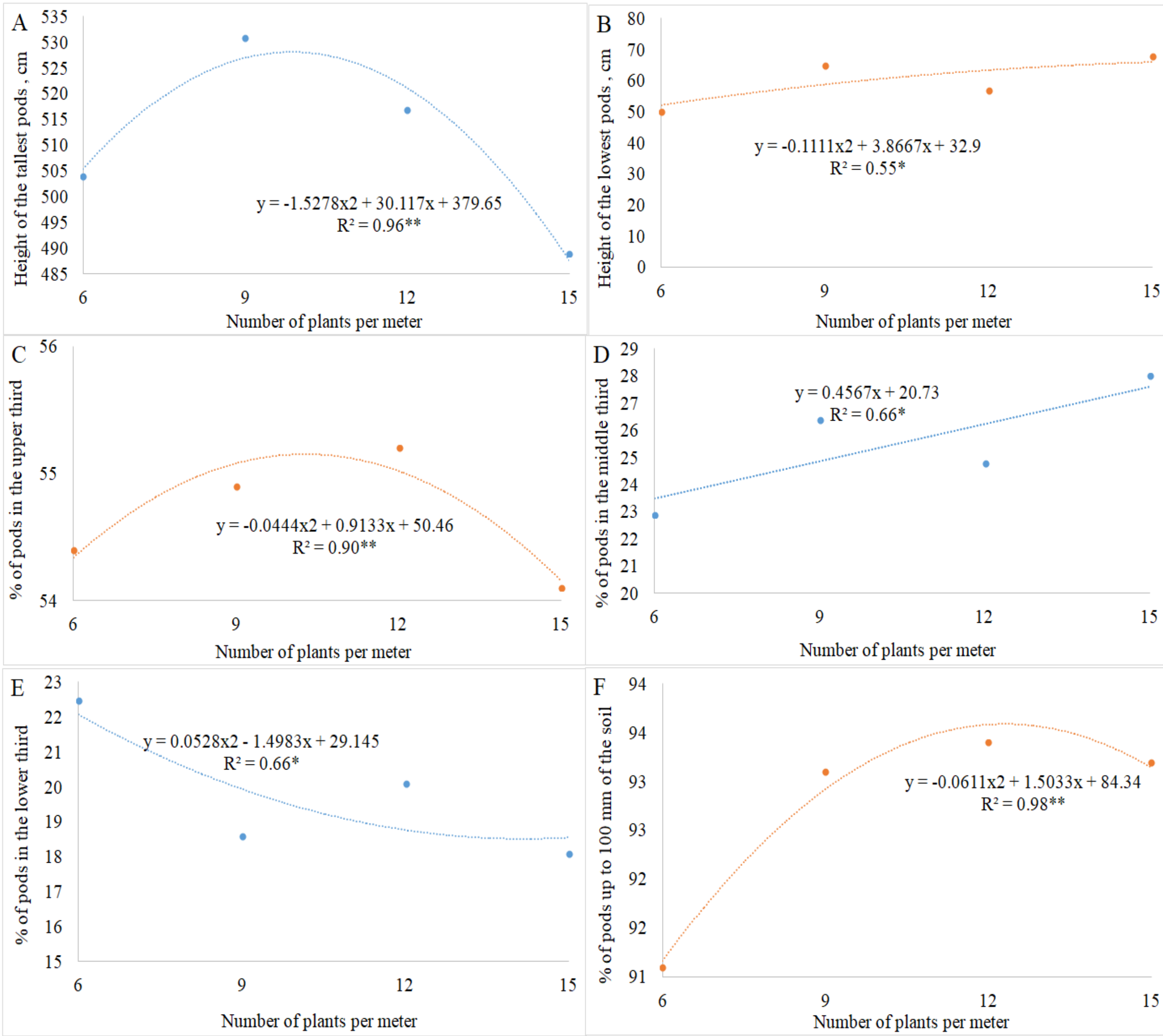

Figure 2. Height of the tallest pod (A), height of the shortest pod (B), percentage of pods in the upper third (C), percentage of pods in the middle third (D), percentage of pods in the lower third (E) and percentage of pods above 100 mm of soil (F) of common bean plants affected by plant density. Average of cultivars BRS FC 414 and BRS FC 415.
Source: Santo Antônio de Goiás (2024).

differences between the presence and absence of rolling for these variables.

