



## Compost tea as a sustainable alternative to promote plant growth and resistance against *Rhizoctonia solani* in potato plants

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### ABSTRACT

Compost teas (CTs) are organic extracts originated by mixing mature compost with tap water under controlled conditions. The application of these extracts could constitute a biostimulant and eco-friendly alternative for sustainable agriculture. Thus, this study was proposed to verify the contribution of different doses and *Trichoderma*-fortified green waste based-CT in plant susceptibility against *Rhizoctonia solani* infection, as well as in plant growth and tuber quality in two potato cultivars (Agria and Hermes) grown under greenhouse and field conditions. The results showed that CT-treated plants displayed a higher resistance to *Rhizoctonia solani*, being Hermes the most susceptible cultivar. Moreover, CT-treated plants showed an enhancement in yield, shoot number, tuber weight and tuber size, as well as an advance in potato sprouting, especially in those plants treated with the highest CT dose. A similar trend was observed in both cultivars. Furthermore, to confirm the effect of CT on sprouting, an additional study in the laboratory was carried out with Agria cultivar, in which it was observed that the advance in the crop cycle is induced by CT supply. Subsequently, the fried-quality parameters of tubers coming from potato plants grown under the different treatments in field conditions were studied. The addition of CT to potato plants reduced fried defects, total soluble solids in tubers, while increasing moisture content. However, both cultivars displayed several differences under control conditions, since Agria displayed high fried defects, as well as a reduction in total soluble solids and in the slice puncture test. Therefore, the application of CT is a dose-dependent effective approach to decrease *R. solani* attack, advance potato cycle and promote plant growth, as well as to obtain a better fried-quality tuber that is highly valued by the agri-food industries.

### 1. Introduction

Potato (*Solanum tuberosum* L.) is an economically relevant staple crop, being the fourth most important in the world. The total potato production has increased around 20% in the last 20 years (FAO, 2019). According to the 2020 report on crop surfaces and production of the Ministry of Agricultural, Fisheries and Food (MAPA, 2020), the total surface of potato cultivated in Spain was 65,404 hectares, which meant a total production of 2051,833 tons. Particularly, in the Castilla y León region, 19,180 hectares were cultivated, from which 933,664 tons of potato were obtained.

Potatoes are a very important food in human nutrition since they provide basic nutrients such as carbohydrates, dietary fiber, vitamins, and minerals (Zaheer and Akhtar, 2014). In addition, a large proportion of potato production is processed into par-fried frozen potatoes and fried

crisps (Miranda and Aguilera, 2007). The most important cultivars for potato chip industries in Spain are Agria and Hermes. For this reason, potato tubers' quality is an important aspect for agri-food industries to obtain better quality processed products. However, there are several constraints like the attack by different insects and diseases that could affect potato production and storage. One of the most important diseases is *Rhizoctonia solani* Kühn, a fungus causing losses of up to 30% of the quantitative and qualitative production (Woodhall et al., 2008). Based on the diagnoses carried out by the Regional center of Diagnosis located in Aldearrubia (Salamanca) in the 2003–2015 period, the incidence of *Rhizoctonia solani* was the most highlighted case in Castilla y León region with the 19% of diagnoses (Junta de Castilla y León, 2016). The disease produced by this pathogen is started by soil- or seed-borne inoculum since it survives as sclerotia or mycelium on infested plant or tubers. The symptoms caused by *R. solani* are black scurf on tubers, damaged young

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sprouts, shoot canker and different lesions on shoots and stolons (Tsror, 2010). Generally, this pathogen is controlled by cultural measures and chemical synthetic fungicides but, nowadays the application of active ingredients authorized for pathogen control are being limited. Thus, not only new environmentally-friendly forms of disease control are required, but also maintaining crop yield and quality. In this line, the application of compost has been related to reduced incidence of soil-borne pathogens in potato crop (Al-Mughrabi et al., 2008; Bernard et al., 2013).

Compost is defined as an organic product obtained from a controlled bioxidative process that must have proper conditions to obtain a high quality humified product, such as proper humidity, aeration or heterogeneous organic materials (Bernal et al., 2009). The starting materials can come from different sources such as green wastes or manures. Moreover, composts coming from green wastes may present better characteristics because of their lower content in heavy metals, fecal coliforms or pollutants, among others (Benito et al., 2005; Moretti et al., 2015). In addition, mature compost could be mixed with running water in 1:5 or 1:10 (v/v) ratio during a specific time varying between 2 and 15 days, leading to a resulting organic liquid product called compost tea (CT) (Al-Dahmani et al., 2003; Morales-Corts et al., 2018). The physical and biochemical quality of CTs depends on the characteristics of the starting compost, as well as on other parameters that affect its production i.e., compost-to-water ratio, and aeration (Ingham, 1999; Scheuerell and Mahaffee, 2002; Martin et al., 2012). Several studies showed that compost and vermicompost extracts enhance plant growth, yield and nutritional quality (Al-Dahmani et al., 2003; Scheuerell and Mahaffee, 2004), since these extracts are a source of microorganisms, soluble mineral nutrients and organic matter (De Corato, 2020; Zaccardelli et al., 2020). The presence of different aerobic microorganisms in these extracts play a role in plant growth and pathogen suppression through different direct and indirect mechanisms such as improved nutrient assimilation through biological N fixation, P solubilisation or Fe acquisition; or, pathogen control by antagonistic and competition processes, among others (Ilangumaran and Smith, 2017). The use of CTs is increasing in the last years as potential enviro-friendly alternative, which seems to display the best suppressive results against a wide range of different plant diseases (Pane et al., 2012; Martin, 2014; Morales-Corts et al., 2018; González-Hernández et al., 2021). Particularly, Raviv (2008) described some examples of compost suppressiveness against several types of soil-borne diseases. Furthermore, Gómez-Sánchez et al. (2017) showed the suppressive effect on *R. solani* pathogen produced by CT application in potato crop grown under pot conditions. However, further studies are required to confirm the efficacy of this extract under greenhouse and field conditions. This suppressive effect is partly related to microorganism's content provided by compost and then transferred to the extract. One of the microorganisms that participates in the latter phases of the composting process by degrading organic matter is *Trichoderma* spp. (Siddiquee et al., 2017). The species of this genera are one of the most commercialized biocontrol agents not only because of their direct activity and the induction of plant defense mechanisms (Verma et al., 2007; Joos et al., 2020), but also because of its effect on promoting plant growth, and improving or maintaining soil productivity (Hermosa et al., 2013). Thus, the enrichment of compost with biological agents has been considered an alternative to increase the suppressive effect (López-Mondéjar et al., 2011). According to this, Trillas et al. (2006) showed that the use of compost and/or *T. aspergillum* strain T-34 reduced the *R. solani* in cucumber plants.

