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Desiccation of potato haulm with contact herbicides and the final quality of tubers

Paulo da Silva[1]*, Silvia Blumer[2], João Pedro Zani Coeti[2], Gustavo Cesar Barbosa[2], Estela Maris Inacio[3], Patricia Andrea Monquero[4]

[1]Federal University of Grande Dourados, Dourados, Brazil
[2]University Center Octavio Bastos Educational Foundation, São João da Boa Vista, Brazil
[3]State University of Ponta Grossa, Ponta Grossa, Brazil
[4]Federal University of São Carlos, São Carlos, Brazil
*Corresponding author, e-mail: paulovsilva@ufgd.edu.br

Abstract

Desiccation of potato (*Solanum tuberosum* L.) haulms makes it possible to establish a physiological homogeneity of the haulms and anticipate the harvest of the tubers. This study aimed to evaluate the efficiency of different herbicides in the desiccation of potato haulms when applied at the maturation phenological stage (potato maturation stage 5), and the effect of these treatments on the quality of tubers. An experiment was conducted in the field, in an area planted with Orchestra potatoes. Experiments were conducted following a RCBD – randomized complete block design with four replication. At the maturation phenological stage, the following herbicides were sprayed onto the crop foliage: diquat dibromide (400 g ha^{-1}), paraquat dichloride (400 g ha^{-1}), saflufenacil (70 g ha^{-1}), and carfentrazone ethyl (60 g ha^{-1}). Visual phytotoxicity assessments were performed at 3, 5, 10 and 15 days after treatment application (DAT). At 15 DAT, tubers were harvested and evaluated for Brix (%), individual weight (g), diameter (cm), texture (kg/cm^2), and starch. All herbicides resulted in crop desiccation levels close to 100%. However, at 10 DAT, saflufenacil was the only treatment that resulted in less than 90% of potato haulms desiccation. Texture, brix and diameter showed no statistical difference. The control treatment and saflufenacil resulted in the lowest concentration of starch in the tubers, whereas the highest concentration was obtained for carfentrazone-ethyl, paraquat and diquat. Treatments containing carfentrazone-ethyl, diquat dibromide, and paraquat dichloride were thus the most suitable for desiccation of potato haulms, in relation to desiccation and greater accumulation of starch in the tubers.

Keywords: Physiological homogeneity, Harvest, *Solanum tuberosum* L.

Introduction

Potato desiccation is usually performed at the phenological stage of tuber maturation and is achieved via the application of contact herbicides. These promote phytotoxic effects in potato shoots very quickly and intensely, resulting in the destruction of haulms in a few days (Silva et al., 2011). This practice consists of removing moisture from the plant, leading to death for failing to perform its metabolic processes (Eifert et al., 2014).

The application of desiccant herbicides should be avoided during cold and humid or hot and dry days. If the application cannot be avoided in hot and dry weather conditions, the doses of desiccant have to be reduced (Kempenaar & Struik, 2007). However, in order to reach the expected qualitative effect in haulm desiccation, it should be carried out when potato plants are no longer transferring most of its nutritional reserves and/or sap to the tuber, thus guaranteeing maximum filling, weight gain and starch accumulation (Christoffoleti et al., 2016).

In terms of final product quality, desiccation makes it possible to control the size of the tubers, physiological uniformity, uniformity in crop maturation, color standardization and skin firmness, thus enabling mechanized harvesting (Kempenaar & Stuik, 2007).

The desiccation of the potato branches can be done to prolong the storage capacity of harvested tubers (Pereira & Dantas, 1995). In post-harvest, desiccation also reduces the chance of tuber weight loss during storage (Woodell et al., 2004). Desiccation reduces the incidence of pathogens and pests that can attack the crop at the end of its cycle, a fact that would reduce and/or make production unfeasible (Schweers et al., 2015; Kee & Mulrooney, 2004). Further, in the last phenological stage (potato maturation stage 5) to the detriment of the natural senescence of potato plants, soil coverage is below par as crop plants lose foliage, resulting in a

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higher light incidence between the rows of the crop and, consequently, an increased germination and infestation by weeds, representing an obstacle to mechanized harvesting (Christoffoleti et al., 2016).

