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Yield of chickpea genotypes as function of row spacing planting in northern Paraná

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Summary

Chickpea (*Cicer arietinum* L.) is a cool-season legume, optimally adapted to regions with low to moderate rainfall. In tropical environments, where its cultivation remains underexplored, it emerges as a potential alternative for winter cropping systems. Proper selection of plant population densities can enhance resource use efficiency, making it a viable component of sustainable agricultural systems. This study aimed to evaluate the agronomic performance of chickpea cultivars under different row spacing in the edaphoclimatic conditions of Northern Paraná, Brazil (Bandeirantes - PR). The experiment followed a randomized complete block design in a 6 × 3 factorial arrangement, comprising six chickpea cultivars (BRS Toro, BRS Cícero, BRS Aleppo, BRS Cristalino, BRS Kalifa, and CP 1605) and three row spacings (40 cm, 50 cm, and 60 cm). Sowing was conducted on March 27, 2020. Evaluated parameters included biometric traits, grain yield, aboveground biomass production, canopy closure rate, and nutritional composition (crude protein and mineral content). Results indicated that 40 cm and 50 cm row spacings significantly increased biomass production ($p < 0.05$). The BRS Aleppo cultivar, at 40 cm spacing, achieved a mean grain yield of 1055.4 kg ha^{-1}, exceeding the global average, along with high crude protein content (24.5%). Additionally, it exhibited efficient canopy closure by the end of the vegetative cycle, suggesting reduced weed competition. In conclusion, BRS Aleppo demonstrates promising adaptation to tropical conditions, with potential for integration into winter cropping systems under high-density planting (40 cm row spacing).

Keywords: *Cicer arietinum* L., Food sovereignty, Legumes, Soil management

Introduction

The increase in legume consumption is driven by the growth of the world population, which is expected to reach 10 billion people by 2050 (UN, 2019), the pursuit of a healthier lifestyle, and concerns about the nutritional quality of food. Furthermore, dietary shifts, such as the rise in vegetarian and vegan consumers, are increasing the demand for vegetable proteins like chickpeas, which are used as main dishes or ingredients in various recipes, thus making them a versatile food source (KAUR and PRASAD, 2021; KOUL et al., 2022; PHIRI, NJIRA, and CHITEDZE, 2023).

Chickpea (*Cicer arietinum* L.) is one of the most important leguminous species cultivated in the world, often cited as the third most significant among these crops, with an annual production of around 18 million tons and growing trends. The main world producers are India (13.5 M t^{-1}), Australia (1.06 M t^{-1}), Turkey (580 k t^{-1}), Ethiopia (492.6 k t^{-1}), and Russia (467.8 k t^{-1}), followed by Myanmar and Pakistan. Eighty-four percent of world production is concentrated in Asia (FAO, 2022; KAUR and PRASAD, 2021; KOUL et al., 2022).

Chickpeas are valued for their high protein content and for containing proteins of high biological value, as well as peptides with bioactive properties beneficial to the immune system. They are also rich in minerals, vitamins, and unsaturated fatty acids, which are essential for controlling cholesterol. Composed mainly of carbohydrates, particularly starch (reaching 39.0% of its dry weight), chickpeas have a low glycemic index due to the resistant fraction of starch, amylose, and fibers that are not digested in the small intestine (KAUR and PRASAD, 2021; KOUL et al., 2022; NASCIMENTO et al., 2016).

The state of Paraná, in the southern region of Brazil, has more than 305,000 farms covering 14.7 million hectares, generating employment for over 846,000 people (IBGE, 2019). Agriculture is an important sector for the state’s economy, which produces more than 34.6 million tons of grains annually, highlighting the production of corn (15.6 M t^{-1}) and soybeans (13.7 M t^{-1}). In 2022, Paraná was the largest producer of beans, rye, barley, and triticale, the second largest producer of oats, corn, wheat, and peas, and the third largest producer of soybeans. The state also produces significant quantities of rice, sorghum, and peanuts (IBGE, 2023).

The plateaus in the interior of Brazil play a crucial role in grain production, hosting two annual harvests locally known as summer and winter harvests. These areas experience periods of low rainfall and, in parts such as the Central-South Region and the northern region of the state of Paraná, cold or mild temperatures. Agriculture in these regions is highly technological and mechanized, making chickpeas a viable option for the second harvest due to their adaptation to low temperatures and dry climates (AVELAR et al., 2018; NASCIMENTO et al., 2016).

Chickpeas can serve as an alternative to wheat and beans in winter cultivation, integrated into crop rotation systems with soybeans and corn. It is a drought-resistant crop, fully mechanizable, and offers a favorable profit margin for producers. Brazilian research faces significant challenges in identifying new options for large-scale cultivation, including: 1) the species’ ability to adapt to existing cultivation systems; 2) achieving balanced production that ensures economic and environmental sustainability; and 3) developing cultivars with high nutritional value for human consumption and animal feed production (QUEIROGA, GIRÃO, and ALBUQUERQUE, 2021).

