Shoot growth, tuber yield and quality of two potato cultivars as affected by prohexadione-calcium application

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ABSTRACT

This study evaluated the effects of the rates and timings of prohexadione-calcium (prohexadione-Ca) application on shoot growth, tuber yield, and quality of two potato cultivars (Agata and Mondial). An experiment with each cultivar was carried out in a greenhouse using a randomized block design with four replications. Treatments consisted of a control and single or sequential foliar applications of prohexadione-Ca at the rate of 50 or 100 g ha^{-1} (50 g ha^{-1} applied once, 50 g ha^{-1} applied twice, 50 g ha^{-1} applied three times, 100 g ha^{-1} applied once, 100 g ha^{-1} applied twice, and 100 g ha^{-1} applied three times). Prohexadione-Ca application changed the distribution pattern of tuber size in both cultivars. A rate of 100 g ha^{-1} prohexadione-Ca was applied three times between the stages of tuber initiation and tuber bulking, making the haulm length of the plants short for a long time. Prohexadione-Ca application did not alter the tuber yield and quality of the cultivar Agata, but 50 g ha^{-1} applied three times or 100 g ha^{-1} applied twice increased tuber yield in the cultivar Mondial. Only in the cultivar Mondial, 50 g ha^{-1} prohexadione-Ca applied three times increase tuber dry matter, starch, and protein contents.

Keywords: plant growth retardants; haulm length; tuber number; tuber size; *Solanum tuberosum*.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the main food sources worldwide. In Brazil, the most planted potato cultivar is Agata (Lazzarini, 2017), and the cultivar Mondial is among the five most planted potato cultivars (Nunes, 2017); both cultivars have the characteristics that are appropriate to the fresh potato market (Fernandes *et al*., 2010b). The cultivar Agata is a more compact plant, with high tuber yield and shorter haulms and fewer leaves than those of the cultivar Mondial (Fernandes *et al*., 2010a). In contrast, the plants of the cultivar Mondial show exuberant shoot growth with long haulms and a high yield of large tubers (Fernandes *et al*., 2010a; Fernandes *et al*., 2011).

Potato tuber yield depends on the synthesis of carbohydrates in the leaves and their translocation to the tubers (Nunes, 2017). However, excessive foliage growth in potato crops is usually unfavorable for tuber production because vigorous foliage growth suggest that considerable amounts of carbohydrates have been used for foliage growth at the expense of tuberization (Mabvongwe *et al*., 2016) and can create a favorable microclimate for incidence of diseases in the plant. The use of plant growth retardants (PGRs) is an alternative approach to reduce the excessive leaf growth of potato cultivars that show vigorous shoot growth (Ellis *et al*., 2020) and may also increase the allocation of assimilates to developing tubers (Prakash *et al*., 2001; Tekalign & Hammes, 2004; Tekalign & Hammes, 2005).

Prohexadione-calcium (prohexadione-Ca), an acylcyclohexanedione, is a PGR that inhibits the final stages of gibberellin biosynthesis that occurs in the cytosol of cells (Rademacher, 2000; Rademacher, 2015). This PGR specifically inhibits the 3â-hydroxylation of GA_{20} by GA 3-oxidase, preventing the synthesis of bioactive GA_1 (Brown *et al*., 1997) and thereby inhibiting the vertical shoot growth of many plant species (Rademacher, 2000; Rademacher, 2015).

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Some studies on the use of PGRs on potato crops have already been carried out using products such as ethephon (Rex, 1992), mepiquat chloride (Prakash *et al.*, 2001), chlormequat chloride (Rex, 1992; Pavlista, 2013), paclobutrazol (Balamani & Poovaiah, 1985; Bandara *et al.*, 1998; Tekalign & Hammes, 2004; Tekalign & Hammes, 2005; Mabvongwe *et al.*, 2016; Ellis *et al.*, 2020), and prohexadione-Ca (Pavlista, 2013; Ellis *et al.*, 2020); however, there are still inconsistencies on which PGR, rate, and time of application provide the best results for this tuber crop. Studies have shown that the application of PGRs, such as paclobutrazol and prohexadione-Ca, is efficient in reducing the haulm length, leaf area, and leaf area index of potato plants (Balamani & Poovaiah, 1985; Tekalign & Hammes, 2004; Tekalign & Hammes, 2005; Ellis *et al.*, 2020), but other studies indicated that the use of prohexadione-Ca also increased the incidence of misshaped tubers (Pavlista, 2013), and the application of ethephon or chlormequat chloride decreased the yield of marketable tuber and increased the yield of small tubers (Rex, 1992), possibly owing to excessive foliage reduction.

