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Performance of potato cultivars grown in the organic production system

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ABSTRACT

In this study we evaluated the performance of potato cultivars in the organic production system, aiming to identify those more productive and less damaged by *Phytophthora infestans* and *Diabrotica speciosa*. The experiment was conducted during the 2013/2014 and 2014/2015 crop seasons. Cultivars Ágata, Aracy Ruiva, Vitória, Clara, Eliza, Catucha and Cris were assessed for severity and area under disease progress curve (AUDPC) of *P. infestans*, external holes and internal galleries caused by *D. speciosa*, and tuber yield. Most cultivars reacted positively to *P. infestans* and *D. speciosa*. 'Ágata' was the most susceptible cultivar, with *P. infestans* severity close to 100% and AUDPC significantly higher than the other cultivars. *D. speciosa* larvae external damages were more intense in 'Eliza' than in 'Clara' and 'Catucha'. 'Eliza' was also among the most internally damaged cultivars in both years, while 'Catucha' and 'Vitória' were among the least internally damaged. The results indicate 'Catucha' and 'Clara' as the most suitable for organic cultivation among the studied materials.

Keywords: *Solanum tuberosum*, *Diabrotica speciosa*, *Phytophthora infestans*, agroecology, alternative production system.

RESUMO

Desempenho de cultivares de batata em sistema orgânico de produção

Neste trabalho, avaliou-se o desempenho das cultivares de batata em sistema orgânico de produção, visando identificar aquelas com maior potencial produtivo e menos danificadas por *Phytophthora infestans* e *Diabrotica speciosa*. O experimento foi conduzido durante as safras de 2013/2014 e 2014/2015. Avaliou-se as cultivares Ágata, Aracy Ruiva, Vitória, Clara, Eliza, Catucha e Cris, quanto à severidade de *P. infestans* e área abaixo da curva de progresso da doença (AUDPC), orifícios e galerias nos tubérculos causadas por *D. speciosa* e produção de tubérculos. 'Ágata' foi a cultivar mais suscetível, com severidade de *P. infestans* próxima dos 100% e AUDPC significativamente mais elevada do que as outras cultivares. Os danos externos das larvas *D. speciosa* foram mais intensos em 'Eliza' do que em 'Clara' e 'Catucha'. 'Eliza' foi também uma das cultivares com mais danos internos em ambos os anos, enquanto 'Catucha e 'Vitória' estiveram entre as menos danificadas internamente. Os resultados indicaram 'Catucha' e 'Clara' como as mais adequadas para o cultivo orgânico entre os materiais estudados.

Palavras-chave: *Solanum tuberosum*, *Diabrotica speciosa*, *Phytophthora infestans*, agroecologia, sistema de produção alternativo.

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Organic potato (*Solanum tuberosum*) system reduces environmental impact, improves plant sanity, and promotes the environmental diversity and abundance of organisms (Krey *et al.*, 2020). However, despite the numerous advantages, these systems still suffer from disease and pest pressure due to the diversity of pathogens and insect pests associated with the crop (Finckh *et al.*, 2006). In Southern Brazil, the primary agents causing losses in potato crops are *Phytophthora infestans* and *Diabrotica speciosa* (Walsh *et al.*, 2020; Nazareno *et al.*, 2020).

Phytophthora infestans is the late blight causal agent, and stands out as one of the main foliar diseases of potatoes, causing lesions on tubers, leaves and stems (Fry, 2008). This disease is particularly important under temperatures from 12 to 25ºC and leaf wetting during over 12 hours (Fry, 2008; Töfoli *et al.*, 2012), conditions that can culminate in severe epidemic and plant death (Finckh *et al.*, 2006). Larvae of *D. speciosa*, in turn, attack potato tubers causing holes and internal galleries, which result in expressive commercial depreciation (Walsh *et al.*, 2020; Nazareno *et al.*, 2020). Considering the main pest of the crop, *D. speciosa* adults cause potato defoliations and females lay eggs in the soil near the plant roots and tubers (Walsh *et al.*, 2020).

In conventional potato crop systems, the management of *P. infestans* is commonly performed with contact fungicides, such as dithiocarbamate and chloronitrile, and systemic ones, such as acylalanine and carbamate (Töfoli *et al.*, 2012), while for *D. speciosa,* organophosphate and neonicotinoid insecticides are usually applied (Walsh *et al.*, 2020).

