Agronomic efficiency of the inoculant FT10 (Trichoderma asperelloides) on four lettuce varieties

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Abstract

The present study aimed to evaluate the agronomic efficiency of FT10 (Trichoderma asperelloides) on four lettuce varieties development and productivity throughout the year. Four greenhouse experiments were carried out to verify the effect of three doses of the bio-product on plant growth and yield on loose-leaf, butterhead, iceberg and salad bowl cultivars. A randomized block design was used, with six replications. The treatments were: 1) control, 2) 300 mL ha⁻¹ of the commercial inoculant ICB Nutrisolo® Trichoderma, 3) 0.05 kg ha⁻¹ of the inoculant FT10, 4) 0.10 kg ha⁻¹ of FT10, and 5) 0.15 kg ha⁻¹ of FT10. The plant height and number of leaves were assessed 35 days after transplanting (DAT) of lettuce seedlings and the plant dry weight and yield were evaluated 42 DAT. The data obtained were compared with Duncan’s test. The majority of the evaluated parameters on lettuce varieties were found to be affected by the higher doses of FT10. Significant increases in yield in up to 21% for loose-leaf and 16% for butterhead were observed with the dose of 0.05 kg ha⁻¹ and 22% for iceberg and salad bowl with the dose of 0.10 kg ha⁻¹ of the bioproduct. It can be concluded that FT10 has the potential to promote plant growth and increase the productivity of lettuce cultivars if applied an appropriate dose of the product.

Keywords: inoculant, biostimulant, beneficial microorganism, Trichoderma

Introduction

The need for higher agricultural yields has led to the excessive use of inorganic fertilizers, creating environmental problems and compromising food security and quality. The use of beneficial microorganisms and biostimulants to maintain production levels and reduce dependency on fertilizers is a highly desirable strategy for ensuring sustainable agriculture (Azarmi et al., 2011; Ye et al., 2020).

Beneficial microorganisms are capable of colonizing plant roots and improving their growth and productivity. Among plant growth-promoting fungi, Trichoderma species are globally recognized and used in a wide variety of agricultural crops (Bettiol et al., 2009). These free-living symbionts influence plant health, growth and production. Their effect on plant development is attributed to different mechanisms of action, such as increasing minerals solubilization and uptake of nutrients, plant hormone synthesis, volatile organic compound production, improved abiotic stress tolerance and the suppression of harmful microorganisms (Machado, 2012; Fiorentino et al., 2018).

According to Leilio et al. (2021), Trichoderma species or strains can have a diverse impact on different crop species, or even genotypes of the same crop. Furthermore, the crop genotype influences significantly the rhizosphere colonization by Trichoderma strains. Therefore, the selection of a Trichoderma strain suitable to be widely used in agriculture depends not only on targeted use, but also on the ecological adaptability of the strain to the various environments, availability of water and nutrients, climatic conditions and crop genotypes that influence its effectiveness in the field.

Leafy vegetables represent 35% of the area of vegetable species produced in Brazil, and lettuce stands out for being the most consumed and produced due to
their culinary characteristics and cultural acceptance, besides it can be produced all year long. The production volume is over than 1.5 million tons a year and the estimated retail market reaches 8 billion of BRL (R$). Besides their economic importance, this crop presents an important social role since it is cultivated mainly by micro and small farmers (Souza et al., 2019; Dalastra et al., 2020).

In this context, the use of Trichoderma species as inoculants could contribute to maintain or improve the lettuce productivity and decrease the need for synthetic fertilizers.

This study aimed to evaluate the agronomic efficiency of three doses of FT10 (Trichoderma asperelloides) in the development and production of lettuce’s cultivars throughout the seasons.