Plant density affected the production components and grain productivity (Figure 4A, B, C and D). Thus, it can be seen that the increase in the number of plants per meter resulted in a reduction in the number of pods per plant. The number of grains per pod conformed to the quadratic equation with an increase in the number of grains with the increase in plant density; however, despite the variation, in all treatments it remained around 5 grains per pod. The mass of 100 grains increased with the increase in the number of plants per meter, in agreement with the statement by Nascente et al. (2016) that the number of pods per plant is inversely proportional to the mass of 100 grains. Carneiro et al. (2015) also report that the number of grains per pod is a peculiar characteristic of each cultivar, genetically determined, with little influence from the environment. Thus, there was little variation in this characteristic, remaining around five grains per pod in all treatments. Productivity was adjusted by a quadratic equation with a maximum value around 11 plants per meter (Figure 4). The increase in the number of plants per meter above 11 plants may have provided shade to the plants and thus a reduction in grain productivity. Mondo and Nascente (2018) report that increasing the number of plants per meter results in greater competition between plants for light and nutrients, which may lead to a reduction in the productivity of

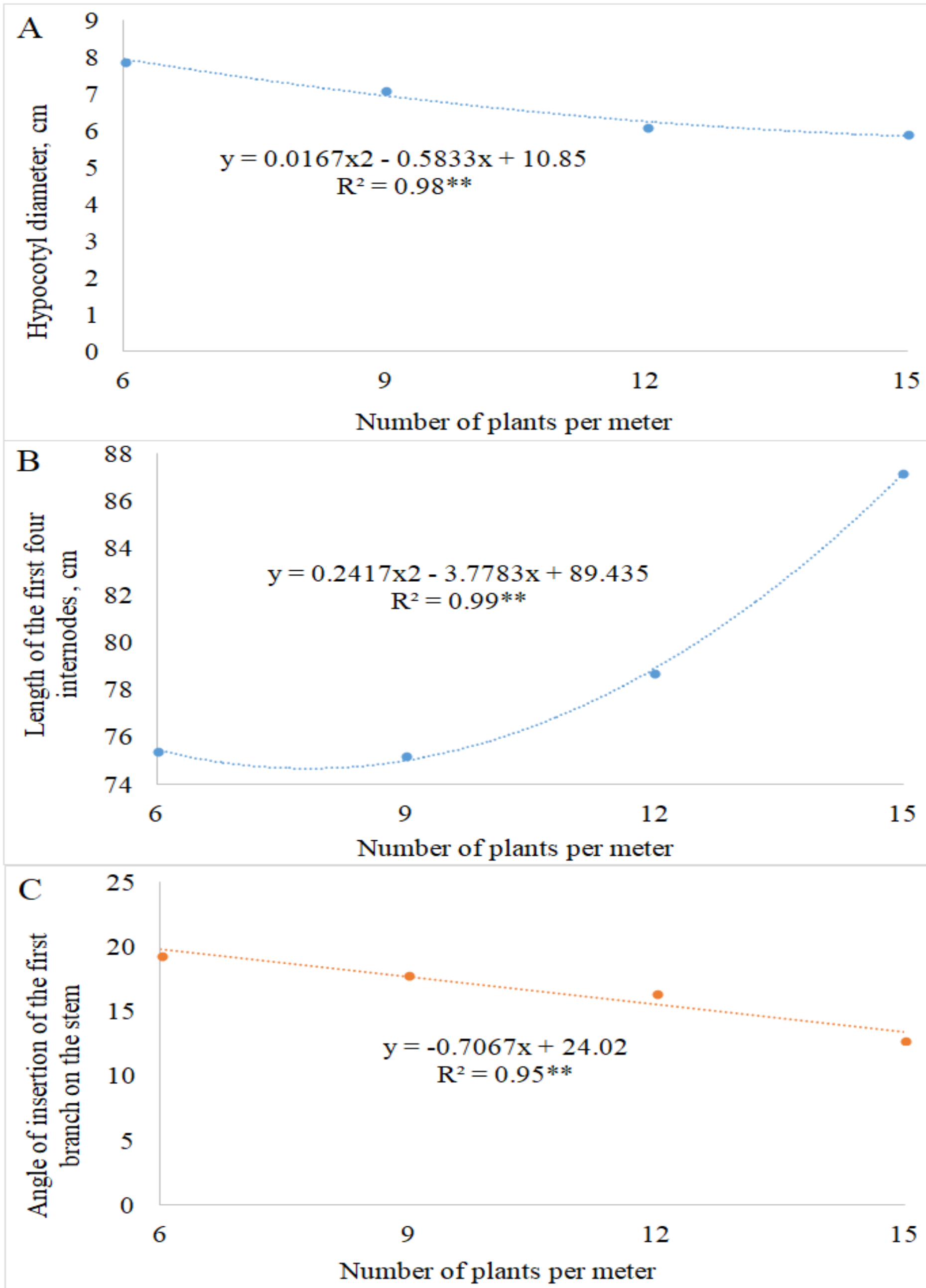

Figure 3. Hypocotyl diameter (A), internode length (B) and insertion angle of the first branch on the stem (C) of common bean affected by plant density. Average of cultivars BRS FC 414 and BRS FC 415.
Source: Santo Antônio de Goiás (2024).

common bean plants.