Therefore, organic potato production is closely linked to the selection of resistant and early maturity cultivars, which together with an accurate cultural management, generate healthy plants and high-quality tubers (Finckh *et al.*, 2006; Möller & Reents, 2007). Resistant cultivars against *P. infestans* generally are developed for each producing region, allowing higher yield characteristics in organic cultivation conditions and high efficiency in mitigating the pathogen (Möller & Reents, 2007). The availability of seed tubers of rustic cultivars is hard to find, especially those produced in organic systems (Krey *et al.*, 2020). However, contrary to what occurs for *P. infestans*, few studies are conducted to characterize the resistance of cultivars to *D. speciosa* (Teodoro *et al.*, 2014), which has a localized distribution in South America, with particular importance in South and Southeast Brazil (Walsh *et al.*, 2020).

The aim of this work was to identify the potato cultivars with high tuber yield and less susceptibility and damage caused by *P. infestans* and *D. speciosa*, respectively. From this study, we intend to generate information about cultivars more indicated for organic potato cultivation in southern Brazil.

MATERIAL AND METHODS

Description of the experimental area

The experiment was conducted under organic potato cultivation, in an area located at the Paraná Institute for Rural Development (IDR) experimental station (25’23”42ºS; 51’27”28ºW; 1029 m altitude), in Guarapuava-PR, during the 2013/2014 (year 1) and 2014/2015 (year 2) crop seasons. The climate of the region is humid mesothermal subtropical with temperate summers (Cfb) and no defined dry season (Peel *et al.*, 2007). Meteorological data for both study periods (IDR-PR, 2021) were obtained from a weather station about 5 km far from the plot areas. The soil is a Latossolo Bruno (Santos *et al.*, 2018) very clayey Oxisoil (USDA Soil Survey).

Soil preparation started one month before planting, with one subsoiling, two harrowing and one light harrowing with subsequent plowing of the experimental area. In both trials, soil was sampled before planting. In year 1, manual planting was performed on November 15th, 2013, using 15 t/ha manure (11.25 t/ha poultry litter + 3.75 t/ha sheep manure) in the planting furrow. In year 2, planting was also done manually, being performed on October 13rd, 2014, using 270 kg/ha natural phosphate and 15 t/ha sheep manure in the planting furrow. Earth up was done approximately 30 days after planting (DAP) in both years.

The experimental design was a factorial randomised design (Moore & Dixon, 2015), with four replications. Each plot was composed of six 4 m long rows, with an inter-row spacing 0.80 m and 0.25 m between plants, with 16 plants per row, totaling 96 plants per plot in year 1 and 10 plants per row totaling 60 plants per plot in year 2.

Cultivars

A total of seven potato cultivars was evaluated: Ágata, IAC Aracy Ruiva (Aracy Ruiva), IAC Vitória (Vitória), BRS Clara (Clara), BRS Eliza (Eliza), EPAGRI 361 – Catucha (Catucha), and IPR Cris (Cris). Cultivars were chosen based on the levels of resistance to *P. infestans* only, since there is no information about resistance to *D. speciosa*. Thus, ‘Ágata’, the main cultivar used in Brazil, was the susceptible control.

Seed tubers were obtained from owners of the cultivars [Clara, and Eliza from the Brazilian Agricultural Research Corporation (Embrapa); Catucha from the Agricultural Research and Rural Extension Company of Santa Catarina (Epagri); Cris from the Rural Development Institute of Paraná (IDR); Aracy Ruiva and Vitória from the Agronomy Institute of Campinas (IAC)]. Seed tubers of cultivar Ágata were obtained from potato growers in the Guarapuava region. In year 1, all seeds were stored for 2 to 3 months in a cold chamber (4°C), removed about three weeks before planting and kept at a cool place with diffused light to stimulate sprouting. In year 2 we used the seed tubers produced in year 1 and all seed tubers were kept for 7-8 months in the cold chamber (4°C).

P. infestans assessment

Evaluations of *P. infestans* severity started at 59 days after planting (DAP) in year 1 and at 68 DAP in year 2, at three to 10 days intervals, totaling four evaluations in both years. Evaluations were based on direct visual observation of all plants, assigning scores from 0 to 100 for severity, according to the proportion of symptomatic leaf area in relation to the total leaf area of the plot (%), following the methodology of James (1971).