In this sense, the general aim of this work was to study the effect of green waste-based CT application and its enrichment with *Trichoderma harzianum* on potato growth and quality, as well as the suppressive effect against *Rhizoctonia solani* in Agria and Hermes cultivars under both greenhouse and field conditions. Moreover, the innovative point of this research is to deepen in the study of different doses of CT application as both biostimulant and fungicide action to constitute an eco-friendly alternative for sustainable agriculture.

## 2. Material and methods

### 2.1. Plant material and compost tea

Two potato cultivars were used for all trials: Agria and Hermes, which are most cultivated in the region of Castilla y León. These cultivars are widely used by the processing industry for their use like chips.

The compost tea (CT) came from the composting of gardening wastes (mainly composed by a mixture of grass cuttings and pruning debris, i.e., leaves and branches of mainly cypress, willow and poplar trees, reaching a C/N ratio of 30), and it was carried out in a garden center located in Salamanca (Spain) (40°57'23"N; 5°41'8"W, 775 m a.s.l.). This process was performed in aerated piles of 15 × 2 × 2 m for 180 days. Piles were turned twice per week for eight weeks and once a week during the rest of the bioxidative process. Moreover, the moisture of the piles was controlled once a week, and when it dropped below 55%, water irrigation was applied up to 65% to keep the moisture average around 60% during the whole process. The mature compost was obtained under ambient conditions in March. Compost was mixed with tap water in a ratio of 1:5 (v/v) in polyethylene non-degradable 1000 L containers at room temperature (20 °C) for a brewing period lasting five days. Water had been previously aerated for 8 h to reduce chlorines concentration. This mixture was aerated for five hours every day by applying circular stirring and making fine bubbles of air with a pump (750 W-300 rpm). Then, it was filtered with a double-layered cheesecloth, and the aerated CT was stored in a dark container (50 L capacity at room temperature) until use. According to a previous study conducted by the authors (González-Hernández et al., 2021), the chemical composition of CT was: pH 7.16; electrical conductivity 1.2 dS m<sup>-1</sup>; C/N ratio 7.1; NO<sub>3</sub><sup>-</sup> 2240.4 mg L<sup>-1</sup>; P<sub>2</sub>O<sub>5</sub> 61.4 mg L<sup>-1</sup>; K<sub>2</sub>O 2851.2 mg L<sup>-1</sup>; SO<sub>4</sub><sup>2-</sup> 43 mg L<sup>-1</sup>; Ca<sup>2+</sup> 280 mg L<sup>-1</sup>; Mg<sup>2+</sup> 20 mg L<sup>-1</sup> and, humic acids 198 mg L<sup>-1</sup>. Furthermore, the microbiological composition of CT was: total aerobic bacteria 2.7 × 10<sup>7</sup> cfu mL<sup>-1</sup>; N-fixing bacteria 2.7 × 10<sup>7</sup> cfu mL<sup>-1</sup>; actinobacteria 7.4 × 10<sup>4</sup> cfu mL<sup>-1</sup>; *Trichoderma* sp. and fungi were valued between 2.7 and 8.7 × 10<sup>2</sup> cfu mL<sup>-1</sup>, respectively.

### 2.2. Pot assays

A growth test was carried out in 25 L pots (33 cm diameter and 30 cm height), with nine plants (one per pot) per treatment and cultivar. Tubers were established on a substrate formed by blond peat and vermiculite in a 1:1 (v/v) ratio. The main characteristics of the substrate were: pH 6; N 70 mg L<sup>-1</sup>; P<sub>2</sub>O<sub>5</sub> 71 mg L<sup>-1</sup>; K<sub>2</sub>O 150 mg L<sup>-1</sup>; organic matter 35% and, EC 0.6 dS m<sup>-1</sup>. The experiment was carried out in a greenhouse (temperature of 24 °C day and 18 °C night; 80% relative humidity) for ten weeks during May, June and July of 2016 and 2017 seasons.

Two doses of CT were used, 40 mL per pot and week, and 120 mL per pot and week, in order to evaluate the suppressive effect against *R. solani* (strain 122, from the collection of The Regional Center for Pest and Diseases Diagnosis, Junta de Castilla y León, Spain). The tested treatments, which were started 10 days after planting, are shown in Table 1.

For the inoculation of the pathogen, the fungus was grown on potato dextrose agar (PDA) until it reached the edge of the Petri plate. Subsequently, each plate was emulsified in 200 mL of distilled water. A total of 20 mL of this mycelial emulsion (10<sup>3</sup> mycelial fragments mL<sup>-1</sup>) were

**Table 1**  
Description of the different treatments used in the pot assays.

Treatment	Description
A0	Control without pathogens and without CT application
A1	<i>R. solani</i> + weekly application of 40 mL per pot of CT
A2	<i>R. solani</i> + weekly application of 120 mL per pot of CT
A3	<i>R. solani</i>

CT: compost tea; n = 9 plants/treatment and cultivar

added per pot, 15 days after planting. The negative control was treated with 20 mL of diluted PDA.

A weekly irrigation until reach 0.5 L per plant was applied and 1 L in the last 3 weeks of the trial given the water needs of the plants.

Throughout the trial, the height of the plants (mm) was measured with a meter stick and the degree of infection of the plants was estimated according to Scholte (1989) with a 0 to 4 scale (0 = no attack on stems or colons; 1 = slight attack, some scattered lesions on the stems; 2 = moderate attack, not more than half the number of stems with a lesion girdling the stems, usually with additional attacks on the stolons; 3 = severe attack, more than half the stems with a lesion girdling the stem and with the stolons severely attacked; 4 = very severe attack, the attack on stems and stolons so severe as to cause "little potato", i.e., many small tubers form near and many break through the soil surface, sometimes aerial tubers form immediately above the ground).

### 2.3. Field assays

Production field assays were carried out in soils affected by *Rhizoctonia solani* located in the municipality of Arabayona de Mójica (Salamanca, Spain) (41°2'50"N; 5°23'10"W, 857 m. a.s.l.) during 2017 and 2018. The growing region has a continental Mediterranean climate. The soil has a sandy-loam soil texture, a pH value of 6.5 and an organic matter content of 1.4%.

