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Growth promotion in maize (*Zea mays* L.) by *Bacillus aryabhattai* strain CMAA 1363

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ABSTRACT: The objective of this study was to evaluate the potential of the bacterium *Bacillus arayabhattai* strain CMAA 1363 in promoting maize growth and productivity, comparing it with a commercial formulation of an inoculant based on *Azospirillum brasilense* Ab-V5 Ab-V6. To this end, in each of four different edaphoclimatic regions, a trial was conducted consisting of six treatments as follows: four doses of *B. aryabhattai*, a standard dose of *A. brasilense*, and an absolute control, with four repetitions, totaling 24 experimental plots. The parameters evaluated were seed germination, phytotoxicity, plant height, stalk diameter, dry mass of the aerial parts and roots, and yield. The results showed that *B. aryabhattai* was not phytotoxic, promoted the growth of maize plants, and increased productivity at a dose of 4 mL kg^{-1} in a statistically similar way to the standard commercial product. Therefore, it may constitute a new inoculant for maize crop.

Key words: *Azospirillum brasilense*; biofertilizers; inoculant; seed treatment

Promoção de crescimento no milho (*Zea mays* L.) por *Bacillus aryabhattai* cepa CMAA 1363

RESUMO: O objetivo desse trabalho foi avaliar o potencial da bactéria *Bacillus arayabhattai* cepa CMAA 1363 na promoção de crescimento e produtividade da cultura do milho, comparando-o com uma formulação comercial de um inoculante à base de *Azospirillum brasilense* Ab-V5 Ab-V6. Para tanto, em cada uma de quatro regiões edafoclimáticas distintas foi conduzido um ensaio composto de seis tratamentos, quatro doses de *B. aryabhattai*, a dose padrão de *A. brasilense* e uma testemunha absoluta, com quatro repetições, perfazendo 24 parcelas experimentais. Os parâmetros avaliados foram germinação de sementes, fitotoxicidade, altura de plantas, diâmetro de colmo, massas secas da parte aérea e da raiz, além da produtividade. Os resultados demonstraram que o B. aryabhattai não foi fitotóxico, promoveu crescimento de plantas de milho e, na dose de 4 mL kg^{-1} incrementou a produtividade de maneira estatisticamente semelhante ao produto comercial empregado como padrão, podendo se constituir em um novo inoculante para a cultura do milho.

Palavras-chave: *Azospirillum brasilense*; biofertilizantes; inoculante; tratamento de sementes

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Introduction

Plant-growth-promoting rhizobacteria (PGPR) are a heterogeneous group of bacteria that are present in the rhizosphere. PGPR belong mainly to the genera *Bradyrhizobium*, *Azospirrillum*, *Azotobacter*, *Bacillus*, *Pseudomonas*, and *Serratia*. Among these, *Bacillus* is the most extensively studied, as it is the most abundant genus in the rhizosphere, and the activity of many species has been known for many years (Sansinenea, 2019). Plant growth is often directly promoted through an increase in bioavailability of mineral nutrients such as nitrogen, phosphorus, and iron (Lugtenberg & Kamilova, 2009), by providing amino acids and other nutritional factors (Liu et al., 2018), or by synthesis of plant-growth-regulating compounds such as indole acetic acid, gibberellins, and cytokinins (Zhou et al., 2019). In addition, rhizobacteria usually metabolize compounds such as the ethylene precursor 1-aminocyclopropane-1-carboxylic acid (ACC) (Zafar-ul-Hye et al., 2019). Several indirect mechanisms exist through which many rhizobacteria promote plant growth. Such mechanisms involve events such as the synthesis of antibiotics and antifungals (Lugtenberg & Kamilova, 2009); enzymes that degrade the cell walls of fungi, e.g. chitinase and β-1,3-glucanase (Alamri, 2014); and production of small iron-chelating molecules, siderophores, to compete for iron in the rhizospheric environment (Yu et al., 2017). Some rhizobacteria species also improve drought tolerance by production of exopolisaccharides, biofilm formation, and accumulation of some organic solutes such as amino acids, and polyamines (Khan et al., 2020). Thus, inoculation of plants with growth-promoting microorganisms can improve drought tolerance of plants in arid or semi-arid regions (Ngumbi & Kloepper, 2016).