Material and Methods

The four greenhouse experiments were conducted in the 2019/2020 growing season, in the city of Ponta Grossa, Paraná state (PR), Brazil (25°09’45.95”S, 50°11’23.63”W, altitude of 807 m). The climate in this area is classified as humid subtropical (Cfb, according to Köppen’s classification), with an average annual temperature of 17.5°C and rainfall of 1495 mm. The climatological data presented in the table 5 were collected during the execution of the experiments, from July of 2019 to May of 2020, at the meteorological station located in the experimental farm area of 3M.

The plant growth commercial substrate used in the experiments was from the Carolina Soil Company, with the following composition: sphagnum moss, expanded vermiculite, lime, gypsum and NPK fertilizer (traces), the potential of hydrogen (pH): 5.5 +/- 0.5, electrical conductivity (EC): 0.7 +/- 0.3, density: 145 kg/m³, water holding capacity (WHC): 55%, maximum moisture content: 50%, reactivity – stable inert product, nontoxic, physical nature: solid.

Four studies were carried out with loose-leaf lettuce (cv. ‘Amanda’), in July, September, November, and April of the 2019/2020 growing season. Paralelly, in September was also included in the experiment the butterhead (cv. ‘Regiane’) variety, in November the iceberg (cv. ‘Angelina’) variety and in April the salad bowl (cv. ‘Mimosa’) variety, to compare the efficiency of the FT10 inoculant in other lettuce types.

Botanical varieties of lettuce used in the experiments: 1. Amanda Loose-leaf cultivar is large, crisp and vigorous, with excellent leaf health, vivid light green coloring, high yields, low wastage and excellent postharvest consistency; 2. Regiane butterhead cultivar has large, bright green cone-shaped plants, with a vigorous root system and an average cycle of 56 days (early); 3. iceberg cultivar ‘Angelina’ has bright green leaves, vigorous, uniform plants with a well-formed base and dense head, and an average cycle length of 70 days and 4. Salad bowl (cv. ‘Mimosa’) are large, light green and easily marketable, with ruffled leaves and an average growth cycle of 56 days.

Five treatments were used: 1) control absolute, 2) 300 mL ha⁻¹ of the agricultural inoculant ICB Nutrisolo® (BioAgritec Ltda, based on T. harzianum, T. asperellum and T. koningiopsis at the concentration of 1 x 10¹⁰ CFU.g⁻¹), 3) 0.05 kg ha⁻¹ of the inoculant FT10 (water soluble powder formulation based on Trichoderma asperelloides at the concentration 1 x 10¹⁰ CFU.g⁻¹), 4) 0.10 kg ha⁻¹ of FT10, and 5) 0.15 kg ha⁻¹ of FT10. The treatments were applied to the planting furrow at a spray volume of 150 L ha⁻¹, before the one-month-old seedlings of the lettuce cultivars were transplanted, using a CO₂ pressurized backpack sprayer, equipped with a bar and spray nozzle (JLP 110.02 ADI), at a working pressure of 35 kgf cm².

A completely randomized design was used, with six replications, each plot consisting of a 5-liter pot with five lettuce plants.

Plant height was determined with a tape measure at 7, 14, 21, 28 and 35 days after transplanting (DAT) in two plants per plot, and the number of leaves on the same days, in three plants per plot. At 42 DAT, one plant was randomly selected to assess shoot (SDW) and root dry weight (RDW), after being dried in an oven (Solab SL-100/1080) at 65°C, until a constant weight. The yield was calculated at 42 DAT, by collecting three plants from each experimental plot and measuring fresh weight in grams, converted into kg ha⁻¹.

The survival of Trichoderma spp. isolates was assessed at the end of each experiment by randomly collecting samples of the substrate from each plot of the treatments. The substrate was analyzed by serial dilution, followed by plating of aliquots of the dilutions in commercial Potato Dextrose Agar (PDA) medium containing antibiotics (0.17 g of ampicillin and 0.05 of pentabiotic per 1 L of culture medium), and Triton X-100 as a reducing agent. Three repetitions were performed for each dilution. The fungal cultures were placed in a BOD incubator for three days at 25 ±2°C, under a 12-hour light-dark photoperiod. The number of colony-forming units (CFUs) per gram of substrate was counted.

