PAB
Pesquisa Agropecuária Brasileira

ISSN 1678-3921

Journal homepage: www.embrapa.br/pab

For manuscript submission and journal contents, access: www.scielo.br/pab

Crop Science/ Original Article

Yield performance and rhizobia inoculation in chickpea in low-altitude areas

Abstract – The objective of this work was to evaluate the productive performance of four chickpea (*Cicer arietinum*) cultivars and their seed inoculation with *Mesorhizobium* strains, in low-altitude areas in the state of Rio de Janeiro, Brazil. The chickpea cultivars used were BRS Aleppo, BRS Cícero, BRS Cristalino, and BRS Toro. Five experiments were carried out in a greenhouse and in the field. Chickpea inoculation experiments with *Mesorhizobium* were performed in sterilized substrate, soil, in a greenhouse and in the field, in the municipality of Seropédica. Cultivar production was evaluated in the municipalities of Seropédica and Campos dos Goytacazes. Yields above 1,400 kg ha^{-1} were observed for BRS Aleppo, BRS Cristalino, and BRS Toro cultivars, in Seropédica, being lower in Campos dos Goytacazes. However, the presence of caterpillar infestations (*Chloridea virescens* and *Helicoverpa armigera*) reduced grain yield and quality in Seropédica. Despite their high-nodulation rates in sterilized conditions, the tested *Mesorhizobium* strains failed to establish an effective nodulation under field conditions. Cultivars BRS Aleppo, BRS Cristalino, and BRS Toro show potential for commercial cultivation in low-altitude areas in Rio de Janeiro. However, the available *Mesorhizobium* strains do not establish nodulation under field conditions.

Index terms: *Cicer arietinum*, *Chloridea virescens*, *Mesorhizobium*, adaptation.

Desempenho produtivo e inoculação de rizóbios em grão-de-bico em áreas de baixa altitude

Resumo – O objetivo deste trabalho foi avaliar o desempenho produtivo de quatro cultivares de grão-de-bico (*Cicer arietinum*) e a inoculação de suas sementes com estirpes de *Mesorhizobium*, em áreas de baixa altitude, no estado do Rio de Janeiro, Brasil. As cultivares de grão-de-bico utilizadas foram BRS Aleppo, BRS Cícero, BRS Cristalino e BRS Toro. Cinco experimentos foram realizados em casa de vegetação e campo. Experimentos com inoculação de *Mesorhizobium* em de grão-de-bico foram realizados em substrato esterilizado e solo, em casa de vegetação e campo, no município de Seropédica. A produção das cultivares foi avaliada nos municípios de Seropédica e Campos dos Goytacazes. Produtividades acima de 1.400 kg ha^{-1} foram observadas nas cultivares BRS Aleppo, BRS Cristalino e BRS Toro, em Seropédica, tendo sido menores em Campos dos Goytacazes. No entanto, a presença de infestações de lagartas (*Chloridea virescens* e *Helicoverpa armigera*) reduziu a produtividade e a qualidade dos grãos em Seropédica. Apesar de apresentarem altas taxas de nodulação em condições esterilizadas, as cepas de *Mesorhizobium* testadas não conseguiram estabelecer nodulação efetiva em condições de campo. As cultivares BRS Aleppo, BRS Cristalino e BRS Toro mostram potencial de cultivo comercial, em áreas de baixa altitude no Rio de Janeiro. No entanto, as cepas de *Mesorhizobium* disponíveis não estabelecem nodulação em condições de campo.

Termos para indexação: *Cicer arietinum*, *Chloridea virescens*, *Mesorhizobium*, adaptação.

Jaqueline Carvalho de Almeida
Embrapa Agrobiologia, Seropédica, RJ, Brazil.
E-mail: jaqronald@gmail.com

Rafael Sanches Pacheco
Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brazil.
E-mail: rafaelrural2003@gmail.com

Josimar Nogueira Batista
Universidade Federal Rural do Rio de Janeiro, Rio de Janeiro, RJ, Brazil.
E-mail: josimarbatista@ufrrj.br

Warley Marcos Nascimento
Embrapa Hortaliças, Brasília, DF, Brazil.
E-mail: warley.nascimento@embrapa.br

Claudia Pozzi Jantalia
Embrapa Agrobiologia, Seropédica, RJ, Brazil.
E-mail: claudia.jantalia@embrapa.br

Jerri Edson Zilli(✉)
Embrapa Agrobiologia, Seropédica, RJ, Brazil.
E-mail: jerri.zilli@embrapa.br

✉ Corresponding author

Received
April 25, 2024

Accepted
July 15, 2025

How to cite
ALMEIDA, J.C. de; PACHECO, R.S.; BATISTA, J.N.; NASCIMENTO, W.M.; JANTALIA, C.P.; ZILLI, J.E. Yield performance and rhizobia inoculation in chickpea in low-altitude areas. **Pesquisa Agropecuária Brasileira**, v.61, e03742, 2026. DOI: https://doi.org/10.1590/S1678-3921.pab2026.v61.03742.

Introduction

Chickpea (*Cicer arietinum* L.) is the fourth most cultivated legume in the world after soybean [*Glycine max* (L.) Merr.], peanut (*Arachis hypogaeam* L.), and common bean (*Phaseolus vulgaris* L.) according to Food and Agriculture Organization of the United Nations (FAO, 2022). It is grown in more than 50 countries, out of which India, Australia, and Ethiopia are the main producers (Dixit et al., 2019; Rani et al., 2020). In 2022, the global cultivated area of chickpea was approximately 15 million hectares, yielding more than 18 million tonnes of grains (FAO, 2022).