By the early 2000s, more than 200 *Bacillus* species had been described, and >10 of which were already in common use in agriculture worldwide, and these numbers are steadily increasing (Fritze, 2004). Among the *Bacillus* species recently reported, *Bacillus aryabhattai* has attracted the interest of researchers due to its versatility and potential uses in different areas of knowledge, including agriculture.

B. aryabhattai was first isolated and identified from cryotubes used to collect air samples from the Earth's stratosphere at an altitude between 27 and 41 km in 2009 (Shivaji et al., 2009), resulting in suggestions of a cosmic origin of this bacterium. Since then, the bacterium has presented a cosmopolitan characteristic, being isolated in many parts of the world, such as South Korea, Tibet, Bangladesh, Mexico, Brazil, and Spain, from various environments, including dense forest soil (Chanasit et al., 2014); urban tunnels (Park et al., 2012); rhizospheric soils of crop plants such as sugarcane, canola, rice, and soybeans (Siddikee et al., 2010; Park et al., 2017); the weeds *Erigeron canadensis*; (Lee et al., 2012) and the cactus *Cereus jamacaru* (Kavamura et al., 2013).

Although *B. aryabhattai* is a recently discovered species, several studies have already been conducted with this microorganism. This is attributable to the fact that, in addition to presenting several important attributes including growth promotion in plants, tolerance to saline environments, water deficit, heavy metals, and UV radiation, this organism shows desirable characteristics for the industry. This is because it is a microorganism to that is not pathogenic to vertebrates, invertebrates, or plants. The growth-promoting activity of *B. aryabhattai* was first reported in canola by Siddikee et al. (2010), who observed an increase of more than 40% in root elongation and in the dry weight of seedlings treated with the bacterium under salt stress conditions as compared to non-inoculated seedlings. Two years later, Lee et al. (2012) showed that *B. aryabhattai* promoted the growth of *Xanthium italicum*. These authors noted that seed germination was facilitated and the length and dry mass of the roots and aerial parts of the seedlings were greater than those of the non-inoculated plants. The root length of *X. italicum* seedlings increased by approximately 121% when treated with *B. aryabhattai*. In Brazil, Kavamura et al. (2012) reported that *B. aryabhattai* was able to promote growth in maize (*Zea mays* L.) under water stress conditions, increasing leaf area, stalk length, and aerial part dry weight by 81, 17, and 66%, respectively, compared to non-inoculated plants. Inoculation also protected the maize plants against the negative effects of desiccation.

Studies in India and South Korea have reported the potential use of *B. aryabhattai* in agriculture and the beneficial effects of the bacterium on plants under stress conditions. After inoculation with *B. aryabhattai* isolates MDSR7 and MDSR14, Ramesh et al. (2014) reported increased dehydrogenase and β-glycosidase enzyme activity, auxin production, microbial respiration, and biomass carbon in soybean and wheat rhizosphere soils. In addition, through these isolates, it was possible to enhance the growth of soybean and wheat plants and increase zinc mobilization and biofortification. Yoo et al. (2019) noted that application of *B. aryabhattai* strain H19-1 to tomato plants under salt stress alleviated the decrease in plant growth and chlorophyll content, increased carotenoid content, decreased electrolyte leakage, and increased Ca^{2+} content compared to untreated plants. Under conditions of high temperature stress, Lee et al. (2018) reported that *B. aryabhattai* H26-2 associated with *Bacillus siamensis* H30-3 can increase the productivity of Chinese cabbage (*Brassica rapa* subsp. *Pekinensis*) through improved plant growth. Park et al. (2017) evaluated the effect of *B. aryabhattai* on soybean growth promotion modulated by phytohormone production. Gas chromatography mass spectrometry analysis showed that the isolate SRB02 produced significant amounts of abscisic acid (ABA), indoleacetic acid, cytokinins, and different gibberellic acids in the crop. SRB02-treated soybean plants showed significantly better heat stress tolerance than untreated plants. These plants also produced consistent levels of ABA under heat stress and exhibited ABA-mediated stomatal closure. These plants produced longer roots and branches than the control plants. Also, *B. aryabhattai* SRB02 was highly tolerant to oxidative and nitroactive stress.