The data of all experiments were submitted to analysis of variance and, when significant, means were compared by Duncan’s test at 5% significance. When
the F-test was not significant at 5% but significant at 10%, the treatment means were compared by Duncan’s test at 10% significance, using SASM-Agri® software [System for analysis and mean separation in agricultural assays - Canteri et al. (2001)].

Results and Discussion

A significant increase in the number of leaves was observed at an FT10 dose of 0.05 kg ha⁻¹ for cv. ‘Amanda’ in 1st (08/21/2019), 3rd (12/10/2019) and 4th (05/12/2020) experiments when compared to the control treatment (Table 1). At doses of 10.0 and 0.15 kg ha⁻¹, the number of leaves rose significantly in all four experiments. For the standard commercial product (ICB Nutrisolo Trichoderma) and control, no significant increases were observed in the 2nd (10/11/2019) and 3rd experiments.

There were no significant differences in loose-leaf lettuce height in the 2nd and 4th experiments; however, significant variations were observed for the 1st and 3rd experiments. The largest increases in plant height (4.2 to 5.5%) were obtained for the doses of 10.0 and 0.15 kg ha⁻¹ of FT10 and with ICB Nutrisolo Trichoderma (Table 1). In the 3rd experiment the greatest increase (14.5%) was observed for 0.15 kg ha⁻¹ of FT10 assessed on 12/10/2019, with no statistical differences with the other treatments.

For iceberg lettuce (cv. ‘Angelina’), evaluated on 10/11/2019, the number of leaves rose significantly (13.3%) at FT10 dose of 0.10 kg ha⁻¹. A significant increase of 8.3% also was observed for salad bowl lettuce (cv. ‘Mimosa’) at 0.5 kg ha⁻¹ on 10/12/2019 and the highest value obtained for butterhead lettuce (cv. ‘Regiane’) on 05/12/2020 was 8.9% at FT10 dose of 0.15 kg ha⁻¹ always comparing with the control treatment.

With respect to plant height, no significant difference among the treatments and control were observed for the iceberg, salad bowl and butterhead varieties (Table 2).

### Table 1. Effect of Trichoderma spp. on the average number of leaves and plant height of looseleaf lettuce, cv. ‘Amanda’, 35 days after transplanting (DAT), in four experiments at different times of year. Ponta Grossa-PR. 2019/2020 growing season.

| Treatments | Doses*** | 08/21/2019 | 10/11/2019 | 12/10/2019 | 05/12/2020 |
|------------|----------|------------|------------|------------|------------|
|            |          | Height (cm)** | No. of leaves* | Height (cm)** | No. of leaves* | Height (cm)** | No. of leaves* | Height (cm)** | No. of leaves* |
| Absolute Control | - | 20.35c | 12.97d | 22.35a | 10.12b | 20.57b | 10.45b | 27.55a | 12.60b |
| ICB Nutrisolo Trichoderma | 0.05 | 20.47bc | 15.55b | 24.47a | 11.28ab | 22.05ab | 11.63a | 28.38a | 13.67a |
| FT10       | 0.10 | 21.47a | 16.45a | 23.81a | 11.50a | 22.23ab | 11.38a | 29.35a | 13.63a |
| Mean       | 0.15 | 21.32a | 14.33c | 23.96a | 11.67a | 23.55a | 11.98a | 28.55a | 13.95a |

*Significant according to the F-test at 5% and ***10% probability level.
Mean followed by the same letter in the column do not differ according to Duncan’s test.
C.V. (%): Coefficient of Variation
*** Dosage unit: ICB Nutrisolo in mL ha⁻¹ and FT10 in kg ha⁻¹

### Table 2. Effect of different doses of two Trichoderma spp-based products on the number of leaves and plant height of iceberg cv. ‘Angelina’, curly endive cv. ‘Mimosa’ and butterhead cv. ‘Regiane’ lettuce, 35 days after transplanting (DAT). Ponta Grossa - PR. 2019/2020 growing season.