In Brazil, chickpea production is considered relatively low (Santos et al., 2021) as it does not meet domestic demands, requiring grain imports (Fonseca et al., 2020; Santos et al., 2021). However, chickpea cultivation in the country has expanded due to increased consumption and export potential, especially to Asia (Nascimento et al., 2016, 2019).

The increase in chickpea consumption is attributed to its nutritional characteristics and its use as an alternative protein source for humans (Fonseca et al., 2020; Santos et al., 2021). The legume is employed as a source of high-quality nutritional protein and carbohydrates, consumed either in the form of whole grain or processed into flour (Arooj et al., 2021; Santos et al., 2021).

An alternative to increase chickpea production in Brazil is using it as a second crop (Santos, et al., 2021; Silva et al., 2021). Besides its good adaptability to annual cropping systems (Artiaga et al., 2015), chickpea can be associated to rhizobia bacteria, enabling the biological nitrogen fixation (BNF). According to Mthulisi & Mcebisi (2020), BNF may meet 80% of chickpea nitrogen demand, potentially fixing 140 kg ha^{-1} N. This process may reduce production costs (Nascimento et al., 2016).

The municipality of Rio de Janeiro is one of the major chickpea consumers in Brazil. Small cultivation areas in the vicinity, which are a characteristic of most rural properties in the region, can benefit themselves from chickpea production. The Northern Fluminense region stands out due to its potential for the production of grain crops, with more than 200 thousand hectares previously cultivated with sugarcane, although it is currently used for extensive livestock or abandoned (Zilli et al., 2021). Therefore, the production of chickpea can be an option for Fluminense producers, but it is necessary to adapt cultivars to the local edaphoclimatic conditions.

The objective of this work was to evaluate four chickpea (*Cicer arietinum*) cultivars and their seed inoculation with *Rhizobia* strains, in low-altitude areas in the state of Rio de Janeiro, Brazil.

Materials and Methods

Five experiments (EXP1 to EXP5) were conducted in 2020, 2021, and 2022, in two areas, both in the state of Rio de Janeiro, Brazil. One of these areas was at the experimental field of Embrapa Agrobiologia, in the municipality of Seropédica (16°29'16.2"S, 49°17'57.80"W, at 30 m altitude). The second one was at the experimental area of Universidade Federal Rural do Rio de Janeiro, in the municipality of Campos dos Goytacazes (21°45’15’’S, 41°19’28”W, at 13 altitude).

In Seropédica, the temperature range was from 9.3 to 35.9°C; its soil is classified as an Argissolo (Santos et al., 2018), equivalent to an Acrisol (IUSS Working Group WRB, 2015), whose granulometry at 0–20 cm was 620 g kg^{-1} sand, 10 g kg^{-1} silt, and 27 g kg^{-1} clay.

In Campos dos Goytacazes, the temperature range was from 15.4 to 31.4°C; its soil was classified as Cambissolo (Santos et al., 2018), equivalent to a Cambisol (IUSS Working Group WRB, 2015), whose soil granulometry at 0–20 cm was 13.6% sand, 40% silt, and 46.4% clay. The results of soil fertility analyses are presented in Table 1.

EXP1 and EXP2 were designed to evaluate cultivar performances in conditions of low-altitude field areas in the state of Rio de Janeiro. EXP3 was a controlled environment to evaluate the *Mesorhizobium* strains performances. The EXP4 was chose to test the best strain in EXP3 and to compare performances with the officially recommended strain under field conditions. Given the results obtained in the EXP4, a fifth experiment (EXP5) was designed, to closely observe the strain performance under controlled conditions. However, differently from EXP3, soil was used in EXP5.

EXP1 (in Seropédica) and EXP2 (in Campos dos Goytacazes) were carried out in fields, in order to evaluate the performance of the cultivars. In both areas, each experimental plot consisted of four 4.0 m long rows, spaced at 0.50 m between lines, with planting density of ten seed per linear meter. The experiment was conducted in a randomized complete block design with four replicates (n = 4), in a 4×2 factorial arrangement, representing the four chickpea cultivars and the two N rates (60 and 120 kg ha^{-1} N as urea applied along with potassium chloride). The chickpea cultivars used were BRS Aleppo, BRS Cícero, BRS Cristalino, and BRS Toro, all belonging to the Kabuli group. They were developed for the Brazilian Cerrado, a savannah-type biome in the central region of Brazil, where altitude is above 500 m. Additional fertilization included 40 kg ha^{-1} P_2O_5 as single superphosphate, 60 kg ha^{-1} K_2O as KCl, and 20 kg ha^{-1} FTE-BR12 (Nutriplant, Barueri, SP, Brazil), a micronutrient-based fertilizer. KCl was applied 50% at sowing, and 50% as top dressing, 40 days after plant emergence (DAE).

Sowing was carried out on May 20, 2020, in EXP1, and on June 2, 2020, in EXP2. Weed control was performed manually, and irrigation was done through a sprinkler system as needed. In EXP2, phytosanitary control was not necessary. In EXP1, methomyl 21.5% (w/v) was used due to caterpillar infestation.