Ngangom et al. (2019) verified that a higher number of leaves and greater stalk diameter, root length, and weight of bell pepper plants resulted from the application of *B. aryabhattai*. In another study conducted in Brazil, inoculation of pre-sprouted sugarcane seedlings with *B. aryabhattai* promoted improved aerial and root development, especially under water stress conditions. The cultivar IAC 911099 was the most responsive to the presence of the bacteria in the rhizosphere of the plants. Additionally, researchers reported that the presence of *B. aryabhattai* on sugarcane roots promoted greater efficiency in the use of available soil water (May et al., 2019).

Therefore, *B. aryabhattai* has highly diverse plant-growth-promoting properties, with the potential to increase not only the development but also the crop productivity, and that it can be a valuable resource to be incorporated into or to constitute an inoculant, promoting improved agricultural production.

The objective of this study was to evaluate the effect of a preparation based on *Bacillus aryabhattai* (1.0×10^8 CFU mL^{-1}), applied via seeds, on the growth and productivity of maize (*Zea mays* L.), comparing its performance with that of a commercial preparation of *Azospirillum brasilense* (Ab-V5 and Ab-V6) at a concentration of 2.0×10^8 CFU mL^{-1}, a product registered by MAPA as an inoculant for maize cultivation, in four agricultural regions with different soil and climate conditions where maize is grown.

Materials and Methods

Feasibility and agronomic efficiency trials were conducted in four different soil and climatic regions as follows:

1. Edaphoclimatic Region 203: Fazenda Faxinal, located on the Faustino Daniel da Silva highway, km 76, in the municipality of Paranapanema, SP, Brazil, with the geographic coordinates 23° 29’ 24.68” South latitude, 48° 48’ 30.77” West longitude, and altitude of 658 m, from April 17, 2019 to September 11, 2019.
2. Edaphoclimatic region 301: Agro Carregal Research and Plant Protection Experimental Station, located on the old Rio Verde - Jataí road, km 05, in the municipality of Rio Verde, GO, Brazil, with the geographical coordinates 17° 47’ 02.04” South latitude, 51° 00’ 03.53” West longitude, and altitude of 775 m, from May 22, 2019 to September 23, 2019.
3. Edaphoclimatic Region 304: Experimental Station of the Phytus Institute, located on highway DF 145, km 03, in the municipality of Planaltina, DF, Brazil, with the geographical coordinates 15° 39’ 56.3” latitude South, 47° 20’ 04.6” longitude West, and altitude of 874 m, from May 30, 2019 to October 21, 2019.
4. Edaphoclimatic Region 303: Fazenda Bom Jardim, located on highway BR 050, km 91, in the municipality of Uberlândia, MG, Brazil, with the geographical coordinates 19° 02’ 22.0” South latitude, 48° 15’ 37.4” West longitude, and altitude of 852 m, from March 20, 2019 to August 02, 2019.

The bacterial preparations used in the trials are listed in Table 1.

An entirely randomized block design was used, with six (6) treatments and four (4) replications, yielding 24 experimental plots. The treatments evaluated in the experiment are described in Table 2.

The experimental plots consisted of eight rows, each 4.0 m wide and 6.0 m long, totaling an area of 24.0 m^2. For the evaluations, the four central rows of each plot were considered, excluding with 1 m at the ends of each row.

In each of the four different soil and climate regions, a trial was set up and conducted following the same methodology. The treatments were applied on the day of sowing by adding the corresponding dose of biological preparations to plastic bags containing the amount of seed to be used in each plot, then the bags were shaken vigorously for 1 minute.

Before planting, soil analysis of the total area was performed to determine the chemical and granulometric parameters for pH and macronutrient correction (N, K, Ca, Mg, and S), taking the recommendations for maize fertilization in the state of Minas Gerais for expected productivity above 8 tons ha^{-1} of grains (Alves et al., 1999) as a reference.

The maize was sown with a spacing of 0.5 m between rows and a density of 3.25 seeds per linear meter, and a population density of 65,000 plants ha^{-1}. The cultivars, 2B533 PW, NS 92 IPRO, 2B433 PW, and DKB 390 PRO were used in Paranapanema, Planaltina, Rio Verde, and Uberlândia, respectively.