New cultivars are frequently developed to withstand abiotic stresses, pests, and diseases, as well as to enhance nutritional characteristics. Studying the performance of these cultivars in the field is essential to ensure food supply (KOUL et al., 2022; MEKUANINT et al., 2018; NASCIMENTO et al., 2016). Agronomic practices also significantly influence production; among them, planting density is a crucial factor for chickpea yield, affecting phytomass and grain production (LORIA et al., 2022; SINGH et al., 2023).

Despite its production potential and domestic demand, chickpeas have received less research attention in Brazil compared to soybeans and beans (CAPES, 2024), and production data are not included in official statistics (IBGE, 2023). To expand production and meet demand, this study evaluated chickpea cultivars at sowing row spacings as an alternative winter crop in northern Paraná, Brazil.

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Materials and methods

Characterization of the experiment and experimental area

The experiment was conducted at the Dashen Consultoria e Pesquisa Agronômica Station, located in the municipality of Bandeirantes, state of Paraná, Brazil (Fig. 1), at geographic coordinates 23º 04' 26.8" South latitude and 50º 23' 59.2" West longitude, with an altitude of 389 m. The soil is classified as a Typical Eutroferric Red Oxisol "Ferralsols" (EMBRAPA, 2024). The experiment took place from March to September 2020.

The experimental design used was a randomized block design in a 6×3 factorial scheme, with four replications. The treatments consisted of 6 chickpea cultivars (BRS Toro, BRS Cícero, BRS Aleppo, BRS Cristalino, BRS Kalifa, and CP 1605) at 3 sowing row spacings (40 cm, 50 cm, and 60 cm). Each experimental plot contained 4 sowing rows, each 4 m long. The two lateral rows were considered borders, while the two central rows were used for evaluations. To standardize the plot sizes, the width of the largest spacing (2.4 m) was used, resulting in plots with a total area of 9.6 m².

Rainfall and temperature data during the experiment (Fig. 2) were obtained from the Agrometeorological Station of the State University of Northern Paraná (UENP/CLM) and the National Institute of Meteorology (INMET), both located in Nova Fátima, Paraná. Complementary sprinkler irrigations were applied according to the crop's requirements.

Soil samples were taken one month before sowing for chemical and granulometric analysis. Samples were collected at depths of 0-20 cm and 20-40 cm, at random points in the experimental area. The analyzes were conducted at the Soil Laboratory at the Luiz Meneghel Campus of UENP/CLM. The particle size distribution found was 640 g kg^{-1} (clay), 160 g kg^{-1} (silt) and 200 g kg^{-1} (sand). The soil tillage system for the planting, plowing was carried out followed by two harrowing operations (crusher and leveling).

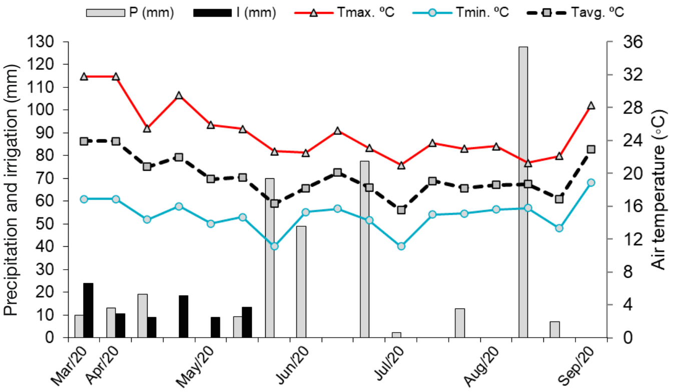

Fig. 2: Precipitation (P), irrigation (I) and maximum (Tmax), minimum (Tmin) and average (Tavg) air temperatures during the experiment period (March-September, 2020).

Fertilization management and pest and disease management

According to the soil analysis (Tab. 1), starter fertilization was conducted with 300 kg ha^{-1} of a 02:20:18 fertilizer blend, equating to 6 kg of N, 60 kg of P_2O_5, and 54 kg ha^{-1} of K_2O (NEPAR/SBCS, 2019). The starter fertilization was manually applied in-furrows at a depth of 7 to 8 cm using a manual furrower. Thirty-two days after