The aim of PGRs is to reduce the excessive vegetative growth of plants; however, depending on application time, the effects of PGRs on potato plant development can vary and are inconsistent. Some studies have shown that the application of paclobutrazol during stolon initiation or before tuberization increased the number of tubers per plant and decreased the mean weight of tubers (Bandara *et al.*, 1998; Ellis *et al.*, 2020); however, the total yield of tubers was not different from that of untreated plants (Ellis *et al.*, 2020). The application of ethephon and chlormequat chloride after the beginning of tuberization stage (largest tubers with diameters between 25 and 30 mm) increased the number of tubers per plant and decreased the mean weight of tubers and yield of marketable tuber (Rex, 1992). In contrast, Ellis *et al.* (2020) found that the application of paclobutrazol or prohexadione-Ca after tuberization stage had no effect on the number or size of tubers, and plants treated with PGR, even with less foliage, had tuber yield comparable to that of the untreated plants. In another study, the application of prohexadione-Ca after the beginning of tuberization stage (largest tuber weighs between 25 and 100 g) increased the total yield of tubers and the incidence of misshaped tubers, which turned the advantage of obtaining high tuber yield unfeasible (Pavlista, 2013).

Thus, it is important to better understand how the application of prohexadione-Ca alters the shoot growth and tuber yield of two potato cultivars with contrasting characteristics of top growth. Therefore, based on the hypothesis that the application of low prohexadione-Ca rates, from tuber initiation stage to tuber bulking stage, can better control the excessive plant leaf growth and favor tuber yield, and that the effects may vary among cultivars, the objective of this study was to evaluate the effect of rates and timings of prohexadione-Ca application on shoot growth, tuber yield, and quality of two potato cultivars (Agata and Mondial) grown under controlled conditions.

MATERIALS AND METHODS

Two experiments, one with the cultivar Agata and the other with the cultivar Mondial, were carried out in a greenhouse at the Center of Tropical Roots and Starches (CERAT) of São Paulo State University (UNESP) located in Botucatu-SP, southeastern Brazil (22°50’36" S; 48º25’32" W and 740 m above sea level). The greenhouse, with a clear plastic cover of 150 µm, has a height of 4.8 m, width of 7 m, and length of 25 m and is closed on the sides with a screen. No artificial lights or shade nets were used. During the crop growth, the temperature inside the greenhouse varied from 11.2 to 42.7 °C. The relative air humidity inside the greenhouse was not monitored. For the experiments, the surface layer (0 to 20 cm depth) of a clayey-textured Oxisol was collected, sieved, and chemically analyzed (van Raij *et al.*, 2001), and then corrected with dolomitic limestone to raise the base saturation to 60% (Lorenzi *et al.*, 1997), and incubated for 30 days with a moisture of approximately 80% of the maximum capacity of the soil water retention. After correction, the soil was sampled and analyzed, and it presented the following characteristics: 5.5 pH ($CaCl_2$); 15 g dm^{-3} O.M.; 5 mg dm^{-3} P_{resin}; 0.9, 34, 12, 30, and 76 mmol$_c$ dm^{-3} K, Ca, Mg, H+Al, and cation exchange capacity, respectively; and 61% base saturation (BS). In both experiments, the planting fertilization was carried out with 50, 150, 150, 27, 15, 5.0, 1.0, 0.4, 1.7, 1.1, and 0.06 mg dm^{-3} of N, P, K, Ca, S, Zn, B, Cu, Fe, Mn, and Mo, respectively. N, P, and K were supplied as urea (45% N), simple superphosphate (18% P_2O_5, 18% Ca, and 10% S), and potassium chloride (60% K_2O), respectively. Fritted trace elements were used as the source of micronutrients.

After planting fertilization, the soil was placed in pots and an uncut seed tuber (type III) was planted per pot at a depth of 12 cm. The planting of the cultivars Agata and Mondial occurred on July 12, 2018 and August 30, 2018, respectively. After planting, 8 L of water per pot was applied to reach 80% of the soil water retention capacity. During the potato growth cycle, irrigation was carried out using a drip system, and was monitored using tensiometers; the amount of water applied per pot varied between 0.8 and 1.7 L per day, depending on the crop demand. The emergence of the cultivars Agata and Mondial occurred at 20 and 15 days after planting (DAP), respectively. Topdressing N fertilization (urea) was carried out with 100 mg dm^{-3} N split applied at 10 and 33 days after emergence (DAE) for the cultivar Agata, and 7 and 30 DAE for the cultivar Mondial.

Pest and disease management was carried out, according to the technical recommendations for the crop, with foliar spraying of tiametoxam (9.0 mg plant^{-1} a.i.) and pyraclostrobin+metiram (19.8+1.8 mg plant^{-1} a.i.) between 14 and 16 DAE, abamectin (0.4 mg plant^{-1} a.i.) and pyraclostrobin+metiram (19.8+1.8 mg plant^{-1} a.i.) between 26 and 27 DAE, metalaxyl+mancozeb (2.4+38.4 mg plant^{-1} a.i.) and dimetomorfe (9.6 mg plant^{-1} a.i.) between 41 and 42 DAE, and dimetomorfe (9.6 mg plant^{-1} a.i.), tiametoxam (9.0 mg plant^{-1} a.i.) and pyraclostrobin+metiram (19.8+1.8 mg plant^{-1} a.i.) between 53 and 58 DAE.

In both experiments, a randomized block experimental design with four replications per treatment was used. The treatments consisted of a control (without prohexadione-Ca application) and single or sequential foliar applications of prohexadione-Ca at the rate of 50 or 100 g ha^{-1} (Table 1). Each plot had a 38 dm^{-3} pot containing one potato plant. Destructive evaluations were performed at 15, 23, 33, 43, and 80 DAE (final harvest), and as such, we used a different number of pots per treatment in order to maintain the same number of replications (four) to carry out the statistical analysis for each time of evaluation.