Agrochemicals to manage weeds, pests, and diseases were applied according to the needs of each region, using products registered for maize cultivation.

The effect of the treatments was determined by evaluating seed germination, phytotoxicity, plant height, stalk diameter, aerial and root dry mass, and yield.

Table 1. Description of the products used to conduct the trial.

Product	Active ingredient	Concentration (CFU mL^{-1})
Preparation	*Bacillus aryabhattai* strain CMAA 1363	1.0×10^8
Commercial preparation	*Azospirillum brasilense* strains Ab-V5 and Ab-V6	2.0×10^8

Table 2. Treatments and doses of the products used.

Treatments	Dose ($mL\ kg^{-1}$)	Form of application
1. Control	-	-
2. *B. aryabhattai*	1.0	Seed treatment
3. *B. aryabhattai*	2.0	Seed treatment
4. *B. aryabhattai*	4.0	Seed treatment
5. *B. aryabhattai*	6.0	Seed treatment
6. *A. brasilense*	5.0[1]	Seed treatment

[1] Manufacturer’s recommended dose, 100 mL per bag of seeds, or 5.0 mL kg^{-1} seed.

The phytotoxicity of the treatments was evaluated until 45 days after sowing by observing chlorosis symptoms and/or injuries and assigning scores according to the scale of Frans et al. (1986).

Plant height was determined using a millimeter tape measure, measuring ten random plants per plot from ground level to the apex of the main stalk or fully expanded leaf. The evaluations were performed in phenological stages V10 and R3.

The evaluation of stalk diameter was performed in phenological stages V10 and R3 by randomly sampling ten plants from the usable plot and measuring the diameter of the stalk with a digital pachymeter.

At 45 days after planting, ten plants were extracted from the four central rows of each plot and divided into aerial and root parts. They were then placed in paper bags and placed in a forced air circulation oven at a temperature of 72 °C until they reached a constant weight. After drying, the material was weighed on a precision digital scale.

At the end of the cycle (R7), productivity in bags 60 kg ha^{-1} (bags ha^{-1}) was estimated by weighing the harvested and threshed grains from the four central rows of each plot, excluding 1 m at the ends of each row and adjusting the moisture content to 13%.

The raw data from the evaluations, when necessary, were transformed and submitted to analysis of variance. Comparisons between means were performed by Tukey test at 10% probability. All analyses were performed using R Statistical Software (v4.1.2; R Core Team, 2021).

Results and Discussion

Daily observations of the plants during the 45 days after planting, regardless of the soil and climate region, showed that the treatments evaluated did not cause any phytotoxicity symptoms that would compromise the growth and development of the maize crop throughout the trials (Table 3).

As regards plant height at the V10 stage, there was a significant effect ($p < 0.1$) in the Paranapanema and Uberlândia regions. According to Table 4, for these two regions, all doses of *B. aryabhattai* were significantly equal to the treatment with *A. brasilense*. In the Paranapanema region, the doses of 1.0 and 4.0 mL of *B. aryabhattai* differed from the control treatment, with increases of 6.1 and 7.2%, respectively. In the Uberlândia region, the dose of 4.0 mL of *B. aryabhattai* was superior to the control, with a 7.7% increase in height.

At phenological stage R3, the treatments of the regions of Paranapanema, Rio Verde, and Uberlândia showed a significant effect ($p < 0.1$). Analyzing Table 5, in Paranapanema, all doses of *B. aryabhattai* showed a significant effect in relation to the control treatment, with an increase ranging from 8.9 to 20.4%. In addition, the 4.0 mL dose of *B. aryabhattai* was equal to the treatment using the commercial preparation of *A. brasilense*, and the 6.0 mL dose showed a positive effect. In the Rio Verde region, the three lowest doses of B. aryabhattai were equal to the *A. brasilense* treatment, as well as equal to the control. The 6.0 mL dose of *B. aryabhattai* was the only one that differed from the control, with an increase of 16.2%. In Uberlândia, the doses of *B. aryabhattai* were all statistically equal to *A. brasilense*. In this same region, the 1.0, 4.0, and 6.0 mL doses of *B. aryabhattai* showed a significant effect in relation to the control, resulting in an average increment in height of 5.6%.

Table 3. Effect of the application of *B. aryabhattai* via maize seed treatment on the phytotoxicity variable in four edaphoclimatic regions.

Treatment	Dose ($mL\ kg^{-1}$)	Phytotoxicity (%)			
		Paranapanema	Planaltina	Rio Verde	Uberlândia
Control	-	0.0	0.0	0.0	0.0
B. aryabhattai	1.0	0.0	0.0	0.0	0.0
B. aryabhattai	2.0	0.0	0.0	0.0	0.0
B. aryabhattai	4.0	0.0	0.0	0.0	0.0
B. aryabhattai	6.0	0.0	0.0	0.0	0.0
Azototal	5.0	0.0	0.0	0.0	0.0
CV (%)		0.0	0.0	0.0	0.0

Table 4. Effect of *B. aryabhattai* application via maize seed treatment on plant height at phenological stage V10 in four edaphoclimatic regions.

Treatment	Dose ($mL\ kg^{-1}$)	Height - V10 (cm)			
		Paranapanema	Planaltina	Rio Verde	Uberlândia
Control	-	109.9 b[1]	116.9 a	83.7 a	196.8 b
B. aryabhattai	1.0	116.6 a	114.1 a	86.3 a	200.8 b
B. aryabhattai	2.0	115.5 ab	118.7 a	92.0 a	201.5 ab
B. aryabhattai	4.0	117.8 a	125.5 a	88.6 a	212.1 a
B. aryabhattai	6.0	115.2 ab	119.1 a	89.1 a	203.6 ab
A. brasilense	5.0	115.0 ab	124.1 a	88.7 a	206.1 ab
CV (%)		3.1	8.0	6.8	2.6

[1] Means followed by equal letters do not differ by the Tukey test at 10% probability.

Table 5. Effect of *B. aryabhattai* application via maize seed treatment on plant height at phenological stage R3 in four edaphoclimatic regions.

Treatment	Dose (mL kg^{-1})	Height - R3 (cm)			
		Paranapanema	Planaltina	Rio Verde	Uberlândia
Control	-	147.6 d[1]	166.0 a	152.4 b	216.2 b
B. aryabhattai	1.0	160.7 c	175.7 a	156.4 ab	227.1 a
B. aryabhattai	2.0	161.7 c	172.9 a	166.0 ab	225.1 ab
B. aryabhattai	4.0	168.1 b	170.0 a	164.7 ab	230.0 a
B. aryabhattai	6.0	177.7 a	171.8 a	177.1 a	228.2 a
A. brasilense	5.0	171.5 b	165.3 a	174.6 ab	231.3 a
CV (%)		3.1	1.7	4.1	7.4

[1] Means followed by equal letters do not differ by the Tukey test at 10% probability.

There was a significant effect ($p < 0.1$) for the variable stalk diameter at phenological stage V10 in the Paranapanema region (Table 6). In the Paranapanema region, all treatments differed statistically from the control, especially the 2.0 mL dose of *B. aryabhattai*, which also differed from the *A. brasilense* treatment. The doses of *B. aryabhattai* promoted an average increase of 10.5% in stalk diameter in relation to the control.

Regarding stalk diameter at the R3 phenological stage, a significant effect ($p < 0.1$) was verified in the Paranapanema, Rio Verde, and Uberlândia regions. Table 7 shows that in Paranapanema, all doses of *B. aryabhattai* had a significant effect in relation to the *A. brasilense* and control treatments, with an average increase of 12% in relation to the control. In Rio Verde, all doses of *B. aryabhattai* were equal to *A. brasilense*, however, the 4.0 mL dose differed significantly from the control, increasing the stalk diameter by 16.5%. In the Uberlândia region, none of the *B. aryabhattai* doses differed from the *A. brasilense* treatment, and the 4.0 mL dose was higher than the control, with an 8.3% increase. A significant effect ($p < 0.1$) was found for the variable aerial dry mass in the Paranapanema, Planaltina, and Uberlândia regions (Table 8).

In Paranapanema, all doses of *B. aryabhattai* were statistically equal to *A. brasilense* and different from the control, with increases ranging from 9.1 to 13.5%. In Planaltina, a similar effect was observed, where all doses of *B. aryabhattai* were equal to *A. brasilense*, but only the 4.0 and 6.0 mL doses differed from the control treatment, with increases of 68.1 and 61.2%, respectively. In the Uberlândia region, the 2.0 and 4.0 mL doses of *B. aryabhattai* did not differ from *A. brasilense*, but showed an additive effect in relation to the control. It was observed that the doses of 2.0 and 4.0 mL of *B. aryabhattai* promoted an increase of 62.4 and 71.7% in relation to the control, respectively. In general, a more pronounced growth-promoter effect was observed at the R3 phenological phase for the two analyzed variables, height and stalk diameter, suggesting that evaluations in maize plants treated with growth-promoter bacteria are preferably carried out at this reproductive phase.

Table 6. Effect of *B. aryabhattai* application via maize seed treatment on stalk diameter at phenological stage V10 in four edaphoclimatic regions.

Treatment	Dose (mL kg^{-1})	Stalk diameter - V10 (mm)			
		Paranapanema	Planaltina	Rio Verde	Uberlândia
Control	-	12.1 c[1]	36.3 a	23.9 a	18.9 a
B. aryabhattai	1.0	13.4 ab	35.7 a	22.8 a	18.8 a
B. aryabhattai	2.0	13.5 a	39.5 a	24.1 a	19.5 a
B. aryabhattai	4.0	13.4 ab	37.3 a	23.9 a	19.8 a
B. aryabhattai	6.0	13.2 ab	38.2 a	24.0 a	19.4 a
A. brasilense	5.0	13.0 b	36.4 a	23.1 a	19.9 a
CV (%)		3.1	1.8	7.1	4.8

[1] Means followed by equal letters do not differ by the Tukey test at 10% probability.

Table 7. Effect of *B. aryabhattai* application via maize seed treatment on stalk diameter at phenological stage R3 in four edaphoclimatic regions.

Treatment	Dose (mL kg^{-1})	Stalk diameter - R3 (mm)			
		Paranapanema	Planaltina	Rio Verde	Uberlândia
Control	-	20.2 b[1]	26.1 a	23.6 b	18.1 b
B. aryabhattai	1.0	22.3 a	27.0 a	26.1 ab	18.4 ab
B. aryabhattai	2.0	22.9 a	27.8 a	25.5 ab	19.1 ab
B. aryabhattai	4.0	22.4 a	28.7 a	27.5 a	19.6 a
B. aryabhattai	6.0	22.9 a	27.3 a	26.7 ab	19.1 ab
A. brasilense	5.0	19.5 b	29.3 a	27.4 a	19.7 a
CV (%)		3.1	2.3	7.5	12.2

[1] Means followed by equal letters do not differ by the Tukey test at 10% probability.

Table 8. Effect of *B. aryabhattai* application via maize seed treatment on the dry mass of the aerial parts in four soil and climate regions.

Treatment	Dose ($mL\ kg^{-1}$)	Aerial dry mass (g)			
		Paranapanema	Planaltina	Rio Verde	Uberlândia
Control	-	37.1 b[1]	11.6 b	28.4 a	33.3 c
B. aryabhattai	1.0	42.1 a	17.2 ab	27.9 a	37.8 bc
B. aryabhattai	2.0	40.5 a	17.0 ab	32.0 a	54.1 ab
B. aryabhattai	4.0	40.7 a	19.5 a	34.1 a	57.2 a
B. aryabhattai	6.0	41.9 a	18.7 a	33.7 a	37.5 bc
A. brasilense	5.0	40.2 ab	16.6 ab	33.8 a	55.9 a
CV (%)		3.1	5.7	21.3	24.9

[1] Means followed by equal letters do not differ by the Tukey test at 10% probability.

The results corroborate the observations of Kavamura (2012), who reported that *B. aryabhattai* was able to promote growth in maize, even under water stress conditions, by increasing leaf area, stalk length, and dry weight of the aerial parts, when compared to non-inoculated plants.

Regarding root dry mass, the treatments of the regions of Paranapanema and Planaltina showed a significant effect ($p < 0.1$). In Paranapanema, the 4.0 mL dose of *B. aryabhattai* stood out, differing statistically from the *A. brasilense* and control treatments. In Planaltina, although the doses of *B. aryabhattai* showed no significant effect in relation to the control, the dose of 4.0 mL differed positively from *A. brasilense* (Table 9).

May et al. (2019) demonstrated that the presence of *B. aryabhattai* not only increased root system growth, but also promoted greater efficiency in the use of available soil water.

There was a significant effect ($p < 0.1$) for the variable productivity in all the soil and climate regions under study (Table 10). In the Paranapanema region, all doses of *B. aryabhattai* were equal to *A brasilense*, although the 4.0 mL dose showed a significant effect in relation to the control treatment, increasing the yield by 43.7%. Similarly, in Planaltina, all doses of *B. aryabhattai* were equal to *A.brasilense*, but the doses of 2.0, 4.0 and 6.0 mL differed from the control treatment, with maize yield increasing by 10.5, 11.0, and 17.4%, respectively. In Rio Verde, it was observed that the 4.0 and 6.0 mL doses of *B. aryabhattai* were equal to *A. brasilense* and statistically different from the control treatment, showing an increase of 20.4% for both doses. Finally, in the Uberlândia edaphoclimatic region, the dose of 4.0 mL of *B. aryabhattai* was equal to *A. brasilense* and showed a significant increase of 5.9% over the control treatment, corresponding to 12.2 bags.

In summary, it can be highlighted that a 4.0 mL dose of a preparation of *B. aryabhattai* at a concentration of 1×10^8 CFU mL^{-1} in the four edaphoclimatic regions (Paranapanema, Planaltina, Rio Verde, and Uberlândia) presented statistical effects equal to the commercial inoculant preparation registered for culture based on *A. brasilense* at a concentration of 2×10^8 CFU mL^{-1}. Furthermore, in all regions studied, the 4.0 mL dose promoted an increase in maize yield that was statistically superior to the control treatment, with increases that varied between 5.9 and 43.7%, corresponding to a minimum increase of 3.2 bags ha^{-1} and a maximum increase of 29.7 bags ha^{-1}.

Table 9. Effect of *B. aryabhattai* application via maize seed treatment on root dry mass in four soil and climate regions.

Treatment	Dose ($mL\ kg^{-1}$)	Root dry mass (g)			
		Paranapanema	Planaltina	Rio Verde	Uberlândia
Control	-	10.7 b[1]	5.3 ab	13.8 a	49.7 a
B. aryabhattai	1.0	11.0 b	5.9 ab	11.8 a	44.4 a
B. aryabhattai	2.0	11.5 ab	5.0 ab	10.5 a	50.5 a
B. aryabhattai	4.0	12.0 a	6.8 a	17.3 a	57.2 a
B. aryabhattai	6.0	11.4 ab	6.1 ab	15.7 a	50.6 a
A. brasilense	5.0	10.8 b	4.3 b	15.0 a	44.7 a
CV (%)		3.1	4.2	22.6	49.3

[1] Means followed by equal letters do not differ by the Tukey test at 10% probability.

Table 10. Effect of *B. aryabhattai* application via maize seed treatment on yield in four edaphoclimatic regions.

Treatment	Dose ($mL\ kg^{-1}$)	Productivity (bags ha^{-1})			
		Paranapanema	Planaltina	Rio Verde	Uberlândia
Control	-	68.0 b[1]	96.4 b	42.8 c	207.1 c
B. aryabhattai	1.0	77.1 ab	105.4 ab	46.5 bc	208.2 bc
B. aryabhattai	2.0	89.5 ab	106.7 a	47.1 bc	210.5 bc
B. aryabhattai	4.0	97.7 a	107.0 a	51.5 ab	219.3 ab
B. aryabhattai	6.0	89.7 ab	113.2 a	51.6 ab	212.3 bc
A. brasilense	5.0	93.1 a	105.5 ab	54.8 a	226.5 a
CV (%)		3.1	15.6	6.0	6.5

[1] Means followed by equal letters do not differ by the Tukey test at 10% probability.

Conclusion

Our findings indicate that *B. aryabhattai,* strain CMAA1363, applied via seed treatment to maize, is an excellent plant growth, which increses the yield by 5.9 to 43.7%.

The preparation of *B. aryabhattai,* at a dose of 4.0 mL kg^{-1} of maize seed, can be used as an inoculant for the crop because of its performance as compared to the *A. brasilense*-based inoculant registered for the crop.

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