From the severity values recorded for each cultivar, the progress curves of disease evolution over time were recorded. In addition, the area under the disease progress curve (AUDCP) was estimated using the formula

$$\sum\left[\left(\frac{y1+y2}{2}\right)*(t2-t1)\right]$$

where y represents the severity in two sequential evaluations and t comprises the interval of days between such evaluations (Shaner & Finney, 1977).

Damage caused by *D. speciosa*

The external and internal damage caused by *D. speciosa* larvae were analyzed on 20 tubers per cultivar, collected from 10 plants per plot at the physiological maturity stage.

In these tubers, the number of surface holes characteristic of larval feeding (diameter of about 1 to 2 mm and a darkened spot in the center) were counted. In addition, the size of the galleries formed by larval feeding was also measured. For this purpose, each tuber was cut into portions to count the number of galleries and to measure the diameter and length of each one.

The tubers’ dimensions (length and width) were recorded with the aid of a universal pachymeter. Thus, it was possible to estimate the area and volume of the tuber, which was considered an ellipsoid according to the methodology established by Barbosa *et al.* (2021). Therefore, we estimated the internal and external damage based on volume and area, respectively, using this method.

Tuber yield

At 96 DAP, plants were harvested

manually, in both years. For yield assessment, 12 plants were collected per plot (3 plants from each one of the 4 central rows of the plot).

Thus, total yield (tubers/plant) and commercial yield (tubers >45 mm ø/plant) were analyzed. The commercial tubers were divided into three weight classes: <100 g, between 100 and 200 g, and >200 g.

Data analysis

Data were analyzed for normality (Kolmogorov-Smirnov, $p<0.05$) and homogeneity of variances (Bartlett, $p<0.05$). Next, data of severity, AUDPC, external and internal damage of *D. speciosa* were transformed by the formula log (x+1) since they were not normal and/or homogeneous. Finally, the data set was submitted to analysis of variance (ANOVA), and the means were compared using the Tukey's test ($p<0.05$).

To define relevant factors for cultivars' suitability for organic systems, the mean values of AUDPC, external damages, internal damages, and commercial yield were submitted to principal component analysis. Afterwards, the cluster grouping analysis was done, adopting the Euclidean distance as the similarity index. For this, such data were standardized by the formula

$$\frac{(x-\bar{x})}{dp}$$

where x represents the original data, $\bar{x}$ the overall mean of the data and *dp* the standard deviation of the data. Moreover, in the cluster analysis, we adopted half of the maximum Euclidean distance obtained as the cutoff point for defining the groups.

The analyses were performed using the Statistica 7 software (Statsoft, 2007).

RESULTS AND DISCUSSION

Environmental conditions were favorable to both *P. infestans* development and *D. speciosa* damage. The temperature range stood suitable for *P. infestans*, with minimum temperature values good for morning dew formation.

Severity of *P. infestans*

P. infestans epidemic on potato plants evolved naturally throughout the crop cycle in both years, showing that the pathogen was endemic in the area during cultivation. However, the epidemic of *P. infestans* was more expressive in year 2 than in year 1 for all cultivars (ANOVA, $p<0.05$) (Figures 1a and 1b). In year 2, the disease symptoms appeared later in the crop cycle (Figure 1) due to the climatic conditions of the