In the control treatment, plants (pots) were harvested at all evaluation times (4 plants per time) and in the treatment with one prohexadione-Ca application, the evaluations started at 23 DAE (8 days after the last application - DALA). In the treatments with two prohexadione-Ca applications, the evaluations started at 33 DAE (10 DALA), while in the treatments with three prohexadione-Ca applications, the evaluations started at 43 DAE (10 DALA). Thus, the control treatment had 20 plants (harvest at 15, 23, 33, 43, and 80 DAE), treatments 50-1ap and 100-1ap had 16 plants (harvest at 23, 33, 43, and 80 DAE), treatments 50-2ap and 100-2ap had 12 plants (harvest at 33, 43, and 80 DAE), and treatments 50-3ap and 100-3ap had 8 plants (harvest at 43 and 80 DAE). Prohexadione-Ca was sprayed on the potato leaves using a backpack electric sprayer (model FT-25DS, Yamaho) equipped with flat fan nozzles (model AXI-110-04, Jacto) that were calibrated to apply a volume of 200 L ha^{-1} of solution (equivalent to 4.8 mL plant^{-1}). Sprayings were carried out at a height of approximately 40 cm above the canopy of the plants. A plastic tarp was placed around the plants to prevent drift at the time of each application.

At 15, 23, 33, and 43 DAE, the haulm length of the plants, number of leaves per plant, leaf area, and relative chlorophyll index (SPAD) of the leaves were determined. The haulm length of the plants was determined using a graduated ruler, accounting for the distance between the base and the apex of each plant. The number of leaves per plant was obtained by counting all leaves of each plant in the plot. The leaf area of each plant was determined using an area meter (LI-310, LI-COR Biosciences). The relative chlorophyll index was determined using a portable chlorophyll meter (SPAD 502, Minolta, Japan) by reading the three-terminal leaflets of the first three fully expanded leaves from the apex of each plant in the pot.

The number of tubers per plant, mean weight of tubers, yield of tubers, and contents of dry matter (DM), starch, and protein in the tubers were evaluated at 23, 33, 43, and 80 (final harvest) DAE. At each evaluation period, the plant in each plot (pot) was harvested, and the number of tubers per plant was determined by counting. Tubers were washed and weighed to obtain tuber yield, while the tuber mean weight was obtained from the relationship between the total weight and the total number of tubers per plant. The harvested tubers were sliced, dried in an oven with forced air circulation at 65 °C for 96 h, and weighed to obtain the DM content. The dry samples were ground using a Wiley

Table 1: Description of treatments with a control and six different forms of prohexadione-Ca application (rate and timing) in two potato cultivars

Treatments[1]	Rate and timing (crop stage) of prohexadione-Ca application			
	15 DAE[2] (Tuber initiation[3])	23 DAE (Tuberization)	33 DAE (Tuber bulking)	Total rate applied
	(g ha^{-1} prohexadione-Ca)			
Control	-	-	-	0
50-1ap	50	-	-	50
50-2ap	50	50	-	100
50-3ap	50	50	50	150
100-1ap	100	-	-	100
100-2ap	100	100	-	200
100-3ap	100	100	100	300

[1] Control: without prohexadione-Ca application, 50-1ap: 50 g ha^{-1} prohexadione-Ca applied at 15 DAE, 50-2ap: 50 g ha^{-1} prohexadione-Ca applied at 15 and 23 DAE, 50-3ap: 50 g ha^{-1} prohexadione-Ca applied at 15, 23, and 33 DAE, 100-1ap: 100 g ha^{-1} prohexadione-Ca applied at 15 DAE, 100-2ap: 100 g ha^{-1} prohexadione-Ca applied at 15 and 23 DAE, 100-3ap: 100 g ha^{-1} prohexadione-Ca applied at 15, 23, and 33 DAE. [2] Days after emergence. [3] Tuber initiation: plants with tubers between stages III and V of tuberization defined by Weeda *et al.* (2009).

mill, and the starch and protein contents determined. The starch contents were determined following the Somogy methodology adapted by Nelson (1944), while the protein content was determined following the Kjeldahl method (method 920.87 of the Association of Analytical Chemists - Aoac) (Horwitz & Latimer, 2005), using a factor of 6.25 for conversion to crude protein. Then, the values of the tuber starch and protein contents were converted to that of fresh weight contents.

The data obtained from each experiment (cultivar) and time of evaluation were separately subjected to analysis of variance (ANOVA). The treatment (forms of prohexadione-Ca application) means were compared using the Tukey test ($p \leq 0.05$).

RESULTS

Between the first (15 DAE) and third (33 DAE) application, the haulm length of cultivar Agata did not differ between prohexadione-Ca treatments, but was significantly shorter than that of the control (Figure 1a). The longest plants at 43 DAE was found in the control treatment, while the shortest plants was found in the treatment with three applications of 100 g ha^{-1} prohexadione-Ca (100-3ap). The haulm length of plants in the treatment with one application of 50 g ha^{-1} prohexadione-Ca (50-1ap) did not differ from that of the control. For the cultivar Mondial, the haulm lengths of all prohexadione-Ca treatments after the first application (23 DAE) were shorter; however, in the period from 33 to 43 DAE, only the treatments with two and three applications of 100 g ha^{-1} prohexadione-Ca (100-2ap and 100-3ap) significantly made the haulm length of the plants shorter than that of the control (Figure 1b).