The height at which the harvester harvested the plants was similar for both cultivars in all treatments, regardless of the factors evaluated (Table 3). In other words, regardless of the plant architecture, the plants were always cut at the same height in relation to the ground, which varied from 51.5 to 54.7 mm. The BRS FC 414 cultivar had lower grain losses during harvest than the BRS FC 415 cultivar, due to the better plant architecture and better positioning of pods on the plant, which favored the operation of the harvester (Tables 2 and 3). The cutting height increased with the increase in plant density. From the lowest to the highest plant density, the increase in harvest height was 5 mm (Figure 4E). The increase in plant density resulted in an increase in grain losses (Figure 4F), possibly due to the reduction in the

Table 2. Length of the first four internodes (L4I), hypocotyl diameter (HD), angle of insertion of the first branch on the stem (ANG), in common bean plants affected by soil rolling and seeding density in two cultivars. Santo Antônio de Goiás, GO, 2023.

Cultivar	L4I	HD	ANG
	mm	mm	grau
BRS FC 414	88.1[a]	7.0[a]	18.1[a]
BRS FC 415	70.1[b]	6.5[b]	15.6[b]
Rolling			
With	78.1	6.6	16.5
Without	80.1	6.8	16.8
Density			
6	75.4	7.9	19.4
9	75.2	7.1	17.8
12	78.7	6.1	16.4
15	87.2	5.9	12.8

*Mean values followed by the same letter do not differ from each other using the LSD test for $p<0.05$.

Table 3. Number of pods per plant (NPP), number of grains per pod (NGP), mass of 100 grains (M100), grain yield (PROD), height of cut in the plants by the machine (HCP) and grain loss in mechanized harvesting (GL) of common bean affected by soil rolling and seeding density in two cultivars. Santo Antônio de Goiás, GO, 2023.

Cultivar	NPP	NGP	M100	PROD	HCP	GL
	unit	unit	g	kg ha^{-1}	mm	kg ha^{-1}
BRS FC 414	9.0[a]	5.0[a]	26.1[a]	2682[a]	51.5	71.9[b]
BRS FC 415	7.3[b]	4.5[b]	21.2[b]	2059[b]	54.7	108.9[a]
Rolling						
With	7.8	4.6	23.6	2354	53.0	99.1
Without	8.5	4.9	23.7	2387	53.3	81.7
Densit						
6	15.5	4.7	23.0	2230	50.9	87.7
9	7.9	4.7	23.7	2512	53.0	78.6
12	5.6	4.6	23.6	2442	52.6	91.0
15	3.7	4.9	24.3	2299	55.9	104.3

percentage of taller pods, in the percentage of pods in the upper third of the plants, and in the increase in the percentage of shorter pods (Figure 2). Silva et al. (2023) reported that pod positioning directly affects grain losses in mechanized harvesting. Corroborating this information, it was found that there was a negative correlation between grain losses and percentage of pods in the lower third with the percentage of higher pods and the percentage of pods in the upper third (Figure 5).

The application of principal component analysis (PCs) revealed that the variability of treatments with cultivar, rolling, and plant density was best described by two PCs, accounting for 71.11% of the data variation, specifically PC1 (48.80%) and PC2 (22.31%) (Figure 5A and 5B). The factor map shows groups of variables (arrows) denoting positive and negative correlations with each PC, with the length of the arrow indicating the magnitude of each response for each PC (Figure 5). PC1 was positively correlated with pods per plant, hypocotyl diameter, and angle of insertion of the first branch to the stem of the plants (Figure 5A).