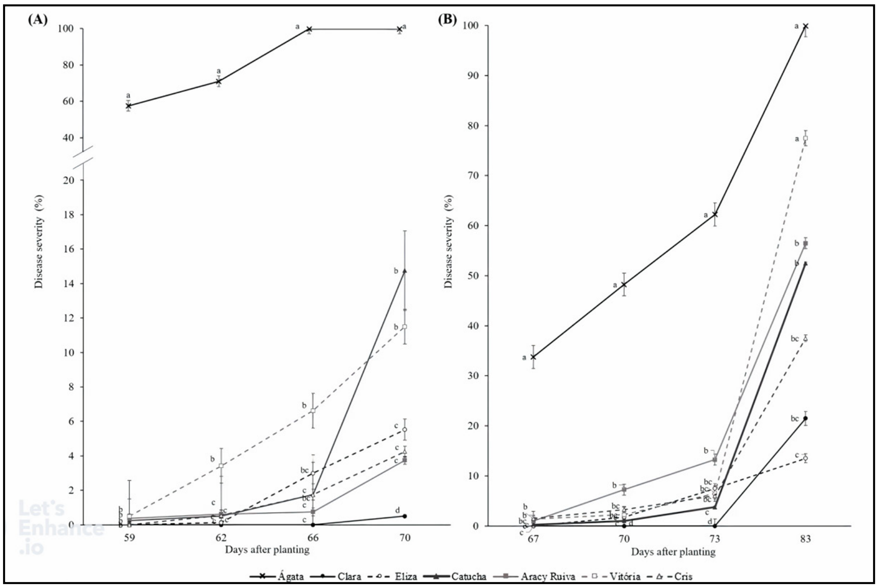

Figure 1. *P. infestans* severity in seven potato cultivars grown under organic production system, in the 2013/14 (a) and 2014/15 (b) crop seasons, assessed four times. *Means followed by different letters indicate a statistically significant difference (Tukey test, p<0,05). Bars show the standard error. Guarapuava, IDR, 2013-2015.

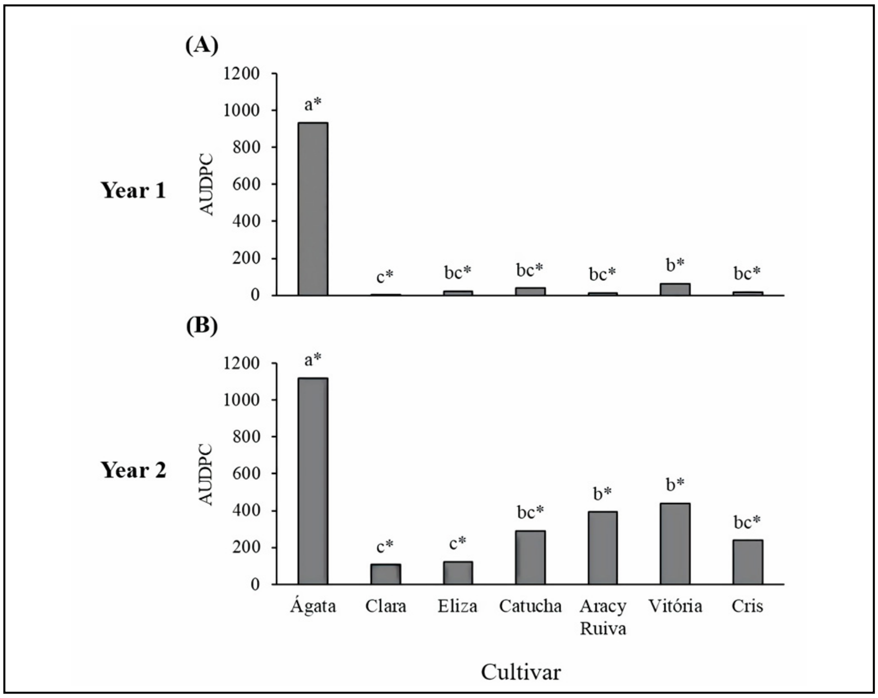

Figure 2. Area under the disease progress curve [AUDPC] of *P. infestans* in seven potato cultivars grown under organic production system, in Guarapuava-PR, southern Brazil, in the 2013/14 (a) and 2014/15 (b) crop seasons. *Means followed by different letters show differences of damages between cultivars, regardless of year, and asterisks indicate differences between the years studied for the same cultivar (Tukey test, p<0,05). Guarapuava, IDR, 2013-2015.