Samples of the aerial part of the plant (aboveground biomass) were collected from five plants from the second row of the plot. The part removed was obtained by cutting at ground level. The collected material was dried in a forced-air circulation oven, at 65°C, for 96 hours, and then weighed. Grain yield estimation was performed by removing one central row of each plot, discarding 0.5 linear meter from each border row of each plot. In EXP1, the aboveground biomass sampling was carried out at 55 DAE, and the grain harvest on September 18, 2020. In EXP2, the aboveground biomass sampling was carried out at 70 DAE, and the grain harvest on September 28, 2020.

EXP3 was conducted in greenhouse, between May and August 2021, to evaluate the performance of the inoculants. Leonard jars were used with autoclaved substrate of sand and vermiculite in a proportion of 1:1 (v/v). The experimental unit was one jar. Fertilization was performed using the modified Norris' nutrient solution, applied and changed weekly (Norris & Date, 1976). Five seed of each cultivar were sown in each jar, and the inoculation was performed on the day of sowing. After emergence, thinning was carried out, and only two seedlings were left out in each jar.

The experimental design was a randomized complete block with three replicates (n = 3), in a 4×7 factorial arrangement, representing the four chickpea cultivars and seven *Mesorhizobium* spp. strains (Table 2). The cultivars used were BRS Aleppo,

Table 1. Soil fertility analysis of the experimental areas in the municipalities of Seropédica and Campos dos Goytacazes, in the state of Rio de Janeiro, Brazil.

Site	Depth (cm)	pH water	P	K	Ca	Mg	Al	Na	SOM(1)
			--------(mg dm^{-3})--------		---------------------($cmol_c$ dm^{-3})---------------------				(g dm^{-3})
Campos dos Goytacazes	0–20	6.0	11.0	76.0	4.6	3.1	0.0	0.1	30.7
	20–40	6.5	4.0	19.0	4.5	2.8	0.0	0.2	22.4
Seropédica	0–20	5.0	28.3	93.4	3.1	2.0	0.9	-(2)	21.0
	20–40	5.2	25.3	40.4	2.1	1.6	0.7	-	11.0

(1)SOM, soil organic matter.. (2)- not determined.

Table 2. *Mesorhizobium* spp. strains used for inoculation in chickpea (*Cicer arietinum*).

Strain	Synonym	Taxonomy	History
BR 521	USDA 3383, LMG 14898, UPM-Ca7, ATCC 51585, WSM 2100	*Mesorhizobium ciceri*	Strains imported from the USA in the 1980s.
BR 522	USDA 3392, UPM-Ca 36, WSM 2102	*Mesorhizobium mediterraneum*	
BR 4507	TAL 1148, Nitragin 27A3, USDA 3378, SEMIA 396	*M. ciceri*	Recommended for chickpea in Brazil and probably imported from the USA, in the 1980s.
BR 14159	-	*M. mediterraneum*	The same as BR 521, but imported from Australia, in 2018.
BR 14160	-	*M. ciceri*	The same as BR 522, but imported from Australia, in 2018.
BR 14161	CC1192, WSM 4542, V2, TAL 620, DSM 1978, CB2855	*M. ciceri*	Imported to Brazil, but there is not an accurate date.
BR 14603	-	*M. ciceri*	The same as BR 14161, but imported from Australia, in 2018

BRS Cícero, BRS Cristalino, and BRS Toro. Two control treatments were added to be used as negative reference (noninoculated) and positive reference (N addition). The N treatment used ammonium sulfate [$(NH_4)_2$ SO_4] as a N source equivalent to 60 kg ha^{-1} N.

Each seed was inoculated with 1.0 mL of the culture broth, and covered with a thin layer of sterilized sand. The *Mesorhizobium* strains used in the inoculation were individually grown in culture medium, as recommended by Scheidt et al. (2020). They were subjected to constant agitation (150 rpm), and kept at 30°C, until reaching 10^8 cell mL^{-1} concentration.

BRS Cícero, an early maturing cultivar, was collected at 45 DAE, while the others were collected at 55 DAE. The aerial part, cut at the ground level, was collected for dry biomass evaluation. This material was dried in an oven with forced-air circulation, at 65°C, for 96 hours, and then weighed. The roots were also collected and washed. The material was placed in paper bags, dried in an oven at 65°C, until a constant weight was attained. Nodules were removed and weighted for the determination of nodule dry mass.

EXP4 was carried out in 2022 in the field experiment in the municipality of Seropédica, using a randomized complete block design with four replicates (n = 4), in a 4×4 factorial arrangement, with four chickpea cultivars of EXP1 and EXP2, and strains BR 522 and BR 4507, the positive control (60 kg ha^{-1} N as urea), and the absolute control (negative control, without N or inoculant). The preparation of the inoculant was the same used in EXP3. Before sowing, seed were inoculated with 5 mL of culture broth per kg of seed. At 45 DAE, the plants were collected. Root samples were collected and used for visualization and evaluation of plant nodulation. For the mass determination of dry nodules, the same method of the EXP3 was used. Grain yield was estimated by collecting one central row of each plot, discarding one linear meter from each border of the row.

EXP5 was set up in greenhouse in 2022. Pots of 3.0 L containing a mixture of soil and sand (1:1) were used. The experiment was designed in randomized blocks. There were nine treatments, out of which seven encompassed BRS Toro cultivar inoculated with one of the seven *Mesorhizobium* spp. strains (Table 2), one positive control (treatment with N), and an absolute control (negative control, without N or inoculant). The inoculation was performed applying 1.0 mL of the culture broth (10^8 cells mL^{-1}) in the plants ten days after its emergence. At 45 DAE, the plants were collected to visualize the root-nodules formation.