The number of leaves per plant was slightly influenced by the treatments for both potato cultivars (Figures 1c, d). Only at the last evaluation (43 DAE) that the plants from the cultivar Agata in the control treatment presented more leaves than the plants in the 50-1ap, 50-3ap, 100-2ap, and 100-3ap treatments. For the cultivar Mondial, only at 33 DAE the plants in the 50-1ap treatment showed more leaves than the control, 50-2ap, and 50-3ap treatments.

The leaf area of the cultivar Agata was similar among all treatments from the first application of prohexadione-Ca to 43 DAE, and only at 43 DAE the plants in the 50-1ap and 100-3ap treatments showed lower leaf area than those of other treatments (Figure 1e). For the cultivar Mondial, there was no difference in the leaf area of the plants up to the second application of prohexadione-Ca (23 DAE) (Figure 1h). However, after the second application, 100-3ap treatment showed lower values of leaf area between the period of 33 and 43 DAE.

In the cultivar Agata, relative chlorophyll index (SPAD) differed between treatments only at 23 and 43 DAE (Figure 1g). At 23 DAE, only the 50-1ap treatment showed SPAD values higher than those in the control, 100-1ap, 100-2ap, and 100-3ap treatments. However, at 43 DAE, the SPAD values in 50-1ap, 50-2ap, 50-3ap, and 100-1ap treatments were higher than that in the control. For the cultivar Mondial, SPAD values differed between treatments only at the last evaluation, in which the 50-1ap treatment showed higher values than those in the 50-2ap, 100-1ap, 100-2ap, and 100-3ap treatments (Figure 1h).

The number of tubers per plant was affected by the treatments for both potato cultivars (Figures 2a, b). For the cultivar Agata, only after the first application of prohexadione-Ca (23 DAE) that the treatments sprayed with 50 g ha^{-1} showed higher number of tubers per plant than the control, but after the third application of the prohexadione-Ca (43 DAE), the 50-1ap treatment showed the lowest number of tubers per plant. In the final harvest (80 DAE), the 50-1ap, 50-3ap, and 100-1ap treatments showed a lower number of tubers per plant than the control and 100-2ap treatments. For the cultivar Mondial, only in the first evaluation after the first application of prohexadione-Ca (23 DAE) that the number of tuber per plant in the control treatment was higher than those in the other treatments. However, after the third application of prohexadione-Ca, the 50-3ap and 100-3ap treatments showed the highest number of tubers per plant, while the lowest numbers of tubers per plant occurred in the 100-1ap and 100-2ap treatments.

Prohexadione-Ca application significantly affected the tuber mean weight of the cultivar Agata only at 33 DAE and in the final harvest (Figure 2c). At the beginning of the tuber bulking stage (33 DAE), the treatments with two and three applications of 50 g ha^{-1} prohexadione-Ca increased the tuber mean weight compared to other treatments. However, in the final harvest, the heaviest tubers were obtained in the 50-1ap treatment and the lightest ones in the 100-2ap treatment. For the cultivar Mondial, there was a significant difference in the tuber mean weight only after 33 DAE (Figure 2d). At 43 DAE, the 100-2ap treatment showed the highest tuber mean weight, and the 100-3ap treatment showed the lowest tuber mean weight. At the final harvest, the tubers with the highest weights were obtained in the 50-1ap, 50-2ap, and 100-1ap treatments, while the tubers with the lowest weight were obtained in the 50-3ap, 100-2ap, and 100-3ap treatments.

The tuber yield of the cultivar Agata was not significantly affected by the treatments (Figure 2e). For the cultivar Mondial, only in the final harvest that the tuber yield was influenced by the treatments (Figure 2f). At the final harvest, the tuber yields in the 50-3ap and 100-2ap treatments were significantly higher than those in the control, 50-1ap, and 100-1ap treatments.

For the cultivar Agata, the contents of DM, starch, and protein of the tubers were affected by the treatments at the beginning of tuber development; however, at the final harvest, these differences did not occur (Figures 3a,c,e). For the cultivar Mondial, the control treatment showed tubers with lower contents of DM, starch, and protein during the tuberization stage (23 DAE), but during the initial stage of tuber bulking (33 DAE), the 100-1ap treatment showed tubers with a higher DM and starch contents (Figures 3b,d,f). However, in the final harvest, the tubers with