| Treatment | Doses*** | 11/10/2019 | 12/10/2019 | 05/12/2020 |
|-----------|----------|------------|------------|------------|
|            |          | Height (cm)** | No. of leaves* | Height (cm)** | No. of leaves* | Height (cm)** | No. of leaves* |
| Absolute Control | - | 23.77a | 11.62b | 23.95a | 15.90b | 26.15a | 17.65b |
| ICB Nutrisolo Trichoderma | 0.05 | 23.42a | 12.70ab | 24.38a | 15.95b | 26.08a | 17.57b |
| FT10       | 0.10 | 24.72a | 13.17a | 24.65a | 16.83ab | 27.33a | 18.53b |
| Mean       | 0.25 | 25.37a | 12.98a | 25.30a | 17.22a | 27.10a | 19.22a |

*Significant according to the F-test at 5% and ***10% probability level.
Means followed by the same letter in the column do not differ according to Duncan’s test.
C.V. (%): Coefficient of Variation
*** Dosage unit: ICB Nutrisolo in mL ha⁻¹ and FT10 in kg ha⁻¹

The Trichoderma spp. isolates had a greater impact on the number of leaves than plant height in all four lettuce varieties studied (Table 1 and Table 2). The number of leaves rose up to 26.8, 15.3, 14.6 and 10.7%
in loose-leaf lettuce for FT10 dose of 0.15 kg ha\(^{-1}\) in July, September, November, and April, respectively, and in 13.3, 8.3 and 8.9\% for iceberg, salad bowl and butterhead lettuce at 10.0 or 0.15 kg ha\(^{-1}\) FT10 doses.

According to Oliveira et al. (2004), the number of leaves and fresh weight of lettuce plants may be influenced by factors such as the cultivar, photoperiod and temperature in the growing environment, as observed here in experiments with different lettuce cultivars and varieties in four different seasons. The largest number of leaves obtained at 35 DAT resulted in a higher yield at the end of the experiment, as reported by Araújo et al. (2011).

Partially corroborating the findings obtained here, previous studies report the positive effect of Trichoderma on plant height and number of leaves. Martins Filho et al. (2019) found that Trichoderma aureoviride inoculation associated with organic fertilizer (cattle manure) significantly improved lettuce height and number of leaves in relation to the control, resulting in increases of more than 131\% at the end of the crop cycle. Chaves (2015) reported a significant rise in the height and number of leaves of ‘Elba’ and ‘Solaris’ loose-leaf lettuce seedlings treated with three Trichoderma spp. isolates 30 days after sowing. Silva et al. (2015) studied 12 Trichoderma spp. isolates and observed a 34\% increase in the height of butterhead lettuce (cv. ‘Regina’) at 21 daysDAT, while Pereira et al. (2019) found that treatment with Trichoderma spp. resulted in respective gains of 45 and 14\% in the height and the number of leaves of iceberg lettuce (cv. ‘Maureen’) at 40 DAT.

The effect of Trichoderma spp. in promoting plant growth and yield in lettuce and other agricultural crops has been reported by several researchers (Chagas et al., 2017; Fiorentino et al., 2018; Pereira et al. 2019). The shoot and root dry weight and yield results of four experiments with the Amanda loose-leaf lettuce cultivar are shown in Table 3.

For the experiment in which transplanting occurred in July and assessment on 08/29/2019, there were significant differences in SDW in relation to the control, with increases of 48.2 and 21.3\% for FT10 doses of 10.0 and 0.5 kg ha\(^{-1}\), respectively. It is important to note that the increases obtained resulted in higher yields, with the greatest increase (11.5\%) recorded for 0.10 kg ha\(^{-1}\) of FT10, followed by ICB Nutrisolo Trichoderma (10.2\%). There was no significant difference between treatments for root dry weight in this experiment (Table 3).