After desiccation of potato haulms, a waiting interval before harvest is mandatory, which can vary from 10 to 15 days after herbicide application (Agrofit, 2020). This period is necessary for firming and adhering of the potato pellicle (skin), thus avoiding skinning during harvest and post-harvest, which consists of mechanical removal of the potato skin (Silva & Lopes, 2015). Among the possibilities of contact herbicides used for desiccation of potato haulms, we can mention four: diquat dibromide, paraquat dichloride, saflufenacil, and carfentrazone-ethyl (Agrofit, 2020).

Given the above, the objective of this study was to evaluate the efficiency of different herbicides for potato haulm desiccation when spraying at the maturation phenological stage, as well as the effect of these treatments onto the quality of harvested tubers.

Material and Methods

Trials were carried out in an experimental field located in the municipality of Vargem Grande do Sul, São Paulo state, intended for commercial potato production. The geographical coordinates of the area are latitude 21°56’21’’S and longitude 46°57’43’’W, at an average altitude of 721 meters. The climate of the region, according to Köppen, is classified as warm and temperate. The average annual rainfall is 1,413 mm, concentrated in summer months, and average classified temperature of the climate Cwa is 20.3 °C.

The experimental design was RCBD – randomized complete block design with four replication per treatment, with four evaluation periods and four treatments with herbicides and untreated control. Plots consisted of five rows grown three meters wide and seven meters long, resulting in 6.5 plants per experimental unit. The two end rows were disregarded from the evaluations, which were adopted as borders with 33 plants per useful plot. Seed-potatoes were planted with 80 cm spacing between rows and 40 cm between plants.

Planting was carried out on May 22, 2018 employing the Orchestra potato variety, type II seed potatoes (41 to 50 mm in diameter) with three months of storage in a cold chamber. Fertilization in the planting furrow was performed with 3 t ha^{-1} of the commercial formula 4-14-08. The cultivation was for commercial purposes, and all plots until desiccation received the same phytosanitary management and cultural treatments. The soil of the experimental area was a clay soil. The results of soil analysis in relation to macronutrients and micronutrients (Table 1).

Table 1. Soil chemical and micronutrient analysis results at 0-20 and 20-40 cm depth. Piracicaba, State of São Paulo.

Depth cm	OM	pH($CaCl_2$)	Al	H+Al	P (resin)	K	Ca	Mg	SB	CTC	V
0-20	11	5.6	1.0	17	56	2.5	22.0	8	32.5	49.5	66
20-40	6	6.0	1.0	11	15	1.5	26	10	37.5	48.5	77

Depth cm	Boron	Copper	Iron	Manganese	Zinc
0-20	0.13	1.0	24	1.7	1.9
20-40	0.10	0.3	11	1.2	0.7

Units: OM (organic matter) (g dm^{-3}); (Al, H+Al, K, Ca, Mg, SB and CEC (mmol$_c$ dm^{-3}); P (resin) (mg dm^{-3}); V (%). Units: Boron; copper; iron, manganese and zinc (mg dm^{-3}).

When the potato crop reached the maturation phenological stages, contact herbicides were applied for haulm desiccation. Four herbicide treatments were applied in post-emergence of the potato crop on 22/08/2018, in addition to an untreated control (no herbicide application). Treatments applied are presented in table 2.

Table 2. Description of the treatments used for potato haulm desiccation.

Treatments	Commercial name	Dose (a.i.)	Commercial rate
Untreated control	-		-
Diquat dibromide[1]	Reglone	400	2 L ha^{-1}
Paraquat dichloride[1]	Gramoxone	400	2 L ha^{-1}
Saflufenacil[2]	Heat	70	100 g ha^{-1}
Carfentrazone-ethyl[3]	Aurora	60	150 ml ha^{-1}

[1]No mineral oil added; [2]Addition of 1% v/v mineral oil; [3]Addition of 0.5% v/v mineral oil.