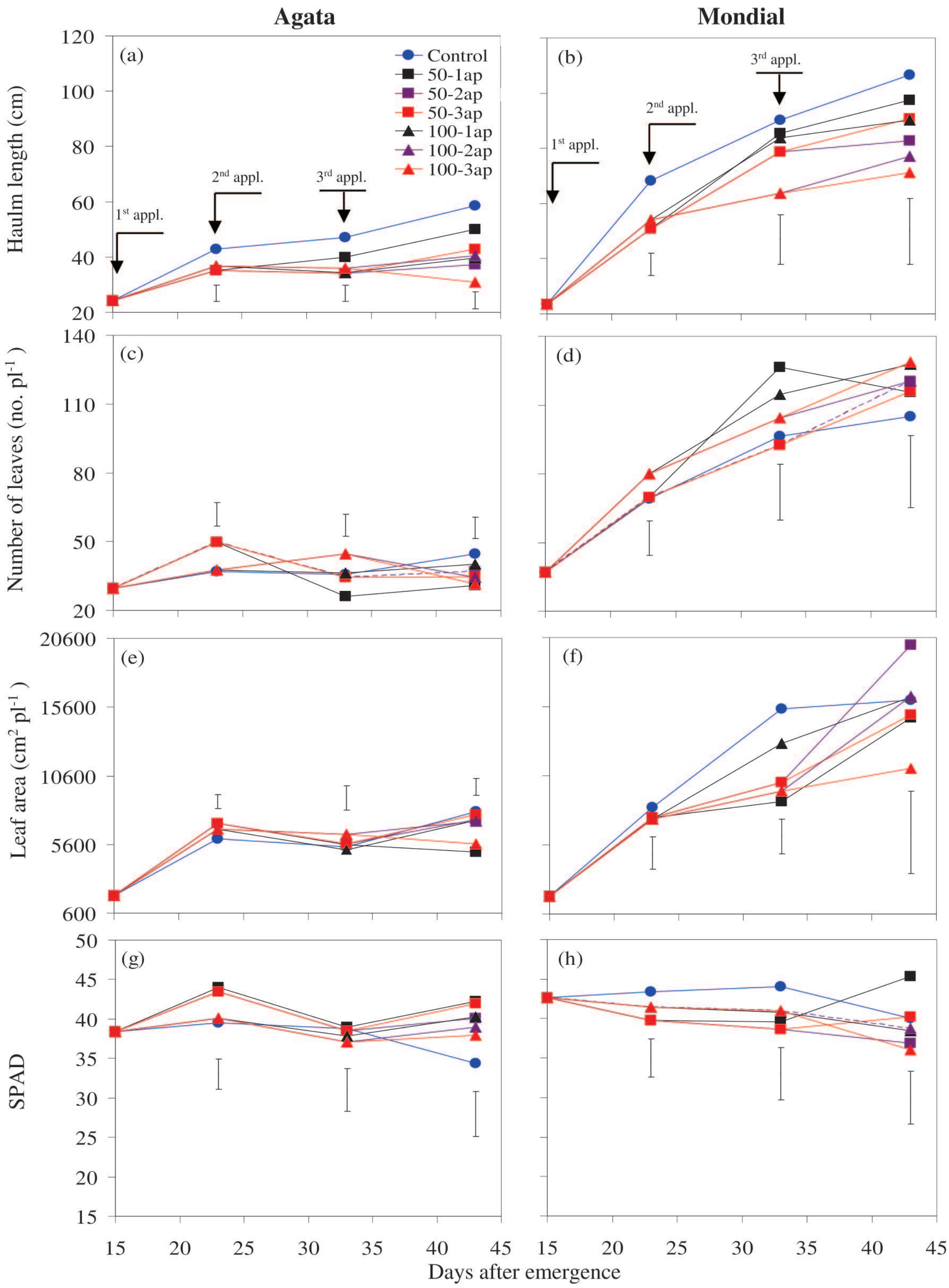

Figure 1: Haulm length (a,b), number of leaves per plant (c,d), leaf area per plant (e,f), and relative chlorophyll index (SPAD) (g,h) of two potato cultivars as affected by the prohexadione-Ca application. Vertical bars indicate the least significant difference at $p \leq 0.05$ by Tukey's test. Control: without prohexadione-Ca application, 50-1ap: 50 g ha^{-1} prohexadione-Ca applied at tuber initiation stage (15 DAE), 50-2ap: 50 g ha^{-1} prohexadione-Ca applied at 15 and 23 DAE, 50-3ap: 50 g ha^{-1} prohexadione-Ca applied at 15, 23, and 33 DAE, 100-1ap: 100 g ha^{-1} prohexadione-Ca applied at 15 DAE, 100-2ap: 100 g ha^{-1} prohexadione-Ca applied at 15 and 23 DAE, 100-3ap: 100 g ha^{-1} prohexadione-Ca applied at 15, 23, and 33 DAE.

the highest values of DM and starch occurred in the 50-1ap treatment, and the 50-1ap and 50-3ap treatments showed tubers with the highest protein content. At the final harvest, the 50-2ap treatment showed the lowest starch content in the tubers, and the lowest protein content occurred in the tubers of the control treatment (Figures 3d and 3f).

