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Differential response of potato cultivars intended for the processing industry

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Abstract

The choice of a cultivar has been the main limitation for the potato processing industry, with low availability of genotypes with adequate shape and size for slicing, absence of non-enzymatic browning after frying, and good storage potential, which is evaluated mainly by the incidence of sprouts. Therefore, the objective of this study was to evaluate the potential of 10 cultivars in the pre-fried potato processing industry over a period of up to 180 days of storage at 8°C. Analyses of accumulated mass loss (AML), sprouting, alcohol insoluble solids (AIS), total soluble sugars (TSS), non-reducing sugars (NRS), reducing sugars (RS), and visual staining and colorimetry (L* and b*) were performed after frying. The cultivar Basin Russet presents lower values for AML. The cvs. Innovator and Umatilla Russet were the cultivars that showed later sprouting, and at 180 days, Umatilla Russet had smaller shoots. The AIS levels did not correlate with sprouting and sugar content. The TSS and NRS varied among the cultivars, and the RS contents were in the range of 0.005–0.206%, with Ranger Russet, Russet Burbank, Umatilla Russet, and Yona showing values above 0.12%, which was considered high when compared to the other cultivars. All cultivars were visually classified in category 2 or 3 for the USDA fry color chart. However, through the L* variable, the cultivars Alverstone Russet and Basin Russet presented sticks with a lighter color and the "Challenger" with a more yellowish hue. L* values above 64.1 and b* values above 50.3 are indicated for the evaluated cultivars. It is concluded that among the evaluated cultivars, the best variables for the pre-fried potato processing industry were obtained in the Innovator, Alverstone Russet, and Basin Russet cultivars.

Keywords: reducing sugars; sprouting; Maillard reaction; colorimeter.

Practical Application: Considering the importance of innovating in the potato processing industry, this study sought to evaluate some cultivars that were not worked in Brazil, knowing that the potato processing industry has a low availability of suitable genotypes for the industry. The potential use of different cultivars with good parameters of quality, color, and reduced sprouting was evaluated. Being suitable for industrial use, it can be stored up to 180 days at 8°C. A long period of storage time would allow a constant supply of the product to the industry.

1. Introduction

Pre-fried potato processing industries have been growing at around 4.58% per year (Wise Guy Reports, 2017), with 40–50% of potato production in the US and 75% of potato production in the Netherlands destined for industrialization (NASS / USDA, 2013). In Brazil, the main limitations to the growth of processing industries are the low availability of cultivars with the right shape and size for slicing, the absence of non-enzymatic browning after frying, and good storage potential, which is mainly evaluated by the incidence of sprouts (Araújo *et al.*, 2016).

Non-enzymatic browning is one of the main quality parameters evaluated by the industry and occurs due to the Maillard reaction, in which reducing sugars react with asparagine, forming melanoidins, dark-colored pigments that depreciate the product during frying (Francisquini *et al.*, 2017). In addition, in the Maillard reaction, a by-product called acrylamide is formed, which is considered a carcinogenic substance (Bethke & Bussan, 2013).

The formation of melanoidins and acrylamide is directly related to the increase in the concentration of sugars in the tubers (Bethke & Bussan, 2013), with a large variation in the amount of sugars between potato genotypes (Halford *et al.*, 2012).

In addition, refrigerated storage at temperatures below 8°C, carried out by industries before processing, promotes changes in the carbohydrate metabolism of tubers, and some genotypes increase the concentration of sugars (Duarte-Delgado *et al.*,

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2016), which is undesirable, making all cultivars not suitable for processing.

Therefore, the objective of this study was to evaluate the potential of 10 cultivars in the pre-fried potato processing industry over a period of up to 180 days of storage at 8°C.

2. Materials and Methods

The tubers of the cultivars Innovator, Challenger, Ivory Russet, Cronos, Ranger Russet, Russet Burbank, Umatilla Russet, Yona, Alverstone Russet, and Basin Russet were obtained from the commercial production area of Perdizes, Minas Gerais, Brazil, at a latitude of 19°35'36"S, a longitude of 46°56'27"W, and an altitude of 997 m in a period with an average of 20–25°C and an annual precipitation of 1626 mm. The cultural practices relevant to the crop, such as hilling and phytosanitary treatments, were performed in accordance with the needs of the culture and schedule of the farm. The tubers were harvested 120 days after planting, cured for 4 days at 25°C, and transported to the Postharvest Physiology Laboratory at the Universidade Federal de Viçosa (UFV), followed by storage in an agricultural plastic box covered with a damp cloth at 8°C and a relative humidity (RH) of 90±2%.