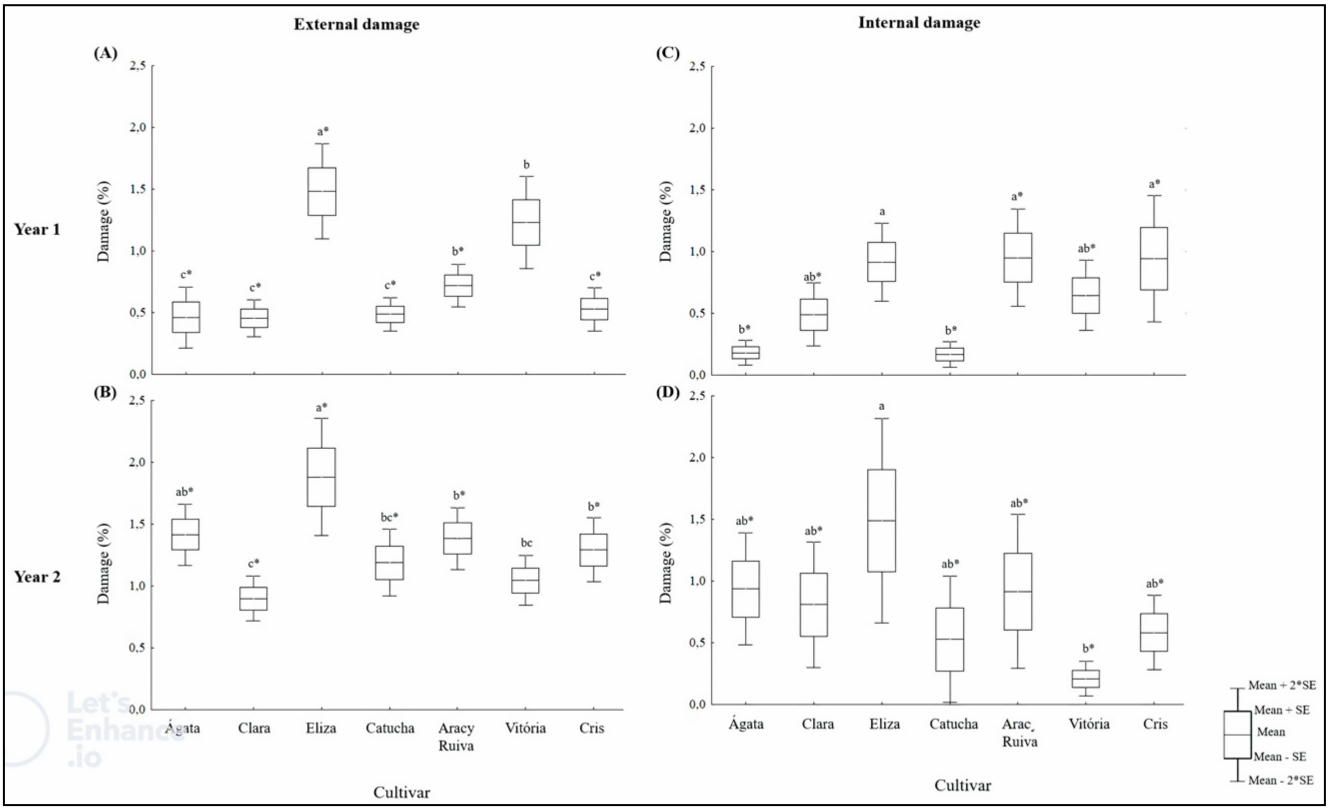

Figure 3. External (a) and internal (b) damage on potato tubers caused by *Diabrotica speciosa* on seven potato cultivars in the organic production system, during the 2013/14 and 2014/15 crop seasons. *Means followed by different letters show differences of damages between cultivars, regardless of year, and asterisks indicate differences between the years studied for the same cultivar (Tukey test, p<0,05). Guarapuava, IDR, 2013-2015.

season.

In both years, cultivar Agata was the most susceptible, with *P. infestans* severity close to 100% and AUDPC significantly higher than the other cultivars (Figures 1 and 2). On the other hand, *P. infestans* severity and AUDPC values were below 20% in year 1 and between 20 and 70% in year 2 of evaluation for the other cultivars. Among the cultivars, Clara, Eliza, Catucha, Aracy Ruiva, Vitória and Cris, there was no difference in AUDPC, indicating similar responses and levels of field resistance to *P. infestans*. However, a severity below 20% in 'Eliza' and 'Clara' in year 2 was observed, lower than in the other cultivars (ANOVA, GL= 6, p<0.0001). Such observations corroborate with Gomes *et al.* (2009) and Pereira *et al.* (2013), who verified the resistance of cultivars 'Cris' and 'Clara' to *P. infestans*. However, cultivar Eliza, previously classified as moderately susceptible to *P. infestans* (Pereira *et al.*, 2013; Töfoli *et al.*, 2012), showed low rates of the disease. Similarly, cultivar Aracy Ruiva, considered moderately resistant to *P. infestans*, showed higher AUDPC than cultivars Clara and Eliza.