DISCUSSION

Plants with vigorous foliage growth use considerable amount of carbohydrates for foliage growth at the expense of tuberization (Mabvongwe *et al.*, 2016). Prohexadione-Ca is a PGR that inhibits the final stage of gibberellin biosynthesis, inhibiting the shoot growth of many plant species (Rademacher, 2000; Rademacher, 2015). In this study, for the cultivar Agata, which shows less foliage growth (Fernandes *et al.*, 2010a), it was observed that a single application of 50 g ha^{-1} prohexadione-Ca at 15 DAE lost its inhibitory effectiveness about haulm growth before the completion of 18 days of application. However, plants treated with more than one application of 50 or 100 g ha^{-1} prohexadione-Ca had smaller haulm length than those in the control during all evaluated periods. For the cultivar Mondial, which has the greatest foliage growth (Fernandes *et al.*, 2010a), the responses were different, and only plants in treatments with two or three

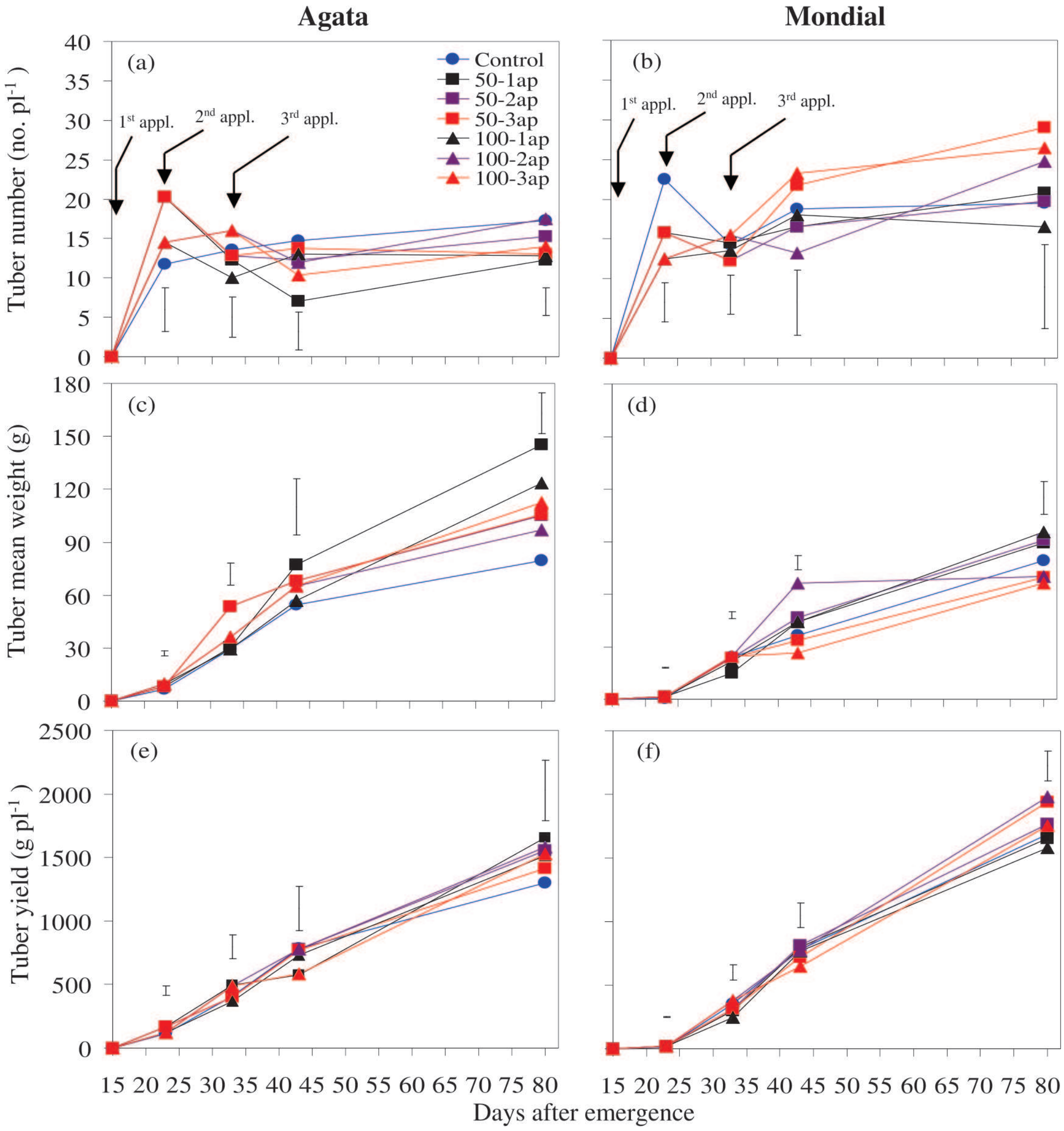

Figure 2: Number of tubers per plant (a,b), tuber mean weight (c,d), and tuber yield of two potato cultivars as affected by the prohexadione-Ca application. Vertical bars indicate the least significant difference at $p \leq 0.05$ by Tukey's test. Control: without prohexadione-Ca application, 50-1ap: 50 g ha^{-1} prohexadione-Ca applied at tuber initiation stage (15 DAE), 50-2ap: 50 g ha^{-1} prohexadione-Ca applied at 15 and 23 DAE, 50-3ap: 50 g ha^{-1} prohexadione-Ca applied at 15, 23, and 33 DAE, 100-1ap: 100 g ha^{-1} prohexadione-Ca applied at 15 DAE, 100-2ap: 100 g ha^{-1} prohexadione-Ca applied at 15 and 23 DAE, 100-3ap: 100 g ha^{-1} prohexadione-Ca applied at 15, 23, and 33 DAE.

applications of 100 g ha^{-1} prohexadione-Ca had smaller haulm length than that in control for a period of 20 days (between 23 and 43 DAE).