The assay was established on April 15th, using a random distribution of the treatment plots with three 7.5 m<sup>2</sup> plots per treatment and cultivar. Two cultivars, Agria and Hermes, were considered in the assay establishment and potatoes were not treated with fungicides before planting. In each plot, 28 tubers of 35 mm of diameter were planted in a disposition of 35×75 cm into ridges. Potatoes were harvested on August 31st. Different doses of CT, which were applied four times along the experiment, were used as treatments in experimental potato crops (Table 2) in order to evaluate growth and production as well as the effect on the *Rhizoctonia solani* control (attack severity). In addition, one of the tested treatments was enriched with 10<sup>4</sup> cfu mL<sup>-1</sup> of *Trichoderma harzianum* fungus spores. The provided nutrients by each treatment were 8.4 g NO<sub>3</sub><sup>-</sup>, 0.2 g P<sub>2</sub>O<sub>5</sub>, 11.4 g K<sub>2</sub>O and 1.1 g Ca<sup>2+</sup> in each B1 and B1+ treated plots and, 25.2 g NO<sub>3</sub><sup>-</sup>, 0.6 g P<sub>2</sub>O<sub>5</sub>, 33.9 g K<sub>2</sub>O and 3.3 g Ca<sup>2+</sup> in B2 treated plots. Three repetitions of each treatment were carried out.

The first CT treatment was just applied into the sown line. The three subsequent applications (1:5, CT:Water ratio) were carried out by spraying the whole plot using a manual sprayer (16 L capacity) every two weeks. Only a common pre-planting fertilization was practised with 500 kg ha<sup>-1</sup> of 9–18–27 mineral fertilizer (45 kg N ha<sup>-1</sup>, 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> and 135 kg K<sub>2</sub>O ha<sup>-1</sup>). No post-sow mineral fertilizations were applied. Regarding phytosanitary products, only Lambda-cihalotrin (10%, Syngenta, Spain) application was needed to fight potato beetle (*Leptinotarsa decemlineata*). Plants were watered by a sprinkler system when needed, specifically 20 mm per week in April, 30 mm per week in May, June and July and 15 mm per week in August.

Analysed parameters were: shoots number three weeks after planting, sprouting (%) as emergence percentage 21 days after planting, mid-cycle chlorophyll content with a SPAD-502 (60 days after planting, SPAD units) (Spectrum Technologies, Inc., Aurora, IL, USA), plant

**Table 2**

Description of the different treatments used in the field assays.

Treatment	Description
B0	No application
B1	1 L of CT per plot
B2	3 L of CT per plot
B1+	1 L of CT enriched with 10 <sup>4</sup> cfu mL <sup>-1</sup> of <i>Trichoderma harzianum</i> fungus spores per plot

CT: compost tea; n = 84 plants/treatment and cultivar.

height (mm) with a meter three months after planting, yield (t ha<sup>-1</sup>), tuber size (mm) and tuber weight (g) at the end of the assay, four months after planting. Sizes were determined with a Vernier digital caliper and weight with a digital scale. Finally, the severity of *R. solani* attack was estimated in the adult plant as the percentage of plants severely or very severely infected following Scholte (1989) scale.

Also, some quality parameters were determined: total soluble solids (TSS), percentage of moisture, slice puncture test and frying defects. Potatoes were peeled with a manual peeler and cut with a knife into pieces of about 3 cm and mashed with a Moulinex A320R1 electric mincer (Moulinex Group SEB Ibérica, Barcelona, Spain).

For the determination of TSS, a refractometric method was carried out. Three grams of chopped potato were taken in a conical flask that was subsequently centrifuged at 12,000 rpm during 5 min in a Sigma 4K15C centrifuge (SIGMA, Osterode am Harz, Germany). The supernatant was measured in a Zuzi handheld refractometer series 300 (Microscopios Barcelona, Spain). The result was obtained in °Brix.

For moisture determination, three grams of chopped potato were dried in an oven at 105 °C for 3 h, cooled in a desiccator, and weighed multiple times until a constant weight was attained.

To obtain the texture of the raw potatoes, the slice puncture test was performed. To carry out this measurement, the method described by Castro (2008) was followed. Five punctures were made on three slices of 1 cm of thickness, one in the middle and four in the external part. Then, a TA.XT Texture Analyser (Stable Micro Systems Ltd., Godalming, UK) with a 2 mm diameter cylindrical probe was used, and the Texture Exponent 32 software (Stable Micro Systems Ltd., Godalming, UK) provides the force results. Finally, frying defects were evaluated. The potatoes were peeled and sliced 1.5 mm thick using a Ufesa CF7691 electric deli food slicer (UFESA, Barcelona, Spain). Sixty slices of six potatoes were obtained per sample and were fried in a Ufesa FR 2000 fryer (UFESA, Barcelona, Spain) with sunflower oil for four minutes at 180±5 °C, allowing them to cool on a filter paper for a few minutes. The hard, dark brown tissue that is the result of an excessive frying process was measured following the food code guidelines (FAO-WHO, 2019) and expressed as percentage of total surface exhibiting browning.

### 2.4. Sprouting experiment

Four plastic laboratory trays (53×37×10 cm) were filled with a substrate consisting of eight parts of vermiculite, and two parts of peat. In each tray, nine potato tubers of the cv. Agria were placed in a 3 × 3 arrangement following an equidistant distribution. Tubers were covered with the substrate mixture. Four different treatments were considered (Table 3). This trial was repeated three times.

These treatments were applied both at the beginning of the experiment and 15 days later. Furthermore, the following parameters were measured: days to sprouting after planting, number of shoots, height and number of leaves per shoot at the end of the experiment (one month after planting).

### 2.5. Statistical analyses

Statistical processing of the data was carried out using IBM-SPSS

**Table 3**

Description of the different treatments used in the sprouting experiment.

Treatment	Description
C0	Control treatment composed of only water
C1	35.6 mL of CT in each potato tuber
C2	107 mL of CT in each potato tuber
C1+	35.6 mL of CT with <i>Trichoderma harzianum</i> enrichment in each potato tuber

CT: compost tea; n = 27 plants/treatment.