Monthly analyses of accumulated mass loss (AML), sprouting, alcohol insoluble solids (AIS), total soluble sugars (TSS), reducing sugars (RS), non-reducing sugars (NRS), and visual staining and colorimetry (L* and b*) were performed after frying for 180 days.

The AML was determined by monthly weighing of 10 tubers and expressed as a percentage in relation to the initial weight. The beginning of sprouting and the size of the shoots were visually determined every 30 days.

For the extraction of TSS and RA, 5 g of fresh mass from 5 tubers as standardized as possible (size and shape) was taken, to which 5 mL of boiling 80% ethanol was added. The mixture was ground and centrifuged three times at 1,500 g for 10 min. At each centrifugation, the samples were filtered, and the combined final volume of the filtrations was standardized and used for the quantification of TSS and AR (Dubois *et al*., 1956).

The TSS were quantified by the phenol-sulfuric method (Dubois *et al*., 1956), using 1% sucrose to create the standard curve. The reaction was composed of 250 µL of the extract, 250 µL of 5% phenol, and 1.25 mL of sulfuric acid. Subsequently, the reaction was placed in a thermostatic bath for 20 min at 30°C. The reading was performed in a spectrophotometer (Genesys-10UV, Sacannig) at 490 nm and expressed as a percentage.

The RS were determined using the dinitrosalicylic acid (DNS) methodology described by Gonçalves *et al*. (2010) with adaptations. Of note, 0.2% fructose was used to compose the curve. The reaction was composed of 500 µL of DNS, 500 µL of sample, and 4 mL of distilled water. Readings were performed in a spectrophotometer (Genesys-10UV, Sacannig) at 540 nm and expressed in percentage.

The NRS was calculated by the difference between the TSS and RS and expressed as a percentage.

To evaluate the post-frying color, the tubers were cut into sticks with a manual cutter and fried in a 3 L electric fryer (Model: Ford®) at 180°C for 4 min, following the recommendations of the industries and in agreement with previous studies in which they determined a reduction in acrylamide accumulation at this temperature and time interval (Pelucchi *et al*., 2011).

The AIS was determined after TSS extraction, and the resulting pellet was dried at 65°C in a continuous flow oven for 72 h. The material was weighed for AIS determination, and the results were expressed in percentage. The AIS was determined by the methodology described by La Bonte *et al*. (2000).

The color of post-frying potatoes was determined visually based on the potato processing industry in categories ranging from 1 (lightest color) to 5 (darkest color), based on the scale of notes recommended by the *United States Standards for Grades of Frozen French Fried Potatoes* (USDA, 1967). A Color Reader CR-10 Minolta colorimeter was also used, with the parameter L* determining the darkening of the sticks (values closer to 100, indicating darkening) and the b* component determining the yellow color of the sticks (values greater than 100, indicating more intense yellow) (Minolta Corporation Instrument Systems Division, 1994).

The experiment was performed in a completely randomized design with five replications, each consisting of two tubers in a split-plot arrangement, the plot being the cultivars (Innovator, Challenger, Ivory Russet, Cronos, Ranger Russet, Russet Burbank, Umatilla Russet, Yona, Alverstone Russet, and Basin Russet) and the subplot the storage times (0, 30, 60, 90, 120, 150, and 180 days).