The effect of prohexadione-Ca on potato haulm length has been reported (Ellis *et al*., 2020). In this study, as observed in other studies (Greene & Schloemann, 2010; Ozbay & Ergun, 2015), the inhibitory effects of prohexadine-Ca were temporary, indicating that prohexadine-Ca has low toxicity and persistence in plants (Ilias & Rajapakse, 2005; Ozbay & Ergun, 2015), suggesting the need for a greater number of applications during the crop cycle. Based on our study, it was observed that the haulm length was short for a longer time, especially in the cultivar with vigorous foliage growth, therefore, it is necessary to make more than one application of 100 g ha^{-1} prohexadine-Ca during the period between 15 and 33 DAE.

The reduction in excessive vegetative potato growth is interesting because it reduces plant lodging and more upright plants may have a lower incidence of diseases caused by soil phytopathogens, such as blackleg (Rodrigues *et al.*, 2007; Soratto *et al.*, 2012). In addition, more compact plants favor air circulation within the crop canopy, and is interesting because in irrigated areas, all conditions that favor better air circulation and foliage drying can minimize late blight development (Demissie, 2019).

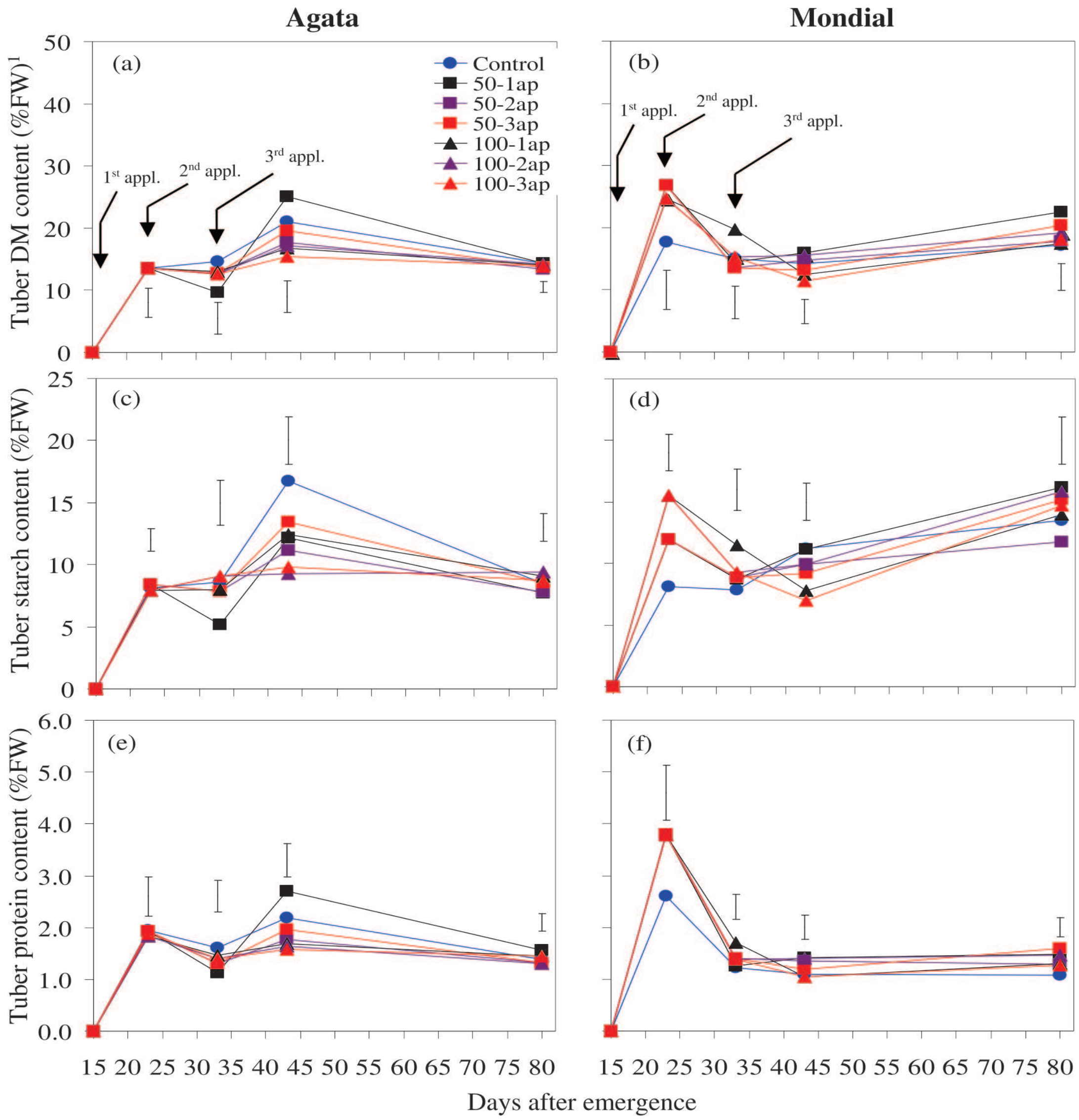

Figure 3: Contents of dry matter (DM) (a,b), starch (c,d) and protein (e,f) in the tubers of two potato cultivars as affected by the prohexadione-Ca application. Vertical bars indicate the least significant difference at $p \leq 0.05$ by Tukey's test. [1] percentage of fresh weight. Control: without prohexadione-Ca application, 50-1ap: 50 g ha^{-1} prohexadione-Ca applied at tuber initiation stage (15 DAE), 50-2ap: 50 g ha^{-1} prohexadione-Ca applied at 15 and 23 DAE, 50-3ap: 50 g ha^{-1} prohexadione-Ca applied at 15, 23, and 33 DAE, 100-1ap: 100 g ha^{-1} prohexadione-Ca applied at 15 DAE, 100-2ap: 100 g ha^{-1} prohexadione-Ca applied at 15 and 23 DAE, 100-3ap: 100 g ha^{-1} prohexadione-Ca applied at 15, 23, and 33 DAE.

In both cultivars, prohexadione-Ca application affected the haulm length of plants without significantly affecting the number of leaves, leaf area, and tuber yield. Although the leaf area of the cultivar Agata had a small value with one application of 50 g ha^{-1} or three applications of 100 g ha^{-1} prohexadione-Ca, there was an increase in the chlorophyll content of the leaves in these treatments (higher SPAD value). This was a satisfactory result because small leaf area can decrease photosynthesis (Ozbay & Ergun, 2015). However, the application of paclobutrazol in potato or prohexadione-Ca in other crops has had a positive effect on photosynthesis (Tekalign & Hammes, 2004; Reekie *et al.*, 2005) because, despite these PGRs affecting the leaf area, they increase the content of chlorophyll in the leaves (Tekalign & Hammes, 2004; Ozbay & Ergun, 2015), as observed in this study for the cultivar Agata.