Herbicides were applied using a backpack sprayer at constant pressure, pressurized by CO_2, with fan tips XR 110.02, pressure of 2.0 kgf cm^{-2}, with a spray volume of 180 L ha^{-1}. After the application of herbicide treatments, visual evaluations were carried out at 3, 5, 10 and 15 days after the application of treatments (DAT). For this step the scale of phytotoxicity scores was used, proposed by the European Weed Research Council, which correlates the percentage of visual damage with the characterization of the phytotoxicity symptom, where 0% is related to the absence of damage and 80-100% total destruction of the plants (plant death) (EWRC, 1964).

At 15 days after herbicide application, potato tubers were harvested, and biometric evaluations were performed. The period at 15 days was adopted to obtain the skin set, thus avoiding its mechanical removal. The harvesting of the experimental units was carried out only on the three central rows of the plot, discarding two lateral rows of the plots and 0.5 m from the beginning and end of the plot.

Tubers were evaluated for (1) soluble solids (Brix); (2) average weight (g); (3) diameter (cm); (5) texture of the tuber with skin (kg/cm) and (6) starch content. The content of total soluble solids (Brix) was determined with the aid of a digital refractometer from the exudate of fresh samples, which were analyzed immediately after harvest. The average tuber weight (g) was obtained by dividing the total weight by the total number of tubers. The diameter of the tubers was determined in the central portion of the tubers with the aid of a caliper. Skin texture, on the other hand, was examined with a texturometer, so that the force used in the apparatus demonstrated the firmness of the tuber.

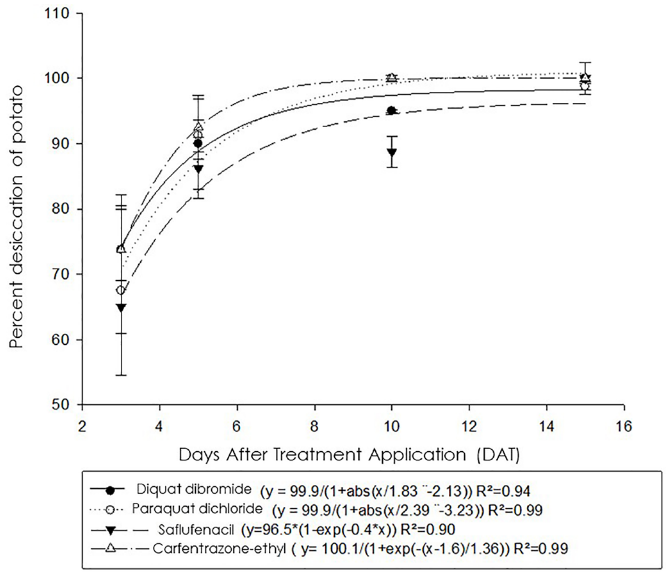
The starch content was evaluated using the lugol staining method, at a concentration of 1% (I_2) + 2% potassium iodide (KI), with dissolution of 5 g iodine, 3 g potassium iodide in 100 mL water, as described by Berlyn and Miksche (1976). Next, the five most homogeneous tubers from each experimental unit were cut in their median region, inside and 3 drops of the lugol solution were added and left to stand for one hour for the interaction of the reagent with the starch content in the tubers. At the end of this process, the development of a blue staining indicates the presence of this polysaccharide, the more intense this color is, the greater the concentration of starch in the tubers. After this, photos of the tubers were taken, which captured the indication of the starch concentration in relation to the color.

Tuber images were used for analysis of the starch concentration, through the dark tint promoted by the reagent; for that purpose, these images were analyzed by an image processing and analysis software, QUANT 1.0.1, developed by Vale et al. (2003). For this experiment, the software was adapted, as it is usually used to measure the degree of pathogen incidence, and in this experiment, it was used to quantify the percentage of the potato tuber colored with iodine to quantify the starch. Data obtained were analyzed by statistical analysis.