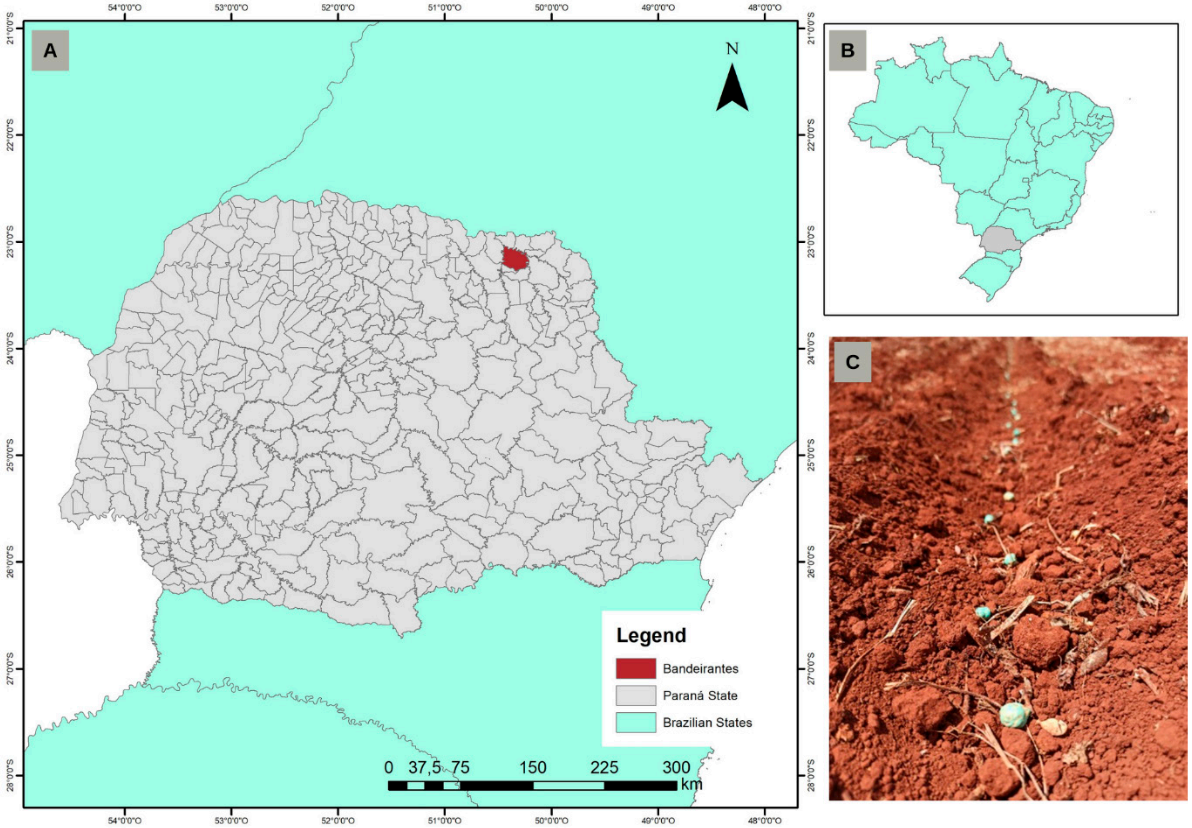

Fig. 1: Geographic location of the experimental area and stages of conducting the experiment. Location of the municipality of Bandeirantes, highlighted in orange, in the state of Paraná (A), Location of the state of Paraná, highlighted in orange, in Brazilian territory (B) and sowing of chickpeas in the experimental area (C).

plant emergence, a side-dressing of 30 kg of N ha^{-1} was applied using urea (46% N), as recommended by NEPAR and SBCS (2019). Due to base saturation exceeding 60% (Tab. 1), limestone application was deemed unnecessary.

Sowing and fertilization were carried out manually at a depth of 2 to 3 cm on March 27, 2020, with a seeding density of 15 plants per linear meter. A wooden ruler was used to deposit the seeds in the furrow, ensuring equal spacing between them for greater uniformity during manual sowing. For all cultivars, seedling emergence occurred in the first ten-day of April 2020. To standardize the stand in the plots, manual thinning was performed when necessary to achieve a density of 10 plants per linear meter in the sowing row.

Weed control was performed using herbicide applications (before sowing and pre-emergence after sowing) and manual weeding after emergence. Plant diseases and pests were managed with the application of agricultural pesticides via a knapsack sprayer (Braga and Wutke, 2014; Nascimento et al., 2016).

Evaluation methods and data collection

The harvest was carried out when 90% of the leaves, pods, and branches of the plants had turned yellowish (Nascimento et al., 2016). Grain yield, aerial biomass, crude protein, and minerals content in the grains were evaluated. Plant height and stem diameter were measured only for correlation analysis.

To obtain the grains, the threshing process was carried out manually, and the grain mass was measured on a digital scale and converted to kg ha^{-1}. For the dry phytomass of the aerial parts, the plants were cut at ground level with pruning shears and dried in an oven with forced air circulation at 65 °C. Crude protein was determined by multiplying the nitrogen content (Kjeldahl method) by the conversion factor 6.25 (method 46-13.01) (American Association of Cereal Chemists, 2018).