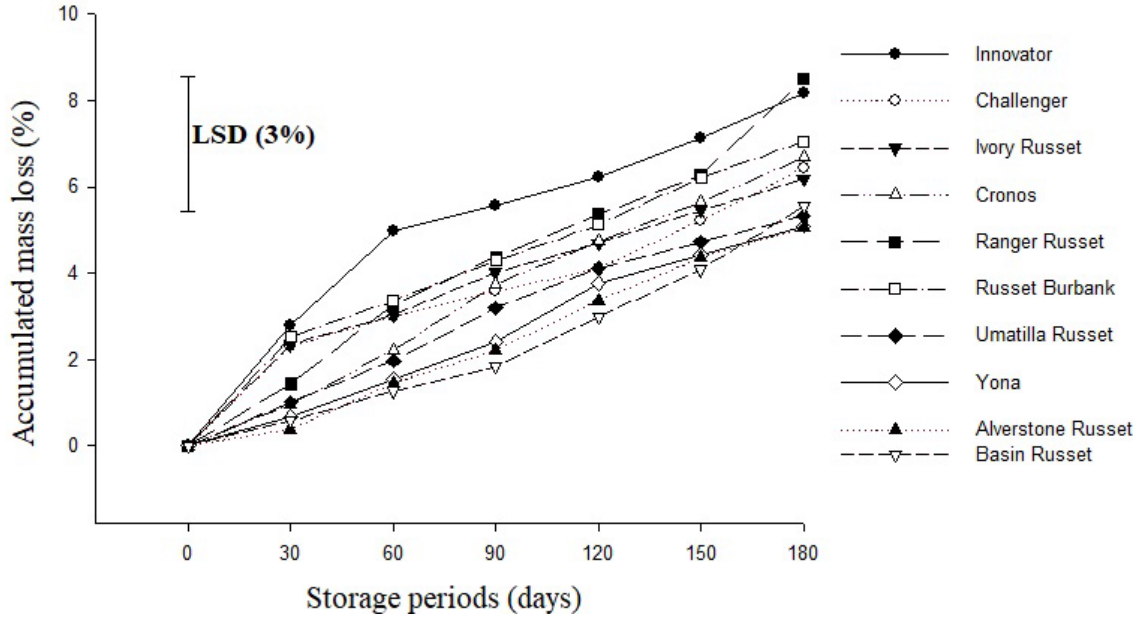
Data were subjected to analysis of variance using the F test ($p \leq 0.05$), and the TSS significant difference (LSD) was determined by Tukey's test at 5% using the R software version 3.4.3 (R Development Core Team, 2017).

3. Results and Discussion

AML of Yona (1.5–2.4%), Alverstone Russet (1.4–2.2%), and Basin Russet (1.2–1.8%) cultivars was lower than that of Innovator (4.9–5.5%) at 60 and 90 days of storage (Figure 1). At 120 days, Basin Russet (2.9%) maintained a lower AML than that of Innovator (6.2%), indicating that the Basin Russet cultivar showed the best conservation in terms of AML during storage (Figure 1). The other evaluated cultivars showed similar AML.

AML occurs as a result of carbohydrates being consumed throughout storage by the respiratory process and water loss through transpiration (Lima, 2018). The storage chamber at 8°C with a relative humidity of 90±2% provided a considerable AML in all cultivars, which ranged from 5 to 8.4% at 180 days (Figure 1); these results corroborate those of Pereira (2019), who at 150 days observed an AML of 8.1% analyzing the cultivar Innovator.

The Innovator and Umatilla Russet cultivars visually started sprouting at 120 days of storage, while Russet Burbank, Yona, Ranger Russet, and Ivory Russet sprouting started sprouting at 90 days, and for the other cultivars, after 60 days of storage, shoots (sprouts of the tuber) were already visible (Figure 2).



LSD: least significant difference by Tukey's test ($p \leq 0.05$).

Figure 1. Weight loss (WL) (%) of tubers of Innovator, Challenger, Ivory Russet, Cronos, Ranger Russet, Russet Burbank, Umatilla Russet, Yona, Alverstone Russet, and Basin Russet stored at 8°C for 180 days.