Statistics 26 software (IBM, Chicago, Illinois USA). Significant differences among cultivars, growing seasons and treatments for all the studied parameters were obtained by Multivariate Analysis of Variance (MANOVA) fitted to a General Linear Model (GLM) (Nelder and Wedderburn, 1972). However, given the complexity and extension of these results, they are presented as supplementary material (Table S1-S4). Instead, in order to gain a better understanding of the effect of treatment and cultivar in each of the growing seasons, a one-way analysis of variance (ANOVA) was carried out. For both analyses, means and standard deviations (SD) were calculated for all variables. The statistical significance of each factor was assessed at a 95% confidence level ( $\alpha=0.05$ ) using Snedecor's F as the contrast statistic. For differentiation of homogeneous subsets, Tukey's test (Tukey, 1949) was used.

In this study the variables measured in terms of proportions, i.e. sprouting and *R. solani* attack, were previously arc sine transformed following the equation proposed by Bartlett (Bartlett, 1936):

$$\arcsin\text{transf} = 2 \times \left( \sin^{-1} \left( \sqrt{X\%} \right) \right)$$

To better understand the results of these two parameters, they were shown as proportion, but the statistical differences were assessed with the arcsine transformation values.

### 3. Results

#### 3.1. Pot assay

The results of the pot assay with inoculation of *Rhizoctonia solani* and CT application on two potato cultivars are shown in Table 4.

The MANOVA analysis revealed significant interactions between the cultivar and the treatment. Hermes cultivar experimented a higher attack than the Agria cultivar (3.9 and 2.8 pathogen infection levels, respectively). *Rhizoctonia* inoculated control plants for both cultivars showed a higher disease severity than those plants treated with CT, also inoculated with the pathogen. Plants without CT supply also displayed a reduced height with respect to those treated with CT despite of the inoculation. *Rhizoctonia* severity attack was clearly reduced in both cultivars when CT treatments were applied in both doses, finding for A1 treatment the least *Rhizoctonia* infection, even though no significant differences between A1 and A2 doses were found. This assay showed the CT's suppressive effect against *R. solani* on potato plants grown in pots.

#### 3.2. Field assay

The effects of CT treatments were studied during 2017 and 2018 seasons on potato crops established in the most important producer region of Spain during 2017 and 2018 seasons. Both growing parameters and production parameters were analysed and the percentage of plants showing marked *R. solani* symptoms was also registered. The MANOVA

**Table 4**  
Suppressive effect against *Rhizoctonia solani* under pot conditions (mean±SD).

Treatment	Plant height (mm)		Pathogen Infection	
	Agria	Hermes	Agria	Hermes
A0	525.8 ± 62.4 <sup>ab</sup>	566.7 ± 8.9 <sup>b</sup>	0.0 ± 0.0 <sup>c</sup>	0.0 ± 0.0 <sup>c</sup>
A1	594.1 ± 37.8 <sup>a</sup>	663.3 ± 23.5 <sup>a</sup>	1.1 ± 0.3 <sup>b</sup>	1.9 ± 1.2 <sup>b</sup>
A2	678.3 ± 74.9 <sup>a</sup>	683.3 ± 28.1 <sup>a</sup>	1.4 ± 0.5 <sup>b</sup>	2.6 ± 0.4 <sup>b</sup>
A3	433.3 ± 80.5 <sup>b</sup>	318.3 ± 24.8 <sup>c</sup>	2.8 ± 0.5 <sup>a</sup>	3.9 ± 0.3 <sup>a</sup>
<b>Significance</b>				
C	NS		**	
T	**		**	
C × T	**		**	

NS, \* or \*\*: non-significant or significant at  $p < 0.05$  or  $0.01$ , respectively.

<sup>a,b,c</sup> Different letters in the same column mean statistically significant differences  $p < 0.05$ , according to Tukey's HSD test; SD: standard deviation, T: treatment and C: cultivar.

revealed significant interactions between cultivars and treatments in tuber size and *Rhizoctonia* attack in 2017, and number of shoots and tuber size in 2018 (Table 5). In addition, multivariate statistical analysis showed significant differences between Agria and Hermes cultivars ( $p < 0.05$ ) (Table 5), reason why the behavior of both cultivars was independently studied. Field results, by season, are shown in Tables 5. In the Agria cultivar, these interactions were found in tuber weight and yield (Table S1). For the Hermes cultivar, interactions were showed in the number of shoot and in *Rhizoctonia* attack (Table S2).

Table 5 showed the results for growth and production parameters obtained in Agria cultivar during two consecutive agriculture seasons. B1, B1+ and B2 treated plants got a significant increase in yield, tuber weight and size, number of shoots and sprouting advances as well as a reduction in *R. solani* affectation with respect to B0 plants in 2017 and 2018. Moreover, B2 plants displayed a significant increase in yield and number of shoots' parameters compared to those treated with B1 and B1+. Regarding yield, the same relationship between treatments was observed in both seasons. No significant differences between treatments were found for chlorophyll content and plant height.

All CT treatments significantly advanced the sprouting of Agria plants in both seasons, with more than 70% of sprouted tubers 21 days after planting, in contrast to the B0, where only 36% of the plants sprouted in the 2017 season and 27% in the 2018 season. Plants under B2 treatment experienced a significantly higher sprouting speed in both seasons. In general, sprouting speed was higher in 2017 than in 2018 due to the higher temperatures in April and May, as a difference of 3 °C was recorded by the Meteorological Station Network of the Agricultural Technological Institute of Castilla y León. In both seasons, B2 treatment showed a yield increase of 27%, in contrast to an 11% increase produced by B1 and B1+ treatments.

Both sprouting speed and yield were lower in Hermes than in Agria in the two growing seasons.

In case of Hermes cultivar (Table 5), all CT treatments were significantly different to the control regarding yield, tuber weight, number of shoots and sprouting speed, as well as they showed a significant reduction in *R. solani* affectation in both seasons. Among the three CT treatments, B2 showed the greatest values in yield, tuber weight and sprouting speed. In the 2018 growing season, the percentage of Hermes plants showing *R. solani* severe symptoms was reduced from 30% in the B0 plants to a mere 1% in the treated ones (B1, B1+ and B2). *Rhizoctonia* attack was much more severe in B0 than in treated plants in both growing seasons. CT treatments led to a clear damage reduction, with 0% and 0.3%–1.7% plants severely or very severely infected in 2017 and 2018, respectively.