The minerals phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), and sodium (Na) were evaluated in grains dried at 65 ºC and ground. The analysis followed the methodology proposed by Malavolta, Vitti, and Oliveira (1997). Similar to the protein analysis, only grains obtained from plots with a spacing of 40 cm between sowing rows were evaluated.

Canopy closure was assessed using remote sensing with an unmanned aerial vehicle (UAV) at a flight altitude of 25 meters. The images were utilized to calculate the Green-Red Vegetation Index (GRVI), following the methodology described in Sanches et al. (2018). A DJI® Phantom 3 Professional UAV equipped with an RGB (red, green, blue) camera was employed for image capture. Image processing was conducted on the Drone Deploy® platform. GRVI was specifically used for graph generation and correlation analysis.

Statistical analysis

The data were subjected to analysis of variance, and when significance was detected by the F Test, they were further analyzed using the Tukey mean test ($p \leq 0.05$). The software used for these analyses was Agrostat (Barbosa and Maldonado Junior, 2015). Pearson correlation, normality, and outlier tests were conducted using Minitab 18® software. Principal Component Analysis was performed using Xlstat software (Lumivero, 2024).

Results

Average yield and statistical analysis of cultivar and spacing effects

Yield averages ranged from 495 kg ha^{-1} to 1,055 kg ha^{-1}, with significant isolated effects observed for cultivar ($p<0.0134$) and spacing ($p<0.0001$), as well as for the interaction between cultivar and spacing ($p<0.0019$). Sowing row spacing affected the productivity of the BRS Cícero and BRS Aleppo cultivars, with their yield decreasing in less dense arrangements (Tab. 2).

At the 40 cm row spacing, the cultivars BRS Aleppo, BRS Toro, and CP 1605 exhibited statistically equivalent grain yields ($p > 0.05$). (Tab. 2). At a spacing of 50 cm between rows, there were no differences in yield among cultivars. While, at a spacing of 60 cm, the BRS Cícero cultivar differed only from the BRS Kalifa and CP 1605 cultivars, which showed higher yield (Tab. 2).

Dry phytomass production and correlation with agronomic traits

The dry phytomass of the aerial part was not influenced by the interaction between factors ($p=0.9160$); however, there were isolated differences observed for both cultivar ($p<0.0001$) and sowing row spacing ($p=0.0003$) (CV 17.6%) (Fig. 3). The BRS Kalifa cultivar recorded the highest average in the field (6,694 kg ha^{-1}), with no statistical difference compared to the BRS Aleppo cultivar (5,776 kg ha^{-1}). The lowest averages were observed for the CP 1605 (3,612 kg ha^{-1}) and BRS Cícero (3,493 kg ha^{-1}) cultivars (Fig. 3A).

Regarding the sowing row spacings, the highest production of vegetative dry phytomass was obtained by spacing 40 and 50 cm (Fig. 3B). The production of vegetative phytomass was mainly influenced by the height and diameter of the plant at harvest, with which it presented significant and positive correlations, phytomass × height (0.631, $p<0.000$) and phytomass × diameter (0.447, $p<0.000$).

Tab. 2: Average yield (kg ha^{-1}) of chickpea cultivars, at different sowing row spacings, in Bandeirantes, PR.

Cultivar	Type	Sowing row spacing (cm)		
		40	50	60
BRS Toro	Kabuli	857 AB	684	715 AB
BRS Cícero	Kabuli	729 Ba	582 ab	495 Bb
BRS Aleppo	Kabuli	1055 Aa	690 b	546 ABb
BRS Cristalino	Kabuli	784 B	758	713 AB
BRS Kalifa	Kabuli	661 B	681	776 A
CP 1605	Desi	825 AB	664	744 A
CV (%)			16,4	

Means followed by different uppercase letters in the columns and lowercase letters in the rows differ from each other using the Tukey test ($p \leq 0.05$).

Tab. 1: Chemical composition of the soil in the experimental area.

Depth cm	MO g kg^{-1}	pH CaCl$_2$	P* mg dm^{-3}	K	Ca	Mg	Al	H+Al	SB	CEC	BS %
				cmol$_c$ dm^{-3}							
0-20	13.4	4.6	10.7	0.24	4.0	1.7	0.2	3.52	5.9	9.5	62.8
20-40	14.8	5.3	1.4	0.10	3.5	2.0	0.0	2.89	5.6	8.5	66.0

*Extractor Mehlich 1; OM: organic matter; SB: base sum; CEC: cation exchange capacity; BS: base saturation.