In the second experiment, with transplantation in September and assessment on 10/18/2019, SDW rose by 69.5 and 61.7\% with 10.0 and 0.15 kg ha\(^{-1}\) of FT10, respectively, representing a significant difference in relation to the control, but not to the other treatments. These gains led to higher yields, albeit only statistically significant at a dose of 0.05 kg ha\(^{-1}\). Once again, root dry weight remained unchanged, regardless of the dose applied (Table 3).

In the third experiment was observed a variation in shoot dry weight between treatments and a significant difference at FT10 dose of 0.15 kg ha\(^{-1}\), and a 24.7\% increase in SDW was observed in relation to the control (Table 3).

The highest yields were obtained for 10.0 and 0.15 kg ha\(^{-1}\) of FT10 and ICB Nutrisolo Trichoderma application, with respective increases of 15, 21 and 17\% in these treatments when compared to the control. Unlike the previous experiments, SDW rose significantly (27.8\%) at 0.10 kg ha\(^{-1}\) of FT10.

In the fourth experiment FT10 application caused changes in the RDW and SDW of looseleaf lettuce, with non-significant increases of 14 and 19\% in the latter at doses of 10.0 and 0.15 kg ha\(^{-1}\), respectively, in relation to the control treatment. The highest significant yield (14\%) was obtained for 0.15 kg ha\(^{-1}\) of FT10 (Table 3).

Similar SDW percentages were recorded for the iceberg, salad bowl and butterhead varieties (20.2, 26.7 and 17.2\%), with the largest increases observed at 0.15 kg ha\(^{-1}\) of FT10 (Table 4).

The average yield of 9.5 metric tons obtained in the four experiments with greenhouse-grown loose-leaf lettuce in different seasons of the year partially agrees with results found in the literature. Torales et al. (2014) reported yields between 8.56 and 11.28 t ha\(^{-1}\) for looseleaf lettuce grown in the field, depending on the cultivar and plant spacing used, while Gonçalves et al. (2017) obtained higher values of 16.38, 4.37, 16.69 and17.72 tons ha\(^{-1}\) for the Itapuã, Paola, Vera and Verônica cultivars, respectively, under greenhouse conditions.

As previously mentioned, climate conditions affect the growth and performance of lettuce, with the best yields occurring at cooler times of the year, at ideal temperature and relative humidity ranges of 18 to 23°C and 60 to 75\%.

The Ponta Grossa region (PR), where this study was conducted, exhibits similar climate conditions, as shown in Table 5. According to the climate data obtained, the temperature was only below the optimal range for lettuce in the experiment carried out in July, with an average of 14°C, which explains the lower yield recorded during this period. The average temperatures
in the remaining experiments were within the ideal range for lettuce production. Additionally, yield is highly dependent on the movement of nutrients within plants, with rapid crop development generally accompanied by increased nutrient absorption (Cavalheiro et al., 2015; Silveira, 2016).

Table 3. Root and shoot dry weight (in g) and yield (kg ha\(^{-1}\)) of looseleaf lettuce, cv. Amanda, treated with different doses of Trichoderma spp-based products at different times of year, under greenhouse conditions. Ponta Grossa - PR. 2019/2020 growing season.

| Treatments | Dry weight | Yield V (%) | Dry weight | Yield V (%) | Dry weight | Yield V (%) | Dry weight | Yield V (%) |
|------------|------------|-------------|------------|-------------|------------|-------------|------------|-------------|
| Absolute Control | - 0.67a 24.62d 8763c | - 3.37a 22.47b 8711b | - 1.94b 25.52b 9480b | - 1.25b 22.68a 8984b |
| ICB Nutrisolo | 300 0.72a 32.07b 8410ab | 10 1.98a 30.29ab 9160b | 1 2.25ab 29.28ab 11065a | 17 1.41b 26.96a 9555ab |
| FT10 | 0.05 0.70a 26.92cd 8795bc | 3 3.00a 30.23ab 10875a | 19 1.97b 28.50ab 9280b | 4 1.28b 23.29a 9002b |
| Mean | - 0.71 29.99 8090.00 | 3.21 31.48 7971 | 2.20 28.99 10550 | 1.41 25.21 9457 |
| C.V. | - 12.43 12.09 5.46 | 44.50 28.09 10.63 | 15.12 13.99 7.45 | 22.48 17.13 6.56 |