Tuber yield was not reduced by prohexadione-Ca applications in both cultivars, and in the cultivar Mondial, three applications of 50 g ha^{-1} and two applications of 100 g ha^{-1} resulted in a greater tuber yield than in the control. Increases of 9 to 22% in tuber yield have already been achieved with the application of prohexadione-Ca after the beginning of the tuberization stage (Pavlista, 2013). However, in this study, prohexadione-Ca changed the pattern of tuber development differently between cultivars, possibly owing to the difference in the sensitivity of cultivars to different inhibitors of gibberellin biosynthesis (Pavlista, 2013).

In the cultivar Agata, only one application of 50 g ha^{-1} prohexadione-Ca in the tuber initiation stage (15 DAE) reduced the number of tubers per plant and increased the tuber mean weight without changing tuber yield. However, in the cultivar Mondial, the plants that received three applications of 50 or 100 g ha^{-1} prohexadione-Ca between the stages of tuber initiation (15 DAE) and tuber bulking (33 DAE) showed a greater number of smaller-size tubers. When prohexadione-Ca was applied after the tuberization stage, it did not increase the number of tubers per plant (Ellis *et al.*, 2020), but could increase the incidence of misshaped tubers (Pavlista, 2013), which was not visually observed in this study. Studies using paclobutrazol, ethephon, or chlormequat chloride before or at the beginning of tuberization stage also increased the number of tubers per plant (Rex, 1992; Ellis *et al.*, 2020), similar to what occurred in this study with prohexadione-Ca in the cultivar Mondial. Although prohexadione-Ca application has not negatively affected tuber yield, field studies need to be carried out under Brazilian conditions to verify if the use of prohexadione-Ca will not lead to a greater production of smaller tubers, as observed in studies with the use of paclobutrazol, ethephon, or chlormequat chloride (Rex, 1992; Ellis *et al.*, 2020).

The use of prohexadione-Ca did not change the tuber quality of the cultivar Agata in the final harvest. However, in the cultivar Mondial, one application of 50 g ha^{-1} prohexadione-Ca at the tuber initiation stage (15 DAE) increased the DM, starch, and protein content of the tubers compared to the control. The application of paclobutrazol has also been reported to provide an increase in the content of starch (Mabvongwe *et al.*, 2016) and protein (Tekalign & Hammes, 2004) of potato tubers. However, in this study, the benefit of prohexadione-Ca application on the quality of tubers was dependent on the cultivar.

CONCLUSION

In both cultivars, prohexadione-Ca application changed tuber-size distribution pattern. However, in the cultivar Agata, three applications of 100 g ha^{-1} prohexadione-Ca between the stages of tuber initiation and tuber bulking made the haulm length of the plants shorter for a longer time without affecting tuber yield and quality.

In the cultivar Mondial, the smallest haulm length occurred in the plants sprayed two or three times with 100 g ha^{-1} prohexadione-Ca between the stages of tuber initiation and tuber bulking; however, it was only in the plants sprayed three times with 50 g ha^{-1} or twice with 100 g ha^{-1} that there was an increase in tuber yield. Three times applications of 50 g ha^{-1} prohexadione-Ca also increased the DM, starch, and protein content of the tubers of the cultivar Mondial.

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