All data were subjected to analysis of variance by F test, with the means of treatments compared by Tukey's test, using the software AgroEstat (Barbosa & Maldonado Júnior, 2009). For percent desiccation of potato haulms by contact herbicides, when significant, they were analyzed with the use of non-linear regressions, with support of the SIGMAPLOT computational program.

Results

Results regarding the interaction between the herbicide treatments and the evaluation periods are presented in figure 1. The herbicide saflufenacil presents less desiccation of the potato haulms compared to the treatments diquat dibromide, paraquat dichloride and Carfentrazone-ethyl at 10 DAT. Saflufenacil was the only treatment that resulted in less than 90% of potato haulms desiccation. At 15 DAT all treatments resulted in desiccation percentages close to 100%. Moreover, all the treatments presented similar results.



Vertical bars represent 95% confidence intervals

Figure 1. Percent desiccation of potato haulms by contact herbicides.

Regarding the biometric variables, texture, diameter, Brix and average tuber weight, there was no statistical difference in the variables to the between detriment of the application of treatments (table 3). That is, the application of herbicides did not result in qualitative losses in the post-harvest of potato.

In relation to the starch concentration, through the diameter analysis illustrated in Figure 2, it is possible to observe that there was a visual difference in color in relation to the starch concentration as a function of the contact herbicide used for desiccation.

Table 3. Biometric variables of potato tubers after haulm desiccation with contact herbicides.

Treatments	Texture (kg/cm²)	Diameter (cm)	Brix (%)	Tuber weight (g)
Control	6.05a	68.55 a	3.54 a	0.250 a
Diquat dibromide	6.63 a	68.2 a	3.40 a	0.243 a
Paraquat dichloride	5.37 a	68.12 a	3.69 a	0.245 a
Saflufenacil	6.35 a	68.47 a	3.63 a	0.245 a
Carfentrazone-ethyl	5.88 a	66.07 a	3.43a	0.253 a
LSD (5%)	1.84	6.05	0.64	0.78
F	1.28 ns	0.46 ns	0.70 ns	0.05 ns
C.V.(%)	13.97	4.48	8.4	14.58

ns = Non-significant; C.V - Coefficient of variation; LSD – Least significant difference at 5%. Means followed by similar lowercase letters are not significantly different by Tukey's test at 5% significance.

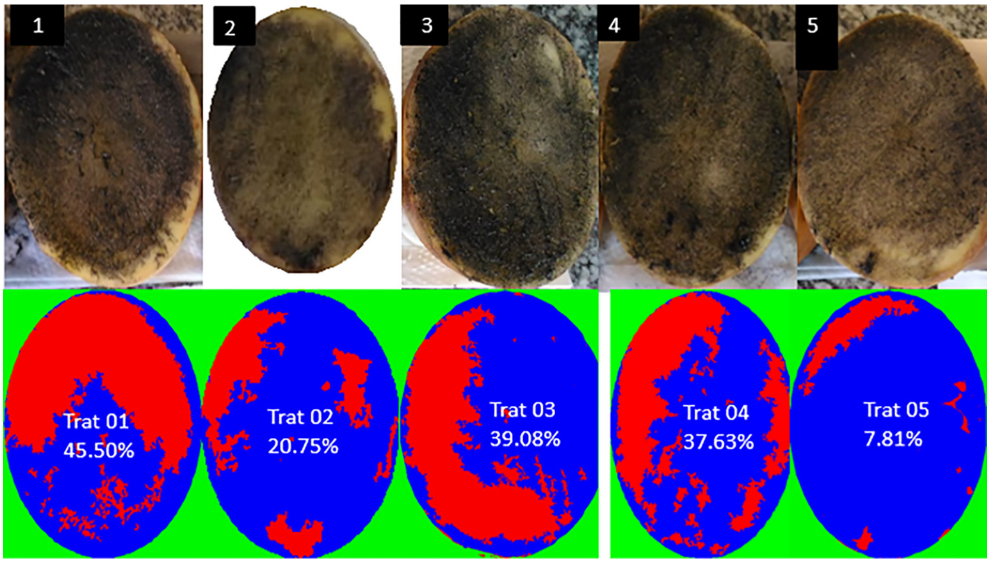


Figure 2. Herbicides: (1) paraquat; (2) saflufenacil; (3) carfentrazone; (4) diquat and (5) Untreated control.