*Significant according to the F-test at 5% and **10% probability level
Means followed by the same letter in the column do not differ according to Duncan’s test; C.V. (%): Coefficient of Variation

Table 4. Shoot and root dry weight (in g) and yield (kg ha\(^{-1}\)) of iceberg, cv. Angelina, curly endive, cv. Mimosa and butterhead lettuce, cv. Regiane, treated with different doses of Trichoderma spp-based products at different times of year, under greenhouse conditions. Ponta Grossa - PR. 2019/2020 growing season.

| Treatments | Dry weight | Yield V (%) | Dry weight | Yield V (%) | Dry weight | Yield V (%) |
|------------|------------|-------------|------------|-------------|------------|-------------|
| Absolute Control | - 3.48bc 32.49a 11800b | - 5.00a 26.31c 9935b | - 1.05a 23.94a 8878b |
| ICB Nutrisolo | 300 4.30a 34.21a 13360ab | 13 4.90a 32.33ab 11345ab | 14 1.14a 26.22a 9377b |
| FT10 | 0.05 3.45c 31.30a 11885b | 1 4.58a 28.06bc 10095b | 2 1.05a 22.83a 8687b |
| Mean | - 3.86 34.94 12870 | 4.50 30.64 11069 | 1.14 25.50 9281 |
| C.V. | - 14.09 25.83 9.88 | 21.68 11.62 10.37 | 23.12 20.10 6.80 |

*Significant according to the F-test at 5% and **10% probability level
Means followed by the same letter in the column do not differ according to Duncan’s test; C.V. (%): Coefficient of Variation

Table 5. Monthly [(average (Av.), maximum (max.) and minimum (min.)) temperature and monthly average relative humidity (RH) in the four seasons studied.

| Month/year | T. min. average (ºC) | T. max. average (ºC) | T. average (ºC) | RH% average | Precipitation average |
|------------|-----------------------|----------------------|-----------------|-------------|-----------------------|
| July/19    | 7.5                   | 22.4                 | 14.95           | 82.1        | 0.9                   |
| August/19  | 8.7                   | 22.8                 | 15.75           | 81.5        | 0.6                   |
| September/19 | 13.2               | 24.8                 | 19               | 76.9        | 1.7                   |
| October/19 | 15.4                  | 28.6                 | 22               | 77.2        | 1.9                   |
| November/19 | 16                   | 28.2                 | 22.1             | 79.9        | 2.6                   |
| December/19 | 16.6                 | 27.7                 | 22.15           | 82.7        | 3.9                   |
| January/20 | 18.5                  | 27.8                 | 23.15           | 85.2        | 2.5                   |
| April/20   | 14.5                  | 25.7                 | 20.1             | 76.3        | 1.8                   |
| May/20     | 8.9                   | 21.5                 | 15.2             | 80.9        | 2.2                   |

For iceberg, butterhead and salad bowl lettuce evaluated on 10/18/2019, 12/17/2019 and 05/19/2020, the yield was lower than that reported in the literature, probably because the plants were harvested at 42 DAT, long before the 70, 56 and 56 days recommended for these cultivars, respectively.
All four lettuce varieties treated with Trichoderma asperelloides showed a significant increase in growth and yield in the four seasons assessed, demonstrating the potential of FT10 doses of 10.0 and 0.15 kg ha⁻¹ as a biostimulant/inoculant.