D. speciosa damage

All cultivars showed damages caused by the larvae of *D. speciosa*, implying that the insect was present in the area and had access to the tubers (Figure 3). The percentage of external and internal damage in potato tubers was higher in year 2 (ANOVA, p<0.05). External damage on tubers remained below 5% for all cultivars, which characterizes it as a light defect (Brasil, 2017) and allows stating that, under the conditions of the experiment, the cultivars proved suitable for organic cultivation without the use of insecticides. However, the cultivars showed differences in the levels of external and internal tuber damages.

In both years, external damages caused by *D. speciosa* larvae were more expressive in 'Eliza' and less intense in 'Clara' and 'Catucha'. 'Eliza' was also among the most internally damaged cultivars in both years, while 'Catucha' and 'Vitória' were among the least internally damaged.

The resistance factors of potato cultivars to rhizophagous insects are poorly known, although some are considered important, such as periderm thickness, pulp texture or fiber percentage, glycoalkaloid content, soluble sugar (°Brix) content, acidity and levels of nutrients and toxins present in the tubers (Barbosa *et al.*, 2021). Besides these, plant architecture and depth of tuber formation have been reported as relevant factors that may reduce the ability of insects to reach the tubers (Pelletier *et al.*, 2010). Among the genetic materials evaluated here, 'Catucha' stands out for its reduced sugar content (Barbosa *et al.*, 2021), a characteristic that may be associated with lower internal damage intensity caused by *D. speciosa* larvae. When external damage is analyzed, the intrinsic mechanisms to explain the lower damage in 'Clara' and 'Catucha' have not yet been elucidated. However, considering that these cultivars are genetically related (Pereira *et al.*, 2013), it is likely that the similar response to *D. speciosa* larval attack between these cultivars might be due to their genetic background.

Tuber yield

Tuber yield was higher in year 2 (ANOVA, p<0.05) (Figure 4). In general, the cultivars with higher yields were Ágata, Clara and Catucha. However, when the characteristics of the produced tubers were evaluated we noticed that cultivar Ágata showed low yield of commercial tubers, especially in year 2.

In both years, 'Catucha' had a higher yield, with a high proportion of commercial tubers, in relation to the total tubers. This high yield of commercial tubers (>100 g) can be attributed to the early formation and rapid tuber growth. Eschemback *et al.* (2014), evaluating different potato genotypes, found that the number and size of tubers directly influence the yield of commercial tubers. The present study results corroborate and are in accordance with Virmond *et al.* (2017), who reported a higher tuber yield of 'Catucha' than other cultivars, attributing this to its higher leaf number and leaf area index. Similarly, Rossi *et al.* (2011), studying 18 potato genotypes including 'Ágata', 'Catucha' and 'Aracy Ruiva' under organic cultivation in a higher temperature region, reported that the first two showed similar yields, while 'Aracy Ruiva' was one of the cultivars with the highest yield.

Additionally, it is observed that soil and climate conditions have a significant effect on the performance of cultivars in an organic system, corroborating with the study of Zarzýnska & Pietrasko (2015) and Passos *et al.* (2017). Thus, it is stressed that the potato cultivar recommendation for organic systems should be beforehand studied for each