In contrast, PC1 was negatively correlated with cutting height. PC2 was negatively correlated with pods in the lower third of the plants and grain losses at harvest, while

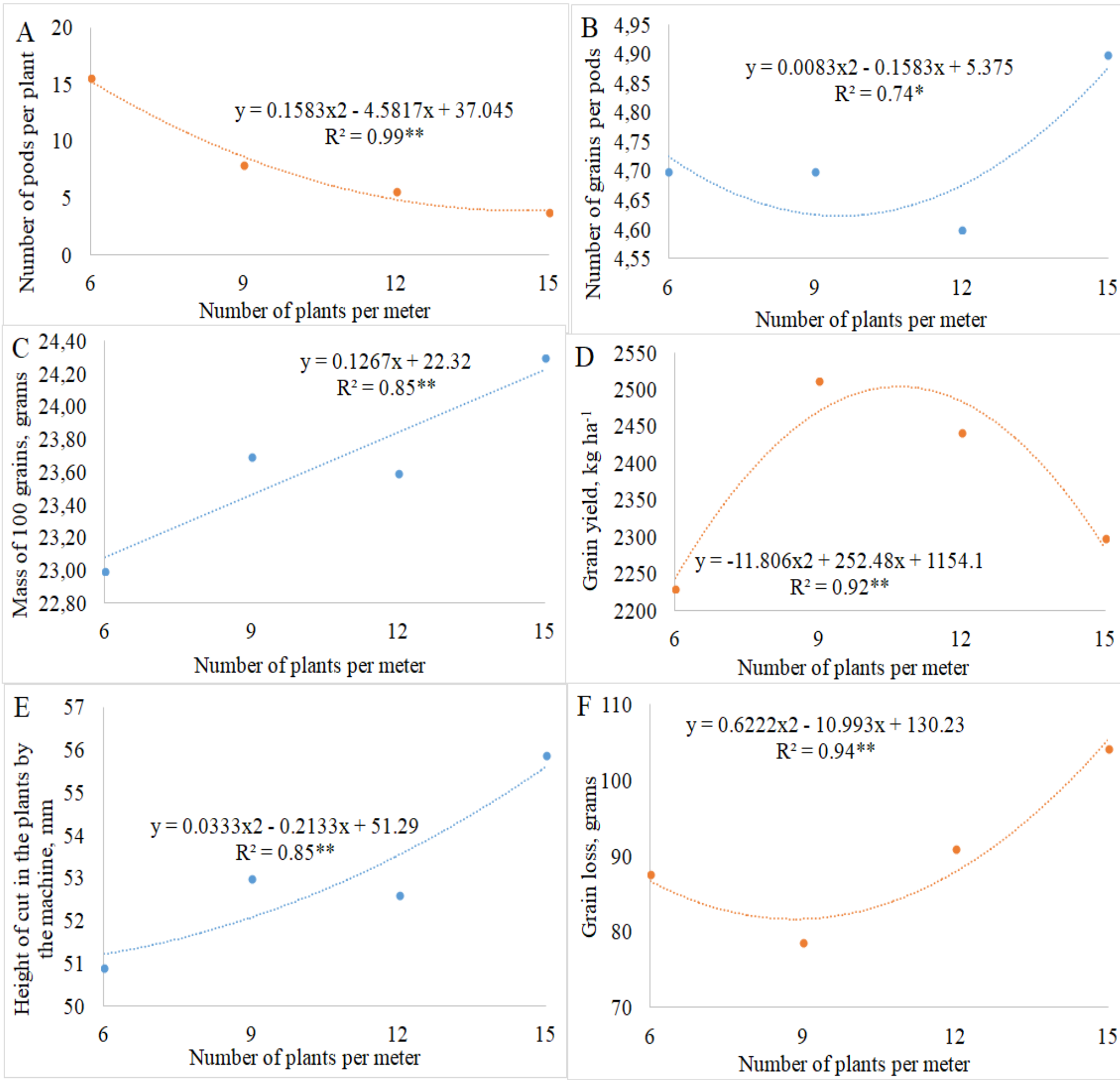

Figure 4. Number of pods per plant (A), number of grains per pod (B), 100-grain weight (C), grain yield (D), plant cutting height (E) and harvest losses (E) of common bean affected by plant density. Average of cultivars BRS FC 414 and BRS FC 415. Source: Santo Antônio de Goiás (2024).

it was positively correlated with pods above 100 mm, 100-grain weight, taller pods, productivity, and pods in the upper third. Based on the representational quality of the treatments with cultivar, rolling, and plant density for the variables analyzed in PC1 x PC2, the treatments with cultivar BRS FC 414 with or without roller at densities of 6 and 9 plants per meter correlated positively with grain productivity, 100-grain weight, taller pods, pods in the middle third, pods in the upper third, and internode length (Figure 5B).