The need for a sustainable increase in crop yields has prompted the growing application of biostimulants in global agriculture, making this strategy a vital technological innovation (Yakhin et al., 2017). The use of certain Trichoderma species with predominantly growth-promoting action as inoculants in agriculture could have significant economic, social and environmental impacts on Brazil, as observed in developing countries that have invested considerable financial resources in limiting the use of highly soluble and polluting inorganic fertilizers.

In lettuce crops, Lima (2019) found that Trichoderma spp. isolates promoted significant growth in different loose-leaf cultivars, as observed here. For the BRS Leilá cultivar, RDW and SDW rose by 44 and 45%, respectively, when T. virens, T. koningiopsis and T. harzianum were applied, with values of 30 and 36.71 for the T. asperellum and T. asperelloides isolates in the Trichoderma spp., and 75 and 78.45 for T. virens, T. asperellum and T. asperelloides application in cv. ‘BRS Mediterrânea’. Pereira et al. (2019) studied the effect of three Trichoderma spp. strains on the growth and yield of iceberg lettuce (cv. ‘Mauren’) and recorded yields 37 and 66% higher for the T. harzianum strains IBLF006 and ESAQL 1306, respectively. Florentino et al. (2018) analyzed the impact on lettuce of biostimulants based on Trichoderma virens (GV41) and T. harzianum (T22) strains associated with different doses of nitrogen fertilizer and found that inoculation with Trichoderma spp. significantly improved yield at all the nitrogen concentrations tested. In the absence of nitrogen fertilization, increases of 34 and 24% were obtained for total and marketable fresh weight, respectively, with GV41 application and moderate improvements of 16 and 17% for isolate T22. Colla et al. (2015) studied the combined application of T. atroviride and the mycorrhizal fungus Glomus intraradices to lettuce grown in the field and observed a 61 and 57% rise in SDW and RDW, respectively. When Trichoderma was applied in conjunction with Glomus intraradices under greenhouse conditions, dry weight rose by 167 in relation to the control, which was attributed to the increase in P, Mg, Fe, Zn and B uptake. In field conditions, SDW and RDW increased by 61 and 57%, respectively, with application the microorganisms.

López-Bucio et al. (2015) attributed the phytostimulation mechanism of Trichoderma to multilevel communication with root and shoot systems as it releases auxins, small peptides, volatile compounds and other active metabolites into the rhizosphere, promoting root branching and the absorption of nutrients such as phosphorus, iron, manganese and zinc.

The survival capacity of T. asperelloides throughout the experiment was confirmed by plating diluted suspensions of the substrate at the end of the experiments. Populations of up to 4x10⁶ CFU.g⁻¹ were found in the substrate at 42 DAT. The beneficial effects of these microorganisms depend on their establishment in the growing environment and adaptability, among other factors. According to Pereira et al. (2019), increased lettuce growth and yield are heavily dependent on the ability of the Trichoderma isolate to establish a relationship with the plant species tested after colonizing the rhizosphere, benefitting the plants through a variety of mechanisms of action. The results obtained here were similar to those reported by Oskiera et al. (2017), who observed a persistent T. atroviride and T. harzianum populations of 10⁵ CFU.g⁻¹ to 10⁶ CFU.g⁻¹ in soil cultivated with lettuce, using conventional sample and molecular plating tests (multiplex-PCR), for up to two years. Harman (2000) reported that the most effective growth-promoting strains can establish lasting interactions with plants, since their effects persist through all or most of the growth cycle. This root-colonizing ability is an important characteristic that allows the beneficial agent to compete with the microbiota for space and/or nutrients and benefit plants (Harman, 2000; Samuels, 2006).

Conclusions

Based on the results of the greenhouse experiments, it can be concluded that the doses 0.10 and 0.15 kg ha⁻¹ of the bioproduct FT10 (Trichoderma asperelloides) applied to the furrow before the lettuce seedlings transplant has the potential to improve the development and yield of lettuce cultivars studied.

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