Legend: The red color represents the highest concentration of starch in the tubers whereas the blue color represents the lowest and / or absence of starch concentration in the tubers.

It is possible to observe in table 4 that the percentage of starch concentration was lower in the treatments of saflufenacil and control, with 18.59 and 16.67% respectively. The application of diquat dibromide, paraquat dichloride and carfentrazone-ethyl resulted in the highest concentrations of starch in the tubers, with 41.44; 40.68 and 39.31% respectively.

Table 4. Mean starch concentration in potato tubers after treatment analysis.

Treatment	% Starch
Untreated control	16.67 b
Saflufenacil	18.59 b
Carfentrazone-ethyl	39.31 a
Paraquat dichloride	40.68 a
Diquat dibromide	41.44 a
LSD (5%)	20.05
F**	4.47
C.V(%)	29.30

** Significant at 5% probability level by F-test; ns = Non-significant; C.V- Coefficient of variation; LSD – Least significant difference at 5%. Means followed by different lowercase letters are significantly different by Tukey's test at 5% significance.

Discussion

At 10 DAT, the herbicides carfentrazone-ethyl, Diquat dibromide and Paraquat dichloride showed a potato haulms desiccation percentage higher than 95%. Specifically, about carfentrazone-ethyl, this was expected since the mechanisms of action of this contact herbicide include the inhibition of the PROTOX enzyme (Rodrigues & Almeida, 2018). Thus, its application results in the inhibition of protoporphyrinogen oxidase (Protox), causing the accumulation of protoporphyrin IX (Proto IX) causing the formation of singlet oxygen, in a light-dependent process, resulting in membrane peroxidation. Leaf lesions after the application of ethyl carfentrazone occur very rapidly (Dayan et al., 1997).

Kardasz et al. (2019) at 7 days after the application of the treatments, a percentage of haulm destruction close to 90%, through the combination of the mechanical method followed by the application of carfentrazone-ethyl at a dose of 60 g.a.i. ha^{-1}, with no significant reduction in yield and quality of harvested potato tubers. Behavior similar to that observed in this experiment, where desiccation with carfentrazone-ethyl promoted effective potato haulms desiccation, reducing their leaf area and disturbing the translocation of sap to the tubers, without, however, affecting aspects of productivity and quality of harvested tubers.

However, although saflufenacil also has the PROTOX enzyme inhibition as a mechanism of action, it did not have the same effect as carfentrazone-ethyl and saflufenacil at 10 DAT. At this time, saflufenacil presents 88.75% of potato haulms desiccation percentage and carfentrazone a percentage of 95%. It means, even with the same mechanism of action, in this experiment, the efficiency of both herbicides were not equivalent.

Unlike other PPO-inhibiting herbicides, saflufenacil has physical and chemical properties that allow for little mobility via phloem (Ashigh & Hall, 2010; Dalazen et al., 2015). Saflufenacil has a pKa of 4.41 and a log Kow of 2.6, which gives it a certain translocation via phloem, which can be explained by its weak acid character (Grossmann et al., 2011). These characteristics place it in the bordering region of mobility via phloem/xylem and mobility only in xylem (Bromilow et al., 1990).

In turn, the starch content showed a significant difference among treatments. For the control and saflufenacil. The application of saflufenacil did not promote the immediate disruption of tuber growth, due to the continuous translocation of sap, until the total death of potato haulms. This prevalent behavior did not end the process of establishing the tubers and concentrating the starch content, justifying the similar results between saflufenacil and the control (which did not present a disruption in translocation, with the death of the haulms caused by natural senescence).

Paraquat dichloride and diquat dibromide, showed an efficient and rapid desiccation of potato haulms, with similar results, since both act on photosystem I and show rapid effect after application. These herbicides are not selective, with contact action, from the group of bipyridyls (Rodrigues & Almeida, 2018). They are quickly absorbed by the leaves, and are not normally removed by rain or irrigation after 30 minutes of application; they are not absorbed by the roots, because they are adsorbed on clays when in contact with the soil (strong cations). Under normal conditions they are little translocated inside the plant (Klingman & Ashton, 1975).

These results indicate that diquat dibromide may be a potential substitute for paraquat dichloride after its total ban from the Brazilian market scheduled to take place on September 22, 2020 (Anvisal, 2017a).

After application of paraquat dichloride and diquat dibromide, in long periods without light and associated with water deficit, after application, some local systemic action of this herbicide can be observed, with little translocation via xylem (Souza & Bonin, 1988). Thus, according to Souza (1990), the application of diquat dibromide and paraquat dichloride should be avoided during dry periods.

This situation can culminate in rapid desiccation of potato haulms, by the action of paraquat dichloride and diquat dibromide, without however interrupting the translocation of sap to the tubers, which can result in herbicide residues in the tubers, degradation of the final quality of the product and problems in the firmament of the potato skin (Pereira & Dantas, 1995). Thus, these herbicides should preferably be applied in the morning, aiming at their immediate activation, thus reducing the possibilities of translocation.

The application of paraquat dichloride requires attention, as according to the norms established by the Ministries of Health and Agriculture, Supply and Agrarian Reform, the use of paraquat requires a withdrawal period of 7 days after its application, with maximum residue tolerance of 0.2 ppm (Anvisal, 2017b). Therefore, because it is a highly toxic product (toxicological class I), its use in cultivation of potato for consumption requires care to avoid possible contamination of the tubers with residues of this herbicide.

Ferebee IV et al. (2019) studied the desiccation of potato haulms and tested the following treatments: (1) paraquat dichloride; (2) ammonium glufosinate (3) saflufenacil; (4) glufosinate + carfentrazone-ethyl and (5) ammonium glufosinate + saflufenacil, and reported phytotoxicity percentages of 80, 37, 62, 63 and 72% respectively. Their results indicate greater efficiency of paraquat dichloride for desiccation of haulms. At 14 DAT, the desiccants resulted in no significant effects on the desiccation of haulms, showing that after that period, the herbicides do not differ from each other, similarly to this experiment.

Although, at 10 DAT saflufenacil had less than 90% of desiccation rate, at 14 DAT the percentage was 100%, considered excellent. It considers that 14 days are necessary for the firmament of potato skin.

Data related to biometric variables, texture, diameter, Brix and average tuber weight did not show significant differences between treatments. These results can be justified by the application of herbicides at stage number 5 (maturation of potato haulms), where the plants had already gone through two stages inherent in the formation of tubers, number 3 related to tuberization and number 4 related to the growth of tubers; so the tubers were already formed, and application of treatments did not affect their growth and development.

Ferebee IV et al. (2019) also observed no significant difference in relation to biometric variables related to tuber size and total yield in which situation and Gonnella et al. (2009) found that environmental conditions have a much stronger impact on potato yield than desiccants, that is, climatic variables such as solar incidence radiation and/or time interval between the application of treatments and the occurrence of rainfall.

Conclusions

The treatments using carfentrazone-ethyl, paraquat dichloride and diquat dibromide resulted in excellent potato haulms desiccation at 10 DAT and promoted high concentration of starch in potato tubers. The herbicide saflufenacil presents excellent potato haulms desiccation at 15 DAT, however with low starch concentration. None of the desiccant treatments result in loss of productivity of potato tubers.

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