The assumptions of independence of errors, normality, and homoscedasticity were verified using the SISVAR software (Ferreira, 2019). Durbin-Watson's, Bartlett's, and Shapiro-Wilk's tests were used, at 5% probability. All assumptions were met. There was no need to transform the data. The data were subjected to the analysis of variance, using the F-test, at 5% probability. When significant, the means were compared using the Student's t-test (LSD, at 5% probability).

Results and Discussion

Before diving into the results, there is a couple of important points to highlight. First, two issues significantly impacted the overall plant performance in EXP1 and EXP2. In both experiments, seed emergence for all four cultivars was notably low, ranging between 50% and 60%, ten days after sowing. Additionally, in EXP1, a caterpillar infestation (primarily *Chloridea virescens*) affected plant pods during grain filling, and required a chemical control. Second, the grain harvest in EXP4 was severely compromised by a caterpillar infestation involving both *Chloridea virescens* and *Helicoverpa armigera* (Borella Júnior et al., 2022; Ricalde et al., 2023).

The results of shoot dry matter of chickpea plants were very similar among cultivars in EXP1 and EXP2, with no significant differences (Table 3). The overall mean was 225 and 432 g m^{-2} in Seropédica (EXP1) and Campos dos Goytacazes (EXP2), respectively. A markedly difference between the two areas was soil texture: Seropédica had a lighter-textured (sandy) soil, while Campos dos Goytacazes had a very clayey soil. As reported in the literature, the crop does not adapt well to clayey soils (Howey, 2020), which could have influenced crop development. However, the biomass differences observed here likely result from the sampling time, which occurred at 55 DAE in EXP1 and at 70 DAE in EXP. Regarding N fertilization, no differences were observed between the two N rates applied, except for 'BRS Toro', for which the 60 kg ha^{-1} N rate provided a greater biomass increase.

In EXP1 and EXP2, the average grain yield was 1,087 and 709 kg ha^{-1}, respectively (Table 4). Generally, except for BRS Cícero, all cultivars showed

DOI: 10.1590/S1678-3921.pab2026.v61.03742

higher grain yields in EXP1 than in EXP2. In EXP1, the average production of 'BRS Cícero' was 593 kg ha^{-1} lower than those of the other cultivars. In EXP2, there was no significant differences for grain yield between cultivars.

In the literature, the productive potential of these cultivars in experimental conditions, in a Cerrado area, is reported as exceeding 2,000 kg ha^{-1}, even as a second crop (Giordano & Nascimento, 2005; Nascimento et al., 2014, 2017a, 2017b). The early maturing cultivar BRS Cícero has a lower productive potential than other cultivars (Artiaga et al., 2015). Other studies in the Brazilian Cerrado showed that the grain yields of cultivars BRS Cícero, BRS Aleppo, BRS Cristalino, and BRS Toro are less than 800 kg ha^{-1} (Artiaga et al., 2015; Fidelis et al., 2024), a range also observed in the present study.

Notably, grain yield in EXP1 and EXP2 showed no differences when the N fertilizer was applied, regardless of the N rate (60 or 120 kg ha^{-1} N), tested sites, or cultivars. This fact indicates that soil-N from organic matter sufficiently supplied the N requirements of the crop under these specific conditions. Other studies have shown significant responses to mineral N application, even at rates exceeding 100 kg ha^{-1} (Almeida Neta et al., 2020).

In EXP2, in which the soil phosphorus level was 11.0 mg dm^{-3}, the application of 40 kg ha^{-1} of P_2O_5 may have limited the crop yield potential. According to Madzivhandila & Ogola (2012), P fertilizer is strongly recommended for maximizing chickpea yield, especially under water stress conditions.

In EXP3, no nodulation was observed in the control treatment, indicating no contamination between treatments. Statistical analysis showed no significant interaction between rhizobia strains and cultivars ($p<0.05$) for chickpea plant nodulation (Table 5). For all cultivars, the highest nodulation was observed in plants treated with strain BR 522 (*M. mediterraneum*), even better than strain BR 4507 (*M. ciceri*) that is recommended for chickpea in Brazil.

As to shoot dry weight, no significant effect of the treatments was observed in EXP3. For all cultivars, the absolute control treatment (without N, and without inoculation) produced less biomass than the inoculated treatments, as expected. Dry matter biomass varied between 756 (BR 522 x 'BRS Cristalino') and 1,473 mg per plant (BR 14603 x 'BRS Cícero'), with no significant differences within each cultivar, but differences between cultivars. Treatment using strain BR 14603 had a higher average than those using BR 522, BR 14159, BR 4507, and both controls (Table 6).

In EXP4, when strains BR 522 and BR 4507 were tested, neither nodule was observed on plant roots, nor significant biomass production within each cultivar.

Table 3. Aerial part dry matter (g m^{-2}) of four chickpea (*Cicer arietinum*) cultivars fertilized with two N rates (60 and 120 kg ha^{-1} N) as urea in two field experiments carried out in 2020, one in the municipality of Seropédica (first experiment) and the other in the municipality of Campos dos Goytacazes (second experiment), located in low-altitude areas in the state of Rio de Janeiro, Brazil.