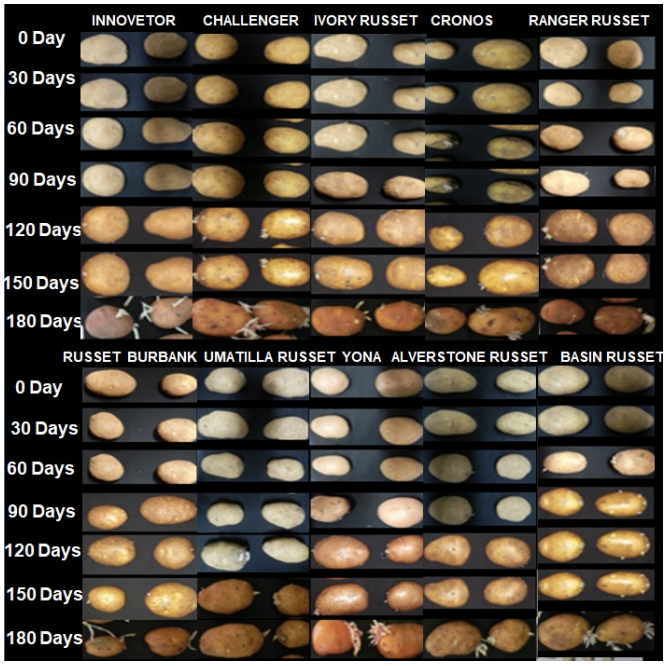


Figure 2. Sprouting of potato tubers of Innovator, Challenger, Ivory Russet, Cronos, Ranger Russet, Russet Burbank, Umatilla Russet, Yona, Alverstone Russet, and Basin Russet stored at 8°C for 180 days.

At 180 days, the cultivars Alverstone Russet, Cronos, Umatilla Russet, and Ivory Russet visually presented shoots with lower incidence compared to the other cultivars (Figure 2).

The content of insoluble solids in alcohol (AIS) was lower in the Cronos cultivar, differing from Umatilla Russet and Basin Russet at 120, 150, and 180 days (Figure 3). The AIS in potato tubers represents the starch content and concentrations of cellulose, hemicellulose, and other compounds (Miao *et al.*, 2014), and its reduction may be related to sprouting due to the cleavage of starch for the production of sucrose due to the higher energy requirement for shoot (sprout of the tuber) growth (Zhang *et al.*, 2013); however, it was not verified in the present study (Figures 2 and 3).

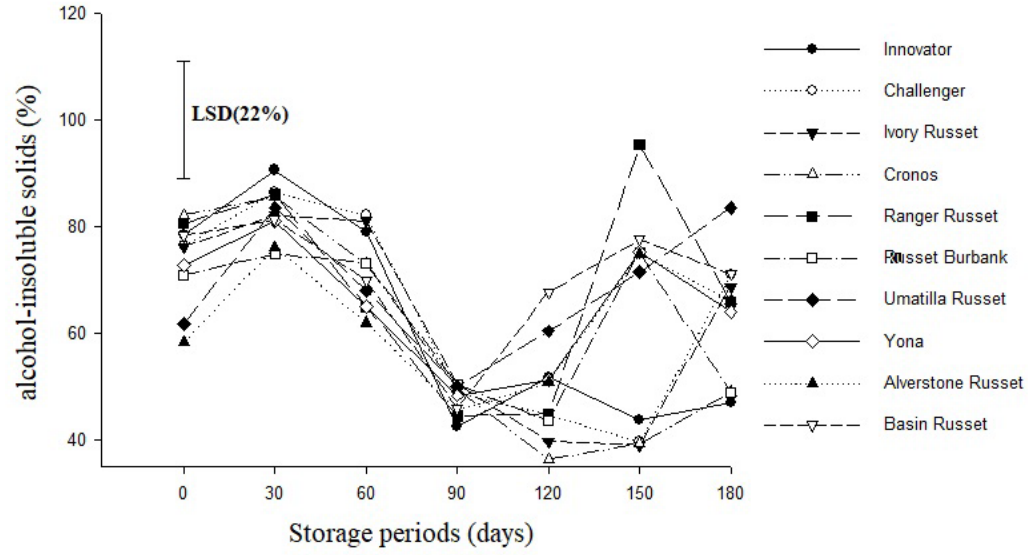
The AIS reduced over the period from 60 to 90 days for all cultivars, and soon after there was an increase in some cultivars, with a greater decline in the period from 90 to 120 days, which was not related to sprouting or the levels of sugars (Figures 2–6).

There was a higher TSS content in the Russet Burbank cultivar (0.67%) than in the Innovator (0.11%) at 30 days (Figure 4). Basin Russet (0.69–0.99%) showed a higher TSS compared to Alverstone Russet (0.05%) at 120 days and Innovator (0.31%) and Ivory Russet (0.30%) at 150 days (Figure 4).

While at 180 days, the highest concentrations of TSS were obtained in the tubers of the cultivars Ivory Russet (0.99%), Russet Burbank (0.95%), Umatilla Russet (0.72%), and Alverstone Russet (0.69%) compared to Innovator (0.22%), Challenger (0.30%), Yona (0.19%), and Basin Russet (0.12%) (Figure 4).