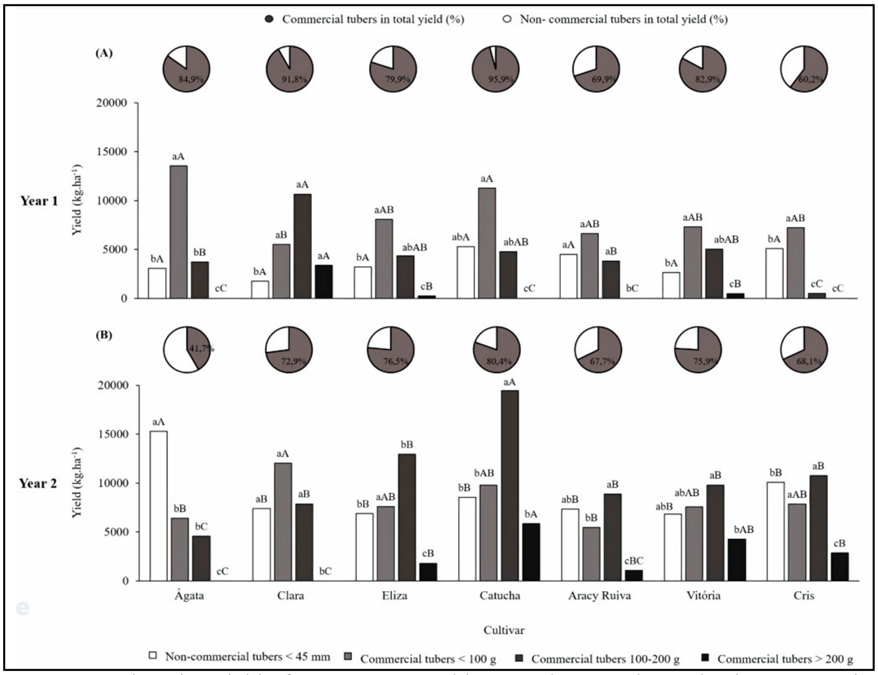

Figure 4. Tuber size yield of seven potato cultivars under organic production system, in the 2013/14 (a) and 2014/15 (b) crop seasons in Guarapuava-PR, southern Brazil. *Means followed by different letters indicate significant statistical difference (Tukey test, p<0,05), with lowercase letters indicating differences among tuber size and uppercase letters indicating differences among cultivars. Guarapuava, IDR, 2013-2015.

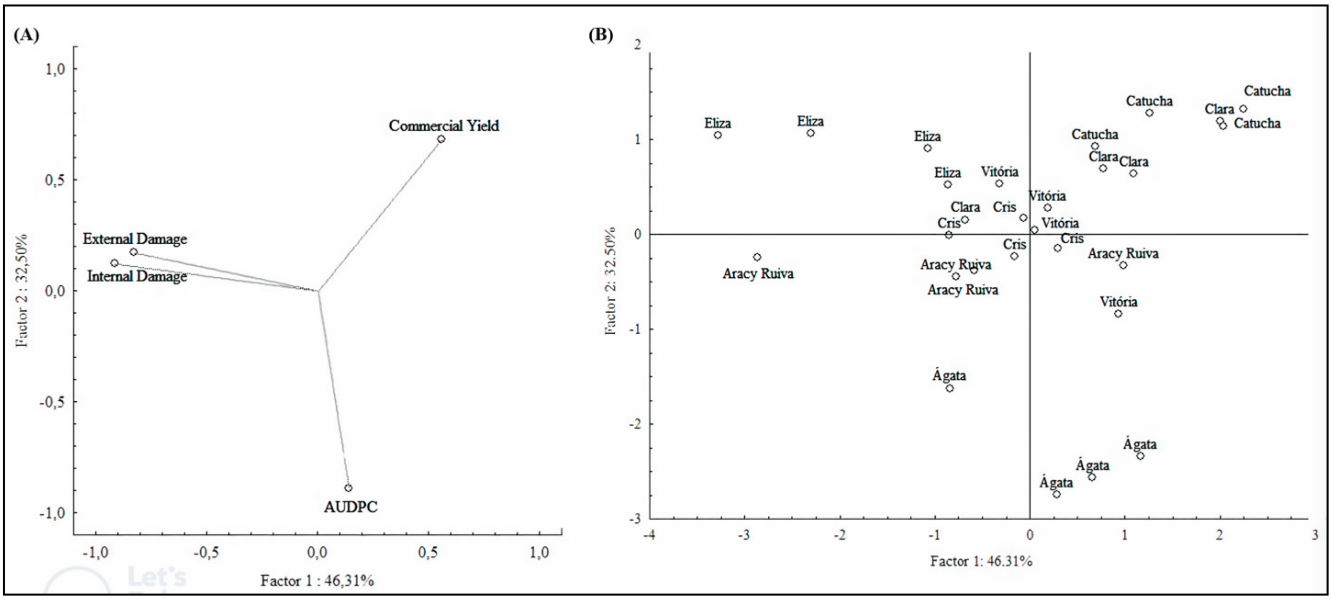

Figure 5. Principal component analysis (a, b) of seven potato cultivars grown under organic production system, in Guarapuava-PR, southern Brazil. Guarapuava, IDR, 2013-2015.