Cultivar	Seropédica			Campos dos Goytacazes		
	60	120	Mean	60	120	Mean
	------------ (g m^{-2}) -----------			----------- (g m^{-2}) -----------		
BRS Aleppo	254^{ns}	180	218	469	440	454
BRS Cícero	239	176	208	463	446	455
BRS Cristalino	243	276	260	490	315	404
BRS Toro	228	196	212	516	311	414
CV (%)	35.84			31.99		

^{ns}Nonsignificant at 5% probability.

Table 4. Grain yield of four chickpea (*Cicer arietinum*) cultivars fertilized, in 2020, with two N rates in two field experiments, one in the municipality of Seropédica (first experiment) and the other in the municipality of Campos dos Goytacazes (second experiment), located in low-altitude areas of Rio de Janeiro state, Brazil(1).

Cultivar	Seropédica	Campos dos Goytacazes	Overall mean
	------------- Grain yield (kg ha^{-1}) --------------		
BRS Aleppo	1,179a	739^{ns}	959
BRS Cícero	593b	807	700
BRS Cristalino	1,397a	579	988
BRS Toro	1,180a	711	946
N rate (kg ha^{-1} N)			
60	1,117	750	934
120	1,058	668	863
Mean	1,087	709	898
CV (%)	22.29	69.8	

(1)Means (n = 4) followed by equal letters, in the columns, do not differ from each other by Student's t-test, at 5% probability. ^{ns}Nonsignificant at 5% probability.

DOI: 10.1590/S1678-3921.pab2026.v61.03742

The average results of dry matter were 82.65, 95.94, 69.07, and 132.63 g per plant for the treatments absolute control, BR 522 inoculation, BR 4507 inoculation, and positive control (mineral nitrogen), respectively. The average grain yield was about 500 kg ha^{-1}, however, it was very variable among plots, limiting any precise analysis.

Chickpea is a N_2-fixing legume, and it has been shown that the BNF process can provide atmospheric N accumulations over 100 kg ha^{-1} per season (Mthulisi & Mcebisi, 2020). Different from legumes like cowpea [*Vigna unguiculata* (L.) Walp.] and siratro (*Macroptilium atropurpureum* (Moc. & Sessé ex DC.) Urb.], which establish nodulation with a broader range of rhizobia species (Keet et al., 2017), chickpea is primarily nodulated by *M. ciceri* or *M. mediterraneum* strains (Wanjofu et al., 2022). These strains have a highly conserved set of nod genes (Rivas et al., 2007). Recently, some other species of *Mesorhizobium* and *Ensifer* genera have been reported to nodulate chickpeas (Dekkiche et al., 2018).

In Brazilian soils not previously cultivated with chickpea, the nodule formation in roots is uncommon, due to bacteria-host specificity (Vargas, 1990). This fact implies the need for using strains imported from other countries. In the present study, as recommended

Table 5. Nodule dry matter mass of four chickpea (*Cicer arietinum*) cultivars inoculated with different strains of *Mesorhizobium* in greenhouse conditions (third experiment)[(1)].

Treatment	Nodule dry matter mass (mg per plant)				
	BRS Aleppo	BRS Cícero	BRS Cristalino	BRS Toro	Mean
Absolute control	0c	0c	0b	0d	0c
Mineral nitrogen	0c	0c	0b	0d	0c
BR 521	85b	90ab	102a	85bc	91b
BR 522	149a	111a	129a	175a	141a
BR 4507	103ab	90ab	86a	112ab	98b
BR 14159	119ab	116a	114a	92bc	110b
BR 14160	92ab	86ab	100a	68bc	87b
BR 14161	114ab	77b	94a	81bc	92b
BR 14603	108ab	87ab	122a	44c	90b
Mean	85.5	73	83	73	
CV (%)	38.88	26.01	36.51	52.46	19.85

[(1)]Means (n = 3) followed by equal letters, in the columns, do not differ from each other by Student's t-test (least significant difference), at 5% probability.

Table 6. Dry matter of aerial parts of four chickpea (*Cicer arietinum*) cultivars inoculated with different strains of *Mesorhizobium* in greenhouse conditions (third experiment).

Treatment	Dry matter of aerial parts (mg per plant)				
	BRS Aleppo	BRS Cícero	BRS Cristalino	BRS Toro	Mean
Absolute control	448b	378c	449c	427b	426d
Mineral nitrogen	1,028a	988b	1,018ab	1,127a	1,040c
BR 521	1,058a	1,347ab	963ab	942a	1,077ab
BR 522	855a	1,227ab	756ab	1,057a	974c
BR 4507	1,095a	1,435a	790ab	1,037a	1,089bc
BR 14159	918	1,458a	947ab	1,145a	1,117bc
BR 14160	1,133a	1,323ab	1,132ab	1,248a	1,209ab
BR 14161	1,403a	1,262ab	1,050ab	1,155a	1,217ab
BR 14603	1,297a	1,473a	1,440a	970a	1,295a
CV (%)	31.82	17.14	32.52	23.40	12.87

[(1)]Mean (n = 3) followed by equal letters, in the columns, do not differ from each other, by the Student's t-test (LSD), at 5% probability.

by the Brazilian Ministry of Agriculture and Livestock (MAPA), the strain of *M. ciceri* (SEMIA 396) was used. It was imported from the USA decades ago, along with three other strains − USDA 3383, USDA 3392, and CC1192 (Table 2). These strains were tested in accessions from the USA and in recently ones imported from Australia. The type strains USDA 3383 and USDA 3392 are of *M. ciceri* and *M. mediterraneum*, respectively. The strain CC1192 is used as inoculant for chickpea in other countries, such as Australia (Haskett et al., 2016).