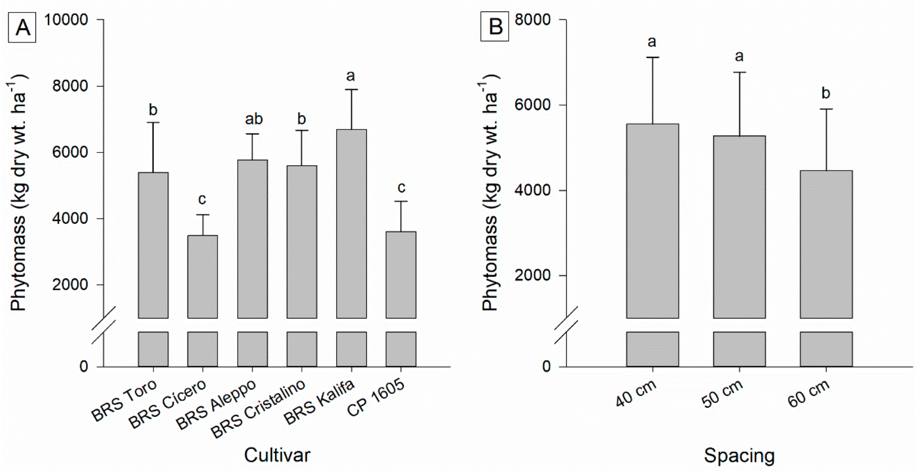

Fig. 3: Vegetative dry phytomass in the aerial part of chickpeas depending on the cultivar or sowing spacing, dry weight. Different letters on the standard deviation bars represent means that differ statistically from each other according to the Tukey test ($p \leq 0.05$).

GRVI varies from -1 to +1, with negative values associated with a greater presence of soil and positive values with a greater presence of vegetation. At 49 DAP (days after planting), the tone that represents the vegetation began to stand out in relation to the tone that represents the exposed soil. At this time, the BRS Aleppo cultivar presented the highest value for the index (Fig. 4). In general, the 40 cm sowing row spacing provided greater soil cover (Fig. 5) and GRVI positively correlated with plant height (0.500, p<0.000), diameter (0.266, p=0.024), vegetative dry phytomass (0.236, p=0.046) and grain yield (0.318, p=0.006).

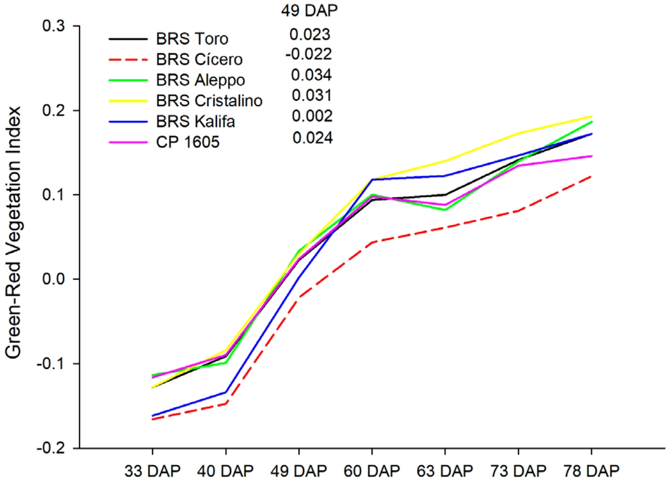

Fig. 4: Green-Red vegetation index for 40 cm spacing row sowing. DAP: Days after planting.

Nutrient and protein content and correlations with agronomic traits

The CP 1605 cultivar had the lowest protein content. The other cultivars showed no significant differences among them (Fig. 6). Protein content demonstrated a strong correlation with phosphorus content in the grain (0.849, p=0.032).

Most minerals were not influenced by cultivars, except for iron and calcium contents (Tab. 3).

With two components, it was possible to explain 78.5% of the variation in the data (Fig. 7). The first component correlates mainly with the contents of Mg, Na, P, K, and productivity, while the second component is mainly related to the values of Fe, Zn, Ca, and protein.

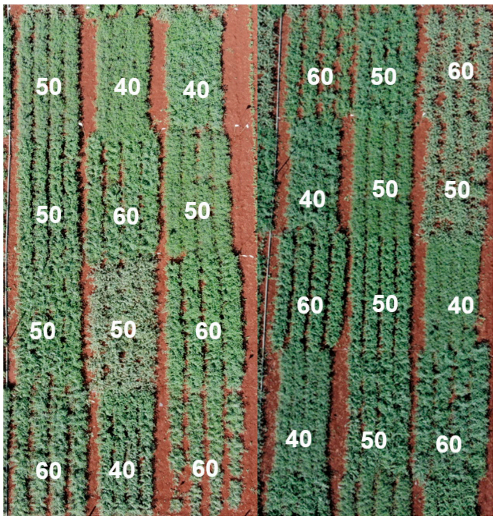

Fig. 5: Sections of the experimental area, image obtained by an unmanned aerial vehicle (UAV). The numbering on the vegetation indicates the sowing spacing used.