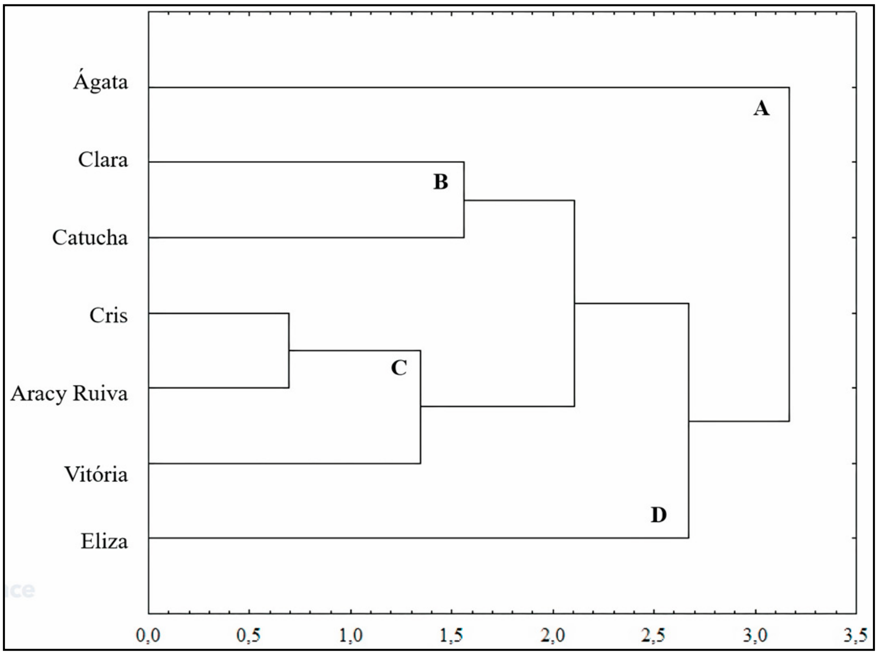

Figure 6. Grouping analysis (cluster) of potato cultivars grown under organic production system, in Guarapuava-PR, southern Brazil, showing the different groups formed (A, B, C, D). Guarapuava, IDR, 2013-2015.

specific soil and climate condition.

Cluster analysis

Considering the data set regarding AUDPC, internal and external *D. speciosa* damage and tuber yield in two years of cultivation, the principal component analysis identified two factors (78.81%), the first consisting of AUDPC and commercial yield, and the second consisting of *D. speciosa* damage (Figure 5). Factor 1 has as components the internal and external damage of *D. speciosa*, which presented communalities of 0.8333 and 0.6843, respectively. Factor 2 is composed by commercial tuber yield and AUDPC of *P. infestans*, with respective communalities of 0.7775 and 0.8125 of the variation. Altogether, factor 1 had a representation of 46.31% variation, and factor 2, 32.50%.

The cluster analysis highlighted the formation of four distinct cultivar groups, with significant similarity among cultivars belonging to the same group and a correlation coefficient of 0.8116 (Figure 6). The cultivars Ágata (group A) and Eliza (group D) were distinct from the others, forming isolated groups; this can be explained by the high severity of *P. infestans* in 'Ágata' and the high level of damage from *D. speciosa* in 'Eliza'. The group (C) formed by 'Aracy Ruiva', 'Vitória' and 'Cris' presented an intermediate performance in all evaluated characteristics in the analysis.

'Clara' and 'Catucha' (group B) stood out from the other analyzed materials. These cultivars showed higher yield, as well as low *P. infestans* AUDPC values and reduced percentages of internal and external damage caused by *D. speciosa* larvae. Such similarity between the two cultivars is explained by genetic proximity since 'Clara' was developed from 'Catucha' (Pereira *et al.*, 2013).

Thus, the results of the joint analysis indicate 'Catucha' and 'Clara' as the most suitable cultivars for organic cultivation in southern Brazil, among the materials studied in this work. Thus, although some cultivars had lower severity of *P. infestans* and reduced *D. speciosa* damage, the overall data showed high variation among the two years of cultivation. It is noteworthy that in years in which the incidence of *P. infestans* occurs early in the crop season and the occurrence of *D. speciosa* is high, these cultivars have their yield reduced. Therefore, greater attention to the management of these agents should be taken to enable higher yields in organic cultivation.

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