Regardless of origin, all strains in EXP3 were capable of nodulating chickpea plants, with particular emphasis on strain BR 522 (USDA 3392), which averaged over 140 mg per plant of nodule dry mass formation (Table 6). Similarly, all strains significantly contributed to biomass production, providing values superior to those of the control and significantly equal to or greater than those of the N treatment (Table 5). However, in EXP4, strains BR 522 and BR 4507 (SEMIA 396) did not form root nodules. Consequently, a new experiment (EXP5) was conducted in pots with soil-sand substrate, in a greenhouse, and seven strains (Table 2) were inoculated in 'BRS Toro', in which effective nodulation was also not observed.

Studies on inoculant performance in chickpea cultivation in Brazil are scarce. In a study with *Rhizobium tropici* (SEMIA 4077), recommended for *Phaseolus vulgaris* (Almeida Neta et al., 2020), no significant effects on grain yields were reported. Although plant nodulation was not evaluated, it would be not possible, since *R. tropici* probably does not nodulate chickpea. Another study reported yield increases of over 100% through inoculation with *Bradyrhizobium* (Braga & Vieira, 1998).

The success of *Mesorhizobium* strains occurred in controlled conditions; however, their failure in soil suggests issues with symbiosis and inoculation practices. Vargas (1990) found that seedling inoculation resulted in lower nodulation than seed inoculation, showing the need for high-bacteria concentration at plant germination stage. This underscores the need for a strain selection and testing program to improve chickpea cultivation and sustainability.

Conclusions

1. The four evaluated chickpea (*Cicer arietinum*) cultivars (BRS Aleppo, BRS Cícero, BRS Cristalino, and BRS Toro) have potential for cultivation in the state of Rio de Janeiro, Brazil.

2. Despite their efficiency under controlled conditions, *Mesorhizobium* strains available in Brazil did not establish nodulation under field conditions.

References

ALMEIDA NETA, M.N.; PEGORARO, R.F.; SAMPAIO, R.A.; COSTA, C.A. da; FERNANDES, L.A.; FERREIRA, J.M. Does inoculation with *Rhizobium tropici* and nitrogen fertilization increase chickpea production? **Ciência e Agrotecnologia**, v.44, e016520, 2020. DOI: https://doi.org/10.1590/1413-7054202044016520.

AROOJ, A.; FAIZ, S.; SHAH, J.; RAMZAN, A.; IHSAN, M.; SALEEM, M. Technological, processing and nutritional aspects of chickpea (*Cicer arietinum*). **Saudi Journal of Pathology and Microbiology**, v.6, p.150-155, 2021.

ARTIAGA, O.P.; SPEHAR, C.R.; BOITEUX, L.S.; NASCIMENTO, W.M. Avaliação de genótipos de grão de bico em cultivo de sequeiro nas condições de Cerrado. **Agrária - Revista Brasileira de Ciências Agrárias**, v.10, p.102-109, 2015.

BORELLA JÚNIOR, C.; CORREA, F.; SILVA, A.R. da; SIQUEIRA, A.P.S.; NASCIMENTO, W.M.; ALMEIDA, A.C. de S.; JESUS, F.G. de. Resistance of chickpea cultivars to *Chloridea virescens* (Lepidoptera: Noctuidae). **Acta Scientiarum. Agronomy**, v.44, e54619, 2022. DOI: https://doi.org/10.4025/actasciagron.v44i1.54619.

BRAGA, N.R.; VIEIRA, C. Efeito da inoculação com *Bradyrhizobium* sp., nitrogênio e micronutrientes no rendimento do grão-de-bico. **Bragantia**, v.57, p.349-353, 1998. DOI: https://doi.org/10.1590/S0006-87051998000200016.

DEKKICHE, S.; BENGUEDOUAR, A.; SBABOU, L.; TAHA, K.; FILALI-MALTOUF, A.; BÉNA, G. Chickpea (*Cicer arietinum*) is nodulated by unexpected wide diversity of *Mesorhizobium* species in Eastern Algeria. **Archives of Agronomy and Soil Science**, v.64, p.285-297, 2018. DOI: https://doi.org/10.1080/03650340.2017.1346791.

DIXIT, G.P.; SRIVASTAVA, A.K.; SINGH, N.P. Marching towards self-sufficiency in chickpea. **Current Science**, v.16, p.239-242, 2019. DOI: https://doi.org/10.18520/cs/v116/i2/239-242.

FAO. **Food and Agriculture Organization of the United Nations**. Statistic Division. Roma: Fao. 2022. Available at: <https://www.fao.org/faostat/en/#data/QCL/visualize>. Accessed on: July 15, 2025.

FERREIRA, D.F. SISVAR: A Computer analysis system to fixed effects split plot type designs. **Brazilian Journal of Biometrics**, v.37, p.529–535, 2019. DOI: https://doi.org/10.28951/rbb.v37i4.450.

FIDELIS, R.R.; VELOSO, D.A.; LOPES, M.B.; CAVAZZINI, P.H.; COELHO, L.B.A.; AGUIAR, H.R.M.; BARROS, L.C.; FERREIRA, S.M.B. Evaluation of chickpea genotypes in Cerrado conditions in the South of the state of Tocantins. **Revista Observatório de la Economía Latinoamericana**, v.22, e3150, 2024. DOI: https://doi.org/10.55905/oelv22n2-050.