#### 3.3. Quality of the field grown potato tubers

Fried quality parameters from Agria and Hermes cultivars of potatoes cultivated under B0, B1, B1+ and B2 treatments in field assays during 2017 and 2018 seasons, were analysed and results are shown in Table 6. The MANOVA showed significant interactions between cultivars and treatments in fried defects and TSS in both growing seasons. B1, B1+ and B2 significantly reduced fried defects compared to control in Agria and Hermes cultivars for both growing seasons. However, in Hermes cultivar, there were significant differences among the CT treatments, displaying potatoes coming from B1 and B1+ treated plants a higher reduction of fried defects compared to B2. Also, B1, B1+ and B2 increased the moisture content of Agria and Hermes potatoes of about 2%, getting moisture values of 75–76%, similar in both seasons. Besides, the TSS also presented a lower value when B1, B1+ or B2 were applied to Agria cultivar in 2017 and 2018 seasons. However, this parameter did not follow the same trend in potatoes of Hermes cultivar, since only B1 and B2 treatments produced a reduction of TSS compared to control treatment in 2017, whereas no differences were found among treatments in 2018. Concerning the puncture force, no significant differences were found among treatments in both cultivars and seasons.

**Table 5**  
Growth-Production parameters and *R. solani* incidence on Agria and Hermes potato plants under CT application for the two different growing seasons (mean±SD).

GS	T	S (%)		NSH		CC (SPAD units)		PH (mm)		TW (g)		TS (mm)		Y (t ha <sup>-1</sup> )		RA (%)	
		Agria	Hermes	Agria	Hermes	Agria	Hermes	Agria	Hermes	Agria	Hermes	Agria	Hermes	Agria	Hermes	Agria	Hermes
<b>2017</b>	<b>B0</b>	36.3 ± 5.9 <sup>c</sup>	25.7 ± 4.5 <sup>c</sup>	1.7 ± 0.5 <sup>c</sup>	2.0 ± 0.6 <sup>c</sup>	51.0 ± 1.9	31.7 ± 2.3	465.2 ± 16.7	34.5 ± 1.5	167.7 ± 9.6 <sup>b</sup>	157.5 ± 18.2 <sup>c</sup>	58.6 ± 6.7 <sup>b</sup>	51.0 ± 6.4 <sup>c</sup>	58.7 ± 5.1 <sup>b</sup>	46.2 ± 3.3 <sup>c</sup>	17.0 ± 5.6 <sup>a</sup>	10.0 ± 2.0 <sup>a</sup>
		91.7 ± 6.5 <sup>ab</sup>	79.0 ± 8.9 <sup>b</sup>	3.4 ± 0.7 <sup>b</sup>	3.6 ± 0.8 <sup>b</sup>	48.5 ± 3.1	31.2 ± 2.1	450.0 ± 25.1	34.2 ± 1.6	207.2 ± 6.8 <sup>a</sup>	207.0 ± 17.3 <sup>b</sup>	76.2 ± 4.0 <sup>a</sup>	64.4 ± 2.6 <sup>b</sup>	70.7 ± 2.1 <sup>a</sup>	55.2 ± 2.5 <sup>b</sup>	0.0 ± 0.0 <sup>b</sup>	0.0 ± 0.0 <sup>b</sup>
	<b>B1+</b>	78.3 ± 10.7 <sup>b</sup>	66.0 ± 5.0 <sup>b</sup>	4.0 ± 0.7 <sup>b</sup>	3.6 ± 0.7 <sup>b</sup>	49.8 ± 3.2	30.3 ± 1.2	452.3 ± 37.8	34.6 ± 1.2	209.7 ± 18.2 <sup>a</sup>	208.0 ± 11.9 <sup>b</sup>	81.8 ± 7.4 <sup>a</sup>	74.8 ± 4.8 <sup>a</sup>	72.4 ± 4.2 <sup>a</sup>	55.4 ± 2.4 <sup>b</sup>	0.0 ± 0.0 <sup>b</sup>	0.0 ± 0.0 <sup>b</sup>
		99.3 ± 1.1 <sup>a</sup>	95.3 ± 2.5 <sup>a</sup>	5.2 ± 0.8 <sup>a</sup>	4.7 ± 1.1 <sup>a</sup>	49.3 ± 3.6	30.2 ± 2.1	451.5 ± 20.6	34.2 ± 2.3	213.5 ± 12.9 <sup>a</sup>	226.2 ± 18.5 <sup>a</sup>	78.5 ± 5.9 <sup>a</sup>	76.8 ± 2.3 <sup>a</sup>	74.7 ± 2.9 <sup>a</sup>	61.4 ± 2.0 <sup>a</sup>	0.0 ± 0.0 <sup>b</sup>	0.0 ± 0.0 <sup>b</sup>
<b>Significance</b>																	
<b>C</b>		**		NS		**		**		NS		**		**		*	
<b>T</b>		**		**		NS		NS		**		**		**		**	
<b>C × T</b>		NS		NS		NS		NS		NS		*		NS		*	
<b>2018</b>	<b>B0</b>	27.0 ± 4.0 <sup>c</sup>	22.7 ± 2.5 <sup>c</sup>	1.8 ± 0.4 <sup>d</sup>	2.9 ± 0.3 <sup>c</sup>	45.0 ± 1.9	24.7 ± 2.3	447.9 ± 12.3	34.7 ± 1.7	148.2 ± 22.6 <sup>b</sup>	154.0 ± 21.8 <sup>c</sup>	58.4 ± 6.7 <sup>b</sup>	50.8 ± 6.4 <sup>c</sup>	58.9 ± 4.1 <sup>c</sup>	58.7 ± 7.1 <sup>b</sup>	22.7 ± 3.2 <sup>a</sup>	30.0 ± 2.0 <sup>a</sup>
		85.3 ± 5.7 <sup>a</sup>	78.3 ± 5.7 <sup>ab</sup>	3.5 ± 0.5 <sup>c</sup>	5.3 ± 0.7 <sup>a</sup>	42.5 ± 3.1	24.2 ± 2.1	441.9 ± 23.0	34.0 ± 2.0	205.0 ± 7.3 <sup>a</sup>	204.5 ± 17.8 <sup>b</sup>	76.0 ± 4.0 <sup>a</sup>	64.2 ± 2.6 <sup>b</sup>	70.2 ± 1.7 <sup>b</sup>	63.4 ± 4.3 <sup>b</sup>	0.0 ± 0.0 <sup>b</sup>	1.7 ± 1.5 <sup>b</sup>
	<b>B1+</b>	69.7 ± 4.5 <sup>b</sup>	73.7 ± 5.7 <sup>b</sup>	4.5 ± 0.5 <sup>b</sup>	3.7 ± 0.7 <sup>b</sup>	43.8 ± 3.2	23.3 ± 1.2	442.4 ± 33.3	34.1 ± 1.6	220.7 ± 21.9 <sup>a</sup>	205.7 ± 12.7 <sup>b</sup>	81.6 ± 7.4 <sup>a</sup>	74.6 ± 4.8 <sup>a</sup>	67.2 ± 2.5 <sup>b</sup>	63.2 ± 4.7 <sup>b</sup>	0.7 ± 1.1 <sup>b</sup>	1.3 ± 1.1 <sup>b</sup>
		96.0 ± 1.7 <sup>a</sup>	92.3 ± 6.7 <sup>a</sup>	5.5 ± 0.5 <sup>a</sup>	5.2 ± 0.4 <sup>a</sup>	43.3 ± 3.6	23.2 ± 2.1	455.1 ± 12.0	33.8 ± 2.5	215.7 ± 11.6 <sup>a</sup>	226.7 ± 17.9 <sup>a</sup>	78.3 ± 5.9 <sup>a</sup>	76.6 ± 2.3 <sup>a</sup>	74.2 ± 2.9 <sup>a</sup>	71.7 ± 2.3 <sup>a</sup>	0.3 ± 0.6 <sup>b</sup>	0.3 ± 0.6 <sup>b</sup>
<b>Significance</b>																	
<b>C</b>		NS		**		**		**		NS		**		**		*	
<b>T</b>		**		**		NS		NS		**		**		**		**	
<b>C × T</b>		NS		**		NS		NS		NS		*		NS		NS	

NS, \* or \*\*: non-significant or significant at  $p < 0.05$  or  $0.01$ , respectively.

<sup>a,b,c</sup>Different letters in the same column mean statistically significant differences  $p < 0.05$ , according to Tukey's HSD test; SD: standard deviation, GS: growing season, T: treatment, C: cultivar, S: Sprouting (%), which is the emergence percentage 21 days after planting, NSH: number of shoots, CC: chlorophyll content, PH: plant height, TW: tuber weight, TS: tuber size, Y: yield and RA: *Rhizoctonia* attack (%), which is the percentage of plants severely or very severely infected following Scholte (1989) scale.

**Table 6**

Quality parameters of Agria and Hermes cultivars under the different CT treatments for the two different growing seasons (mean±SD).

GS	T	Fried defects (%)		Moisture (%)		Total soluble solids (°Brix)		Slice puncture test (N)	
		Agria	Hermes	Agria	Hermes	Agria	Hermes	Agria	Hermes
2017	B0	36.5 ± 6.9 <sup>a</sup>	15.9 ± 1.7 <sup>a</sup>	74.0 ± 0.7 <sup>b</sup>	73.5 ± 0.6 <sup>b</sup>	4.7 ± 0.1 <sup>a</sup>	5.1 ± 0.1 <sup>a</sup>	9.3 ± 0.2	11.1 ± 0.2
	B1	6.9 ± 1.9 <sup>b</sup>	2.5 ± 1.9 <sup>c</sup>	75.7 ± 0.3 <sup>a</sup>	74.9 ± 0.5 <sup>a</sup>	4.3 ± 0.1 <sup>b</sup>	4.9 ± 0.1 <sup>b</sup>	8.7 ± 0.5	10.9 ± 0.3
	B1+	5.7 ± 1.0 <sup>b</sup>	1.4 ± 2.1 <sup>c</sup>	76.0 ± 0.7 <sup>a</sup>	75.0 ± 0.7 <sup>a</sup>	4.3 ± 0.1 <sup>b</sup>	5.0 ± 0.1 <sup>ab</sup>	8.9 ± 0.5	10.9 ± 0.2
	B2	6.3 ± 1.6 <sup>b</sup>	7.7 ± 1.3 <sup>b</sup>	75.6 ± 0.5 <sup>a</sup>	75.4 ± 1.1 <sup>a</sup>	4.3 ± 0.1 <sup>b</sup>	4.9 ± 0.1 <sup>b</sup>	8.9 ± 0.5	10.8 ± 0.2
<b>Significance</b>									
C		**		**		**		**	
T		**		**		**		NS	
C × T		**		NS		*		NS	
2018	B0	36.8 ± 5.4 <sup>a</sup>	14.8 ± 2.0 <sup>a</sup>	74.1 ± 0.7 <sup>b</sup>	73.8 ± 0.7 <sup>b</sup>	4.4 ± 0.1 <sup>a</sup>	5.2 ± 0.2	9.2 ± 0.2	11.0 ± 0.2
	B1	6.8 ± 2.0 <sup>b</sup>	2.0 ± 1.6 <sup>c</sup>	76.1 ± 0.8 <sup>a</sup>	75.7 ± 0.9 <sup>a</sup>	4.1 ± 0.1 <sup>b</sup>	5.2 ± 0.1	8.6 ± 0.5	10.8 ± 0.3
	B1+	4.3 ± 1.0 <sup>b</sup>	1.2 ± 1.7 <sup>c</sup>	76.3 ± 0.3 <sup>a</sup>	75.5 ± 0.6 <sup>a</sup>	4.1 ± 0.1 <sup>b</sup>	5.2 ± 0.1	8.8 ± 0.5	11.0 ± 0.4
	B2	5.4 ± 1.6 <sup>b</sup>	5.9 ± 1.6 <sup>b</sup>	75.9 ± 0.6 <sup>a</sup>	75.9 ± 0.8 <sup>a</sup>	4.1 ± 0.1 <sup>b</sup>	5.1 ± 0.1	8.8 ± 0.5	10.7 ± 0.2
<b>Significance</b>									
C		**		NS		**		**	
T		**		**		**		NS	
C × T		**		NS		*		NS	

NS, \* or \*\*: non-significant or significant at  $p < 0.05$  or  $0.01$ , respectively.<sup>a,b,c</sup>Different letters in the same column mean statistically significant differences  $p < 0.05$ , according to Tukey's HSD test; SD: standard deviation, GS: growing season, T: treatment and C: cultivar.

As for potato quality parameters, there were significant differences between Agria and Hermes cultivars. Control tubers of Agria cultivar showed more fried defects, higher TSS and less PF than those of Hermes.