Conversely, the variables cutting height and harvest losses were negatively correlated with the treatments with cultivar BRS FC 415 at a density of 15 plants per meter, with or without roller. The results indicate that cultivar characteristics and plant density significantly affect grain losses in common beans, with more upright plants like BRS FC 414 resulting in lower grain losses compared to more prostrate plants like BRS FC 415. The analyzed variables, such as internode length, hypocotyl diameter, first internode insertion angle, pod positioning, and presence of pods in the upper, lower, and middle thirds, provided insight into the reasons for these losses. Given the scarcity of studies on this topic, this research highlights factors that directly affect plant architecture and influence harvest losses, providing valuable information for adjustments that can minimize losses and increase

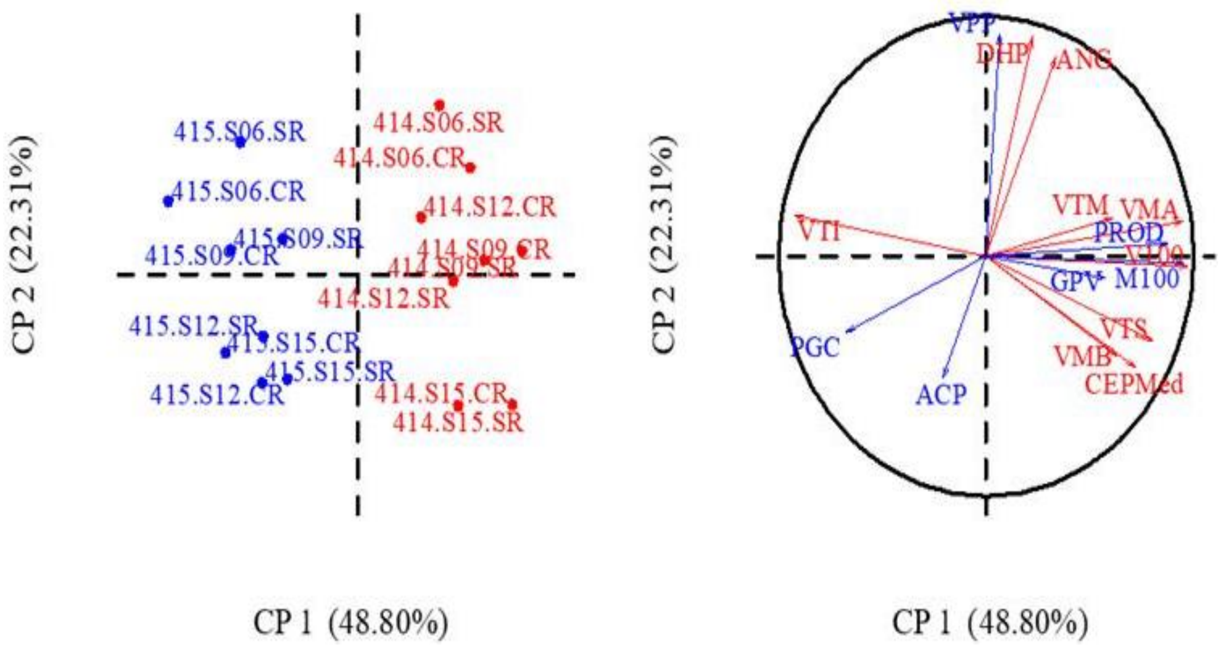

Figure 5. Principal component analysis explaining the correlations between variables and between treatments. (A), Two principal components (PCs) accounted for 71.11% of the data variation. 414 and 415 represent the cultivars BRS FC 414 and BRS FC 415; CR and SR, with and without roller and; S, number of plants per meter. (B), Pods in the upper third (VTS), pods in the middle third (VTM), pods in the lower third (VTI), average height of the tallest pods (VMA), percentage of pods positioned above 100 mm from the ground (V100), hypocotyl diameter (DHP), internode lengths (CEP), angle of insertion of the first branch to the stem of the plants (ANG), number of grains per pod (NGV), number of pods per plant (NVP), mass of 100 grains (M100) and grain yield (PROD).

profitability for rural producers.

Conclusion

The BRS FC 414 cultivar exhibited superior characteristics, including higher internodes, a greater insertion angle of the first internode, larger hypocotyl diameter, greater pod height, and consequently lower harvest losses compared to the BRS FC 415 cultivar. However, the use of a roller crusher had no significant effect on reducing harvest losses. Increasing plant density led to a reduction in the height of the tallest pods, a decrease in the percentage of pods in the upper third, and an increase in the percentage of shorter pods, ultimately resulting in greater harvest losses.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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