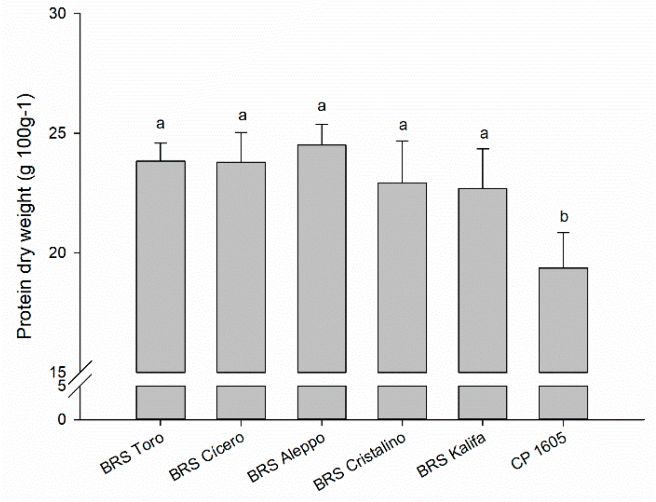

Fig. 6: Protein content in chickpea cultivars, at 40 cm sowing spacing. Different letters on the standard deviation bars represent means that differ statistically from each other according to the Tukey test (p ≤ 0.05).

Tab. 3: Mineral content in grains of chickpea cultivars, dry weight.

Cultivar	P	K	Ca	Mg	Fe	Zn	Na
				mg $100g^{-1}$			
BRS Toro	358	837	131	117	12.1 B	6.89	6.21 A
BRS Cícero	345	944	106	120	9.88 B	6.26	6.34 A
BRS Aleppo	351	969	112	125	9.25 B	6.94	5.78 A
BRS Cristalino	309	806	93.7	103	7.67 B	5.96	3.12 C
BRS Kalifa	320	825	119	109	7.50 B	6.03	3.93 BC
CP 1605	296	806	137	113	22.3 A	7.38	4.50 ABC
Average	330	865	117	115	11.5	6.57	5.01
CV (%)13.2	12.0	22.0	10.3	29.4	13.5	19.3	

Means followed by different uppercase letters in the columns differ from each other using the Tukey test ($p \leq 0.05$).

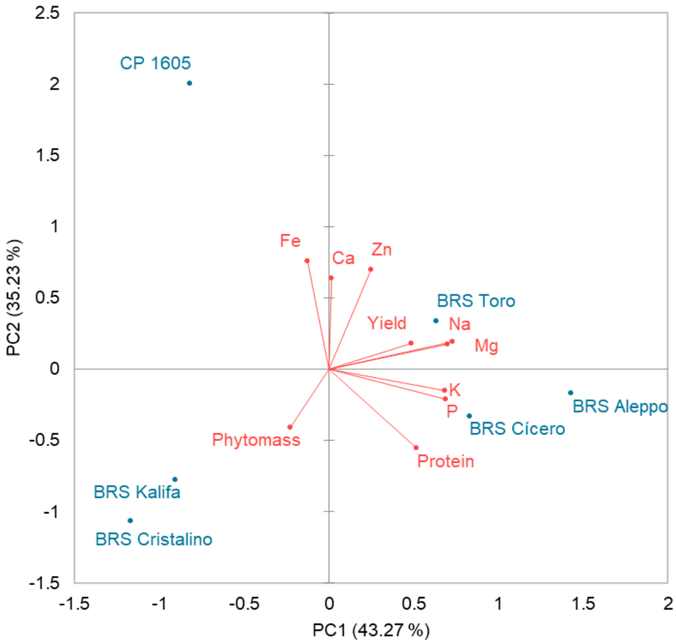

Fig. 7: Principal component analysis for nutrients and plant tissue production (vegetative dry phytomass and grain).

According to the principal component analysis, BRS Aleppo is associated with higher levels of Mg, P, K, Na, and also with good yield. The CP 1605 cultivar is associated with higher levels of Ca, Fe, and Zn.

Discussion

The cultivars BRS Cícero and BRS Aleppo showed higher yields in denser arrangements (Tab. 2). Previous studies have also reported increased chickpea yields with tighter spacing (Ali, Al-Kikani and Al-Mashhadany, 2024; Khan et al., 2010; Shamsi, 2009; Shiferaw, Tamado, and Asnake, 2018). In contrast, spacing did not affect grain yield for the other cultivars (BRS Toro, BRS Cristalino, BRS Kalifa, and CP 1605) (Tab. 2), consistent with findings from other studies on chickpea row spacing effects (Felton et al., 1996; Mekuanint, Tsehaye, and Egziabher, 2018). These results demonstrate that the genotypes BRS Cícero and BRS Aleppo exhibit greater phenotypic plasticity, enabling enhanced adaptation to high plant density conditions and more efficient utilization of production factors.

In another study conducted across two locations, BRS Aleppo yielded 3,600 kg ha^{-1} and 5,000 kg ha^{-1} in treatments with the highest averages at each site (Avelar et al., 2018). Over a four-year evaluation period on plateaus in the Central-West region of Brazil, BRS Aleppo averaged a grain yield of 2,994 kg ha^{-1} (Nascimento et al., 2014). Yield may have been influenced by the distribution of rainfall. While the total amount of rain was sufficient for the crop during the experimental period, its distribution was uneven, concentrating precipitation during less favorable periods such as grain filling and near harvest. In the second ten-day of August, precipitation exceeded 120 mm, potentially causing crop damage (Fig. 2). Excessive rainfall during the reproductive and harvest stages is detrimental to chickpea crops (Nascimento et al., 2016; Phiri, Njira, and Chitedze, 2023), which is one reason why the crop is included in agricultural climate risk zoning (Braga et al., 2023). Avelar et al. (2018) mention that the grain yield of the BRS Aleppo cultivar was adversely affected by excessive rainfall during the harvest period.

Nevertheless, brazilian technical bulletins report average grain yields ranging from 600-800 kg ha^{-1} under rainfed crop conditions to 750-1,200 kg ha^{-1}, and from 1,500-1,852 kg ha^{-1} to 2,500-2,700 kg ha^{-1} under irrigated crop systems (Braga and Wutke, 2014; Nascimento et al., 2016). Brazilian chickpea production is not officially recorded, complicating comparisons with national production realities. However, production statistics are available for neighboring countries: 1,254 kg ha^{-1} (Argentina), 1,978 kg ha^{-1} (Bolivia), 640 kg ha^{-1} (Chile), 792 kg ha^{-1} (Colombia), and 1,163 kg ha^{-1} (Peru) (FAO, 2022). Thus, except for Bolivia, these countries have grain yields similar to or lower than those achieved in this study by the BRS Aleppo cultivar. This is noteworthy even in Argentina, a significant player in global grain production.

The higher production of vegetative dry phytomass achieved with denser sowing densities (Fig. 3) has also been documented in other chickpea studies (Chala, Abera, and Nandeshwar, 2020; Shamsi, 2009; Shiferaw, Tamado, and Asnake, 2018). In a crop succession system or an established no-tillage system, this phytomass, combined with canopy closure (Fig. 4; Fig. 5), offers enhanced protection to the soil against erosion, excessive evaporation, water infiltration, and nutrient cycling. This is particularly attributable to the deep taproot of chickpeas, which can reach depths of 1.5 m to 2.0 m (Kaur and Prasad, 2022; Lago-Oliveira et al., 2023; Phiri, Njira, and Chitedze, 2023). Singh et al. (1999) demonstrated that improving light interception and water infiltration during the rainy season could lead to higher grain yields for soybeans and chickpeas in crop succession systems, thereby sustaining rainfed crop development. These findings are supported by the positive and significant correlations observed between GRVI and agronomic performance metrics.

Denser sowing can also aid in suppressing weed growth, which competes for nutrients and diminishes the yield of the main crop. Australian studies have shown that denser chickpea cultivation effectively suppressed ryegrass, a significant weed, while increasing grain yields (Mahajan, McKenzie, and Chauhan, 2019). Environmental benefits and greater grain and financial yields have been demonstrated for the rotational cultivation system between chickpeas and wheat, partly due to nitrogen fixation by the crop, which reduces input costs and water use efficiency (Hemmat and Eskandari, 2004; Lago-Oliveira et al., 2023).

Regarding nutritional quality, the average protein content ranged from 19.4 g 100g^{-1} to 24.5 g 100g^{-1}. The cultivar CP 1605 (Desi type) had the lowest protein content (Fig. 6). The other cultivars presented levels above 22.7 g 100g^{-1}, consistent with the expected range for the Kabuli type (21.3 g 100g^{-1} to 28.9 g 100g^{-1}). Typically, cultivars from the Kabuli type have a higher protein content than those from the Desi type (Patil et al., 2024). In a study with 11 chickpea genotypes, researchers found protein contents of 18.6 g 100g^{-1} to 23.3 g 100g^{-1}, with an overall average of 20.4 g 100g^{-1} (Vural and Karasu, 2007). Regardless of the type, Desi or Kabuli, chickpea protein has high biological value due to its digestibility, which is greater than that of soy and pea protein, for example. Despite the low levels of methionine and cysteine, the traditional combination with cereals rich in these amino acids and low in lysine, which is abundant in chickpeas, balances consumers' diets (Koul et al., 2022; Patil et al., 2024).

The mineral content varied according to the cultivars only for the iron (Fe) and sodium (Na) contents (Tab. 3). In general, the cultivar BRS Aleppo was associated with higher levels of phosphorus (P), potassium (K), magnesium (Mg), and sodium (Na), while the cultivar CP 1605 had higher levels of iron (Fe), zinc (Zn), and calcium (Ca) (Fig. 7). Except for the zinc content, which was higher in this research, the results found were very close to those presented by Koul et al. (2022): 250-310 mg 100g^{-1} (P), 700-718 mg 100g^{-1} (K), 57-160 mg 100g^{-1} (Ca), 79-138 mg 100g^{-1} (Mg), 4.0-12.3 mg 100g^{-1} (Fe), and 2.76-4.1 mg 100g^{-1} (Zn).

Among the analyzed minerals, sodium warrants particular attention due to its significant implications for human health. Excessive sodium intake is strongly associated with hypertension and cardiovascular diseases, prompting global health authorities to recommend a safe daily limit of 2,000 mg here. (Cappuccio et al., 2022). The sodium content in foods is mandatory on packaging labels according to the Brazilian regulatory agency (Brasil, 2003). Although the cultivars differed in terms of sodium content, the concentration was low. According to the results (Tab. 3), the consumption of 100 g of chickpeas contributes only 0.2% of the recommended daily intake. Thus, according to Brazilian standards, it can be stated on the labels as 'Zero' or 'Does not contain' (Brasil, 2003).

In addition to being consumed as whole grain, chickpeas can be processed to obtain a gluten-free flour, popular in India, the United States, and Europe, which can replace wheat in baked products, offering greater nutritional value with high levels of minerals, proteins, and vitamins (Kaur and Prassad, 2021; Koul et al., 2022; Vinod et al., 2023). There is a growing increase in the consumption of flours made from fruits or seeds, which are emerging as an alternative to wheat. However, many of these flours are deficient in proteins, so mixing them with other protein sources becomes interesting for nutritional gains (Cândido et al., 2022; Demarinis et al., 2024). These flours have been added as a source of fibers and bioactives in meat and dairy products to obtain healthier foods, also contributing to the reduction of fat in these products. Promising results have been obtained for chickpea flour, although there is still demand for rheological improvements (Demarinis et al., 2024; Kaur and Prassad, 2021; Patil et al., 2024).

Given the increasing demand for chickpeas in Brazil and the domestic production deficit, the adoption of locally adapted cultivars represents a strategic advantage for producers. Chickpea cultivars are classified into two main types: Desi and Kabuli. The Desi type accounts for approximately 85% of global production (Koul et al., 2022). However, the Brazilian market is primarily supplied by the Kabuli type, which better aligns with national consumer preferences.

In this context, the BRS Aleppo cultivar, a Kabuli-type variety, emerges as a promising alternative for tropical regions. This cultivar has demonstrated favorable agronomic performance, including high grain yield, dry biomass production, efficient canopy closure, and enhanced nutritional composition, positioning it as a viable option for expanding chickpea production particularly as a winter crop. The well-established expertise of Paraná's grain producers, combined with the agronomic resilience of BRS Aleppo, could significantly contribute to increasing domestic production and reducing reliance on imports.

Conclusions

This study demonstrates that the BRS Aleppo cultivar exhibited superior performance under high-density planting arrangements, specifically at a 40 cm row spacing, reflecting greater phenotypic plasticity and enhanced competitive adaptation. With an average yield of 1,055 kg ha^{-1}, coupled with increased biomass production and efficient soil canopy coverage, this cultivar presents a viable winter cropping alternative for tropical regions.

The cultivar further distinguishes itself through its nutritional quality, with protein and mineral contents meeting market standards - particularly relevant given the rising domestic demand for Kabuli-type chickpeas, which better align with Brazilian consumer preferences. Its adaptability to crop rotation systems and potential for diversified applications in the food industry (e.g., as gluten-free flour or functional ingredients) further enhance its economic and environmental viability. The adoption of BRS Aleppo could significantly contribute to: Increasing domestic chickpea production; Reducing import dependence (some tons/year); Improving farm profitability through winter crop diversification; Meeting industrial demand for premium-quality Kabuli chickpeas.

These findings position BRS Aleppo as a strategic cultivar for tropical cultivation systems, addressing both agronomic challenges (yield gaps in dense planting) and market needs (quality standards and import substitution).

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Conflict of interest

No potential conflict of interest was reported by the authors.

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