### 3.4. Sprouting assay

A sprouting experiment (Fig. 1) was carried out in order to confirm the sprouting advance that occurred in the field when CT treatments were applied. The results are shown in Table 7.

The sprouting advance with C2 dose was 4 days with respect to control while C1 produced an advance of 2.5 days. Interestingly, no sprouting advancement was obtained in C1+ with respect to control tubers. C1, C1+ and C2 produced a significant increase in shoot height, and number of leaves, especially in C2 treatment. Fig. 1 showed the shoots of the potatoes at the end of the assay (30 days after planting). C1+ treatment, got at the end of the assay similar or better results than C1. Moreover, the CT-treated plants grew more vigorously as evidenced by the increased shoot height and greater number of leaves per shoot.

## 4. Discussion

CTs are organic solutions that constitute an interesting option for plant growth promotion and protection in sustainable agriculture. This study showed that green waste-based CT at different doses and *Trichoderma*-fortified CT improves productivity and quality, as well as the control of *R. solani* in potato crop grown under laboratory, greenhouse, and field conditions.

The application of CT in agriculture involves the supply of nutrients, organic matter and a wide range of microorganisms, which not only play a role in plant growth and resistance, but also improving soil quality (Morales-Corts et al., 2018). The chemical and microbiological properties of the supplied CT have been previously described by González-Hernández et al. (2021). The extract analyses revealed a relevant concentration of nitrogen (N) and potassium (K), as well as a

**Table 7**

Sprouting behavior (1 month after planting) of potato in response to compost tea treatments (mean±SD).

Treatment	Days to sprouting after planting	Number of shoots	Shoot height (mm)	Number of leaves per shoot
C0	17.0 ± 1.5 <sup>a</sup>	6.6 ± 1.5 <sup>b</sup>	38.2 ± 3.5 <sup>c</sup>	3.0 ± 0.4 <sup>c</sup>
C1	14.6 ± 1.8 <sup>b</sup>	8.0 ± 3.5 <sup>ab</sup>	93.4 ± 2.6 <sup>b</sup>	5.0 ± 1.5 <sup>b</sup>
C1+	17.5 ± 1.7 <sup>a</sup>	13.5 ± 2.5 <sup>a</sup>	158.3 ± 1.5 <sup>a</sup>	5.5 ± 1.1 <sup>b</sup>
C2	13.1 ± 1.2 <sup>b</sup>	13.6 ± 1.8 <sup>a</sup>	171.3 ± 2.1 <sup>a</sup>	6.7 ± 0.9 <sup>a</sup>

<sup>a,b,c</sup>Different letters in the same column mean statistically significant differences  $p < 0.05$ , according to Tukey's HSD test.

high content of humic acids and microorganisms. In the present work, the effect of this CT in potato plant growth and resistance against *Rhizoctonia solani* under greenhouse conditions was firstly studied. Two potato cultivars, Agria and Hermes, were considered to carry out this experiment in order to know whether rusticity or susceptibility to *R. solani* could induce different changes in potato responses to CT treatments. The results corroborated those obtained by Gómez-Sánchez et al. (2017) using the same CT in pot-trials, indicating that *R. solani* inoculated control plants displayed a reduction in plant height and a higher attack severity compared to those treated with CT in both cultivars. These effects in plant growth and pathogen suppression when CT is applied have been previously described by several authors (Hargreaves et al., 2009; Pant et al., 2012; Marín et al., 2014).

Following this line, a previous study conducted by the authors, Morales-Corts et al. (2018) explained that the growth effect induced by CT application could be not only explained by humic acid content, but also by nutrient concentration, phytohormones, and the richness of beneficial microorganisms. The application of humic substances has been previously related to plant growth promotion since they seem to be

**Fig. 1.** Potato sprouting responses to the different treatments.

related to an increase in phenolic and flavonoid compounds (Gholami et al., 2018). Moreover, the large number of microbial communities contained in this extract (González-Hernández et al., 2021), which mainly belongs to the genera *Trichoderma*, *Bacillus*, *Penicillium*, *Aspergillus*, *Enterobacter*, *Rhizobacteria* or *Pseudomonas* spp., among others, could also play an additional role in stimulating plant growth and inducing plant resistance through direct and indirect effects (Scheuerell and Mahaffee, 2002; Ingham, 2005; De Corato, 2020). Concretely,  $2.7 \times 10^2$  cfu mL<sup>-1</sup> of *Trichoderma* sp. and  $7.4 \times 10^4$  cfu mL<sup>-1</sup> of actinobacteria were determined in the studied CT. In addition to the previous statement, it should be pointed out that aerated and non-aerated CT application produces a reduction of mycelial growth of *R. solani* under *in vitro* conditions (Dionne et al., 2012; Tian and Zheng, 2013; González-Hernández et al., 2021). These authors also highlighted that sterilization of CT caused partial or complete loss of the inhibitory effect, which suggests that the suppression effect is mainly due to the presence of antagonistic microorganisms. Nevertheless, this response could change in *in vivo* assays because it has been also described that CT also induced plant resistance in the primed state leading to an enhancement of defense-related enzymes to cope with pathogen attack (Li et al., 2020a).

Taking into account the previous statements, we secondly proposed to consider a third CT treatment based on *Trichoderma*-fortified CT (B1+) to study potato resistance, productivity and quality under field conditions. It should be pointed out that the three CT treatments significantly reduced *R. solani* attack in potato plants. Previous studies have described the importance of the agricultural system since the use of CT and amendments showed that *R. solani* infection was not reduced in plots where potato was cultivated in monoculture agriculture systems, whilst there were significant reductions in polyculture systems (Larkin and Griffin, 2007). Moreover, the efficacy of CT supply could change depending on CT production parameters such as the procedure, source, composition and maturity (Scheuerell and Mahaffee, 2002, 2004). Thus, the studied green waste-based CT possesses a good richness of microorganisms, which leads it to be effective against the attack of different pathogens as already shown in previous studies (Gómez-Sánchez et al., 2017; Morales-Corts et al., 2018; González-Hernández et al., 2021).

In the present work, it also has been observed that CT-treated plants displayed an advance of potato sprouting, together with an increase in number of shoots, tuber weight, tuber size and yield compared to untreated control plants of both cultivars grown under commercial field conditions in both seasons. A similar trend was observed previously by the authors (González-Hernández et al., 2021), where we described that CT applications reduce production times in pepper. However, it may be noted that the differences in the growth responses, especially plant height, may be due to the additional nutrients (mainly N and K) in the CTs. Specifically, 8.4 g NO<sub>3</sub><sup>-</sup>, 0.2 g P<sub>2</sub>O<sub>5</sub>, 11.4 g K<sub>2</sub>O and 1.1 g Ca<sup>2+</sup> have been provided by the CT application in each B1 and B1+ treated plots and 25.2 g NO<sub>3</sub><sup>-</sup>, 0.6 g P<sub>2</sub>O<sub>5</sub>, 33.9 g K<sub>2</sub>O and 3.3 g Ca<sup>2+</sup> in B2 treated plots. Despite, this mineral supply did not cover the nutritional requirements of potato (Westermann, 2005). In accordance with our results, Al-Mughrabi et al. (2008) showed that potato plants treated with CT coming from aerated organic slurries displayed a higher yield, and number and weight of tubers compared to other treatments. Moreover, our data showed that the Agria cultivar displayed a higher yield mean (around 10%) compared to Hermes under the described conditions. In addition to these results, Arioglu et al. (2018) determined the tuber characteristics of potato cultivars grown in winter season and they observed that the Agria cultivar showed higher total and marketable tuber yield than Hermes. Furthermore, yield especially increased when both potato cultivars were treated with B2 treatment. In contrast, Knewton et al. (2009) did not showed differences between microbial tea from a commercial source and a homemade manure tea in crop yield of spinach and collard green. In general, our results showed that no differences were found between B1 and B1+, except for the increase of tuber size and the slight reduction of sprouting in plants treated with the

*Trichoderma*-biofortified CT. Perhaps, this slight effect was due to the *Trichoderma* content of CT is enough for the biostimulant effect and the biofortification did not provide an improvement in the studied parameters. However, in the lab sprouting experiments no differences were observed between C1 and C1+. These results suggest that *Trichoderma*-based biofertilizers not only depend on the type of inoculum and concentration, but also on the properties of the medium in which the fungi develop as it was previously described by Marín-Guirao et al. (2016). It is noteworthy that CT amounts applied in the different treatments might be considerably high to be manage in commercial farms.

Concerning the quality parameters of tubers, CT treatments increased moisture content, and reduced TSS and fried defects in potatoes of both cultivars. Moisture values obtained in this study are comparable to those pointed for Agria and Hermes potatoes by Castro (2008) with values around 75 and 73%, respectively. Nevertheless, TSS contents are lower than those found by this author. The reason for this is that our analyses were carried out immediately after harvest and many authors, as Hunjek et al. (2020), suggest that TSS content increases in the storage and it is influenced by temperature and time. Concerning fried defects, a fairly common problem is the darkening of the potato when frying. It usually occurs because sugar reduction (glucose and fructose) interacts with amino acids, ascorbic acid and some other organic compounds during frying, producing an unacceptable toasted flavor and a dark coloration (Beukema and Van Der Zaag, 1990). In this sense, the minor TSS content in CT treatments might be directly related to the reduced fried defects. Moreover, a darker-color in potato chips could be also related to a higher content of acrylamide, a neurotoxic and carcinogenic compound (Friedman, 2003; Granda and Moreira, 2005; Silva and Simon, 2005; Pedreschi et al., 2006). On the other hand, the moisture content of tubers grown under CT supply is within the quality range admitted by the potato industry since the dry matter range is between 23 and 27% (Van Es and Hartmans, 1981). Concerning this quality parameter, Pardo et al. (2000) described that potato cultivars with high tuber moisture content have less firmness and their flavor is rated low when boiled, while their texture is rated high when fried. These authors also found a high negative correlation between tuber moisture content, TSS content, and firmness. Our results are according to those obtained by these authors in relation to this negative correlation between moisture and TSS content. Furthermore, the moisture content is also in negative correlation with oil quantity consumed in the frying process (Li et al., 2020b), which indicates a positive point for agri-food industries. Finally, it should be pointed out that the resistance of tubers to an applied force is related to texture and potato structure (Nourian and Ramaswamy, 2003; Abu-Ghannam and Crowley, 2006; Kaur et al., 2007). In this study, the puncture force test is slightly reduced by B1 and B2 treatments, indicating the softness of the tubers developed under these treatments, which could be related to the moisture content.

As mentioned above, a lab experiment was carried out in order to confirm the induction of potato sprouting produced by CT application in field trials. It has been observed that the three CT-based treatments induced shoot height, number of leaves and shoot vigor, while only C1 and C2 promoted sprouting. It has been previously described that cytokinins and gibberellins mediated bud break and sprout growth, respectively, and auxin seems to play a role in vascular development (Sonnewald and Sonnewald, 2014). Moreover, exogenous application of gibberellic acid induced sprouting and productivity of seed tubers of potatoes (Biemelt et al., 2004). In addition, other CT properties such as humic acid or plant growth promoting rhizobacteria (PGPR) content are responsible for plant growth promotion. Supporting this statement, Man-hong et al. (2020) showed that exogenous application of humic acids enhanced the potato plant growth and yield, and improved photosynthesis parameters under different water deficits. A significant increase was also observed in potato growth, tuber yield and quality in potato crops inoculated with PGPR and humic acids (Ekin, 2019). Moreover, these authors also described tuber size and weight, dry

matter, starch, protein and mineral were improved when both treatments were applied.

## 5. Conclusion

The application of CT derived from the composting of gardening wastes contribute to recycle and recover these debris. It constitutes an eco-friendly alternative for sustainable agriculture as it allows to reduce the use of fertilizer and phytosanitary products. To sum up, the conclusions of this study are that the three CT-based treatments decrease *R. solani* incidence. Moreover, B1 treatment improved potato production and quality, decreasing frying defects. Nevertheless, when plants were treated with *Trichoderma*-fortified CT (B1+), no significant differences were found compared to B1, suggesting that the *Trichoderma* content of CT is enough for the biostimulant effect and a fortification is not an economically profitable alternative. It should be noted that B2 treatment improved potato production and quality, being the best treatment for almost all the studied parameters. Thus, depending on the CT cost, the farm size and the proximity of the CT producer, the application of this treatment will be recommended to a greater or lesser extent. Nonetheless, B1 treatment seems to be a good alternative since it improves potato quality and it could be an interesting option for the agri-food industry. However, given the large amounts of CT required from the doses applied in this work, further studies on the concentration of the extract are required, thereby minimizing the applied volume.

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## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.scienta.2022.111090.

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