FONSECA, J.H. dos S.; ALMEIDA NETA, M.N.; PEGORARO, R.F.; ALMEIDA, G.F.D.; COSTA, C.A. da; ALMEIDA, E.S. de. Chickpea production in response to fertilization with zinc and doses of phosphorus. **Comunicata Scientiae**, v.11, e3106, 2020. DOI: https://doi.org/10.14295/cs.v11i0.3106.

GIORDANO, L. de B.; NASCIMENTO, W.M. **Cícero**: grão de bico: sabor e qualidade. Brasília: Embrapa Hortaliças, 2005. Available at: <http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/778474>. Accessed on: July 15 2025.

HASKETT, T.; WANG, P.; RAMSAY, J.; O'HARA, G.; REEVE, W.; HOWIESON, J.; TERPOLILLI, J. Complete genome sequence of *Mesorhizobium ciceri* strain CC1192, an efficient nitrogen-fixing microsymbiont of *Cicer arietinum*. **Genome Announcements**, v.4, e00516-16, 2016. DOI: https://doi.org/10.1128/genomeA.00516-16.

HOWEY, E.V.**Response of chickpea to different soil pH and texture**. 2020. 97p. Thesis (Doctorate) - Murdoch University, Australia. Available at: <https://researchportal.murdoch.edu.au/esploro/outputs/graduate/Response-of-chickpea-to-different-soil/991005544407107891>. Accessed on: July 15, 2025.

IUSS WORKING GROUP WRB. **World Reference Base for Soil Resources 2014**: international soil classification system for naming soils and creating legends for soil maps: update 2015. Rome: FAO, 2015. (FAO. World Soil Resources Reports, 106).

KEET, J.-H.; ELLIS, A.G.; HUI, C.; LE ROUX, J.J. Legume–rhizobium symbiotic promiscuity and effectiveness do not affect plant invasiveness. **Annals of Botany**, v.119, p.1319-1331, 2017. DOI: https://doi.org/10.1093/aob/mcx028.

MADZIVHANDILA, T.; OGOLA, J.B.O. Growth and yield response of four chickpea cultivars to phosphorus fertilizer rates. **Journal of Food Agriculture and Environment**, v.1010, p.451-455, 2012. Available at: <https://www.researchgate.net/publication/233933616>. Accessed on: July 15, 2025.

MTHULISI, M.; MCEBISI, M. Current status of chickpea production: opportunities for promoting, adoption and adapting the crop in Zimbabwe: a review. **Journal of Dryland Agriculture**, v.6, p.1-9, 2020. DOI: https://doi.org/10.5897/JODA2019.0029.

NASCIMENTO, W.M.; ARTIAGA, O.P.; BOITEUX, L.S.; SUINAGA, F.A.; PINHEIRO J.B.; SILVA, P.P. da. **BRS Toro**: grão-de-bico: rusticidade e desempenho. Brasília: Embrapa Hortaliças, [2017b]. Available at: <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/195000/1/digitalizar0168.pdf>. Accessed on: July 15 2025.

NASCIMENTO, W.M.; ARTIAGA, O.P.; BOITEUX, L.S.; SUINAGA, F.A.; REIS, A.; PINHEIRO J.B.; SPEHAR, C.R. BRS **Aleppo**: grão-de-bico: maior tolerância a fungos de solo. Brasília: Embrapa Hortaliças, 2014. Available at: <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/134623/1/digitalizar0025.pdf>. Accessed on: July 15 2025.

NASCIMENTO, W.M. (Ed.). **Hortaliças leguminosas**. Brasília: Embrapa, 2016.

NASCIMENTO, W.M.; SUINAGA, F.A.; BOITEUX, L.S.; PINHEIRO J.B.; ARTIAGA, O.P. **BRS Cristalino**: grão-de-bico: nova cultivar de grão-de-bico de dupla aptidão. Brasília: Embrapa Hortaliças, [2017a]. Available at: <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/160738/1/digitalizar0197.pdf>. Accessed on: July 15 2025.

NASCIMENTO, W.M.; SILVA, P.P. da. Grão-de-bico: nova aposta do agronegócio brasileiro. **Seed News**, v.23, p.18-22, 2019. Available at: <https://seednews.com.br/artigos/2969-grao-de-bico-nova-aposta-do-agronegocio-brasileiro-edicao-maio-2019>. Accessed on: July 15 2025.

NORRIS, D.O., DATE, R.A. Legume bacteriology. In: SHAW, N.H., BRYAN, W.W. (Eds.). **Tropical pasture research: principles and methods.** Hurley: Commonwealth Bureau of Pasture and Field Crops, 1976. p.134-174. (Bulletin, 51).

RANI, A.; DEVI, P.; JHA, U.C.; SHARMA, K.D.; SIDDIQUE, K.H.M.; NAYYAR, H. Developing climate-resilient chickpea involving physiological and molecular approaches with a focus on temperature and drought stresses. **Frontiers in Plant Science**, v.10, p.1759, 2020. DOI: https://doi.org/10.3389/fpls.2019.01759.

RICALDE, M.P.; SILVA, A. de C.; ALMEIDA, J.C. de; PACHECO, R.S.; JANTALIA, C.P.; ZILLI, J.E. Caterpillars associated with chickpea pods (*Cicer arietinum* L. – Fabaceae) and their damage on four cultivars in the state of Rio de Janeiro, Brazil. **International Journal of Tropical Insect Science**, v.43, p.2289-2292, 2023. DOI: https://doi.org/10.1007/s42690-023-01125-0.

RIVAS, R.; LARANJO, M.; MATEOS, P.F.; OLIVEIRA, S.; MARTÍNEZ-MOLINA, E.; VELÁZQUEZ, E. Strains of *Mesorhizobium amorphae* and *Mesorhizobium tianshanense*, carrying symbiotic genes of common chickpea endosymbiotic species, constitute a novel biovar (ciceri) capable of nodulating *Cicer arietinum*. **Letters in Applied Microbiology**, v.44, p.412-418, 2007. DOI: https://doi.org/10.1111/j.1472-765x.2006.02086.x.

SANTOS, H.G. dos; JACOMINE, P.K.T.; ANJOS, L.H.C. dos; OLIVEIRA, V.A. de; LUMBRERAS, J.F.; COELHO, M.R.; ALMEIDA, J.A. de; ARAUJO FILHO, J.C. de; OLIVEIRA, J.B. de; CUNHA, T.J.F. **Sistema brasileiro de classificação de solos**. 5.ed. rev. e ampl. Brasília: Embrapa, 2018. 356p.

SANTOS, L.P.; PEREIRA, W.J.; SILVA, D.Z.; GONÇALVES, D.J.; ALVES, G.C.S.; PINHEIRO J.B.; SILVA, G.O.; MELO, R.A.C.; NASCIMENTO, W.M; SILVA, P.P. Chickpea genotype resistance to *Meloidogyne javanica* and *Pratylenchus brachyurus* in field conditions. **Pesquisa Agropecuária Brasileira** v.56, e02529, 2021. DOI: https://doi.org/10.1590/S1678-3921.pab2021.v56.02529.

SCHEIDT, W.; PEDROZA, I.C.P.S.; FONTANA, J.; MELEIRO, L.A.C.; SOARES, L.H.B.; REIS, V.M. Optimization of culture medium and growth conditions of the plant growth-promoting bacterium *Herbaspirillum seropedicae* BR11417 for its use as an agricultural inoculant using response surface methodology (RSM). **Plant and Soil,** v.451, p.75-87, 2020. DOI https://doi.org/10.1007/s11104-019-04172-0.

SILVA, K.F.; MORAES, D.H.M. de; MESQUITA, M.; OLIVEIRA, H.F.E. de; NASCIMENTO, W.M.; BATTISTI, R.; FLORES, R.A. Water requirement and crop coefficient of three chickpea cultivars for the edaphoclimatic conditions of the Brazilian savannah biome. **Irrigation Science**, v.39, p.607-616, 2021. DOI: https://doi.org/10.1007/s00271-021-00737-z.

VARGAS, M.A.T. Competitiveness and rhizosphere colonization of *Bradyrhizobium* sp. strains on chickpea. **Pesquisa Agropecuária Brasileira** v.25, p.599-607, 1990.

WANJOFU, E.I.; VENTER, S.N.; BEUKES, C.W.; STEENKAMP, E.T.; GWATA, E.T.; MUEMA, E.K. Nodulation and growth promotion of chickpea by *Mesorhizobium* isolates from diverse sources. **Microorganisms**, v.10, art.2467, 2022. DOI: https://doi.org/10.3390/microorganisms10122467.

ZILLI, J.E.; POLIDORO, J.C.; ALVES, B.J.R.; LUMBRERAS, J.F. (ed.). **A produção da soja e do milho como um caminho para o desenvolvimento do agronegócio da Região Norte Fluminense**. Rio de Janeiro: Embrapa Solos, 2021. 44p. (Embrapa Solos. Documentos, 221). Available at: <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/223075/1/CNPS-DOC-221-2021.pdf>. Accessed on: July 15, 2025.

Author contributions

Jaqueline Carvalho de Almeida: conceptualization, methodology, writing - original draft, writing - review & editing; **Rafael Sanches Pacheco**: conceptualization, data curation, methodology, writing - review & editing; **Josimar Batista Nogueira**: methodology, writing - review & editing; **Warley Marcos Nascimento**: methodology, resources, writing - review & editing; **Claudia Pozzi Jantalia**: conceptualization, writing - review & editing; **Jerri Edson Zilli**: conceptualization, data curation, formal analysis, funding acquisition, methodology, project administration, writing - original draft, writing - review & editing.

Chief editor: Edemar Corazza
Edited by: Daniel Kinpara

Data availability statement

The data supporting the findings of this study are available in the article. Should any raw data be needed, they will be provided by the corresponding author upon reasonable request.

Declaration of use of AI technologies

During the preparation of this work, the author(s) used ChatGPT 5.0 and M365Copilot in order to review the writing. After this use, the author(s) reviewed and edited the content as needed and take(s) full responsibility for it.

Conflict of interest statement

The authors declare no conflicts of interest.

Acknowledgments

To Universidade Federal Rural do Rio de Janeiro (UFRRJ) and Embrapa Agrobiologia, for institutional support; to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), for productivity grants awarded to C.P.J. and J.É.Z. and for financial support (process 405968/2022-1 and CNPq 408267/2024 - Fundação Araucária); to Fundação de Apoio à Pesquisa do Estado do Rio de Janeiro, for the fellowship Cientista do Nosso Estado.

Disclaimer/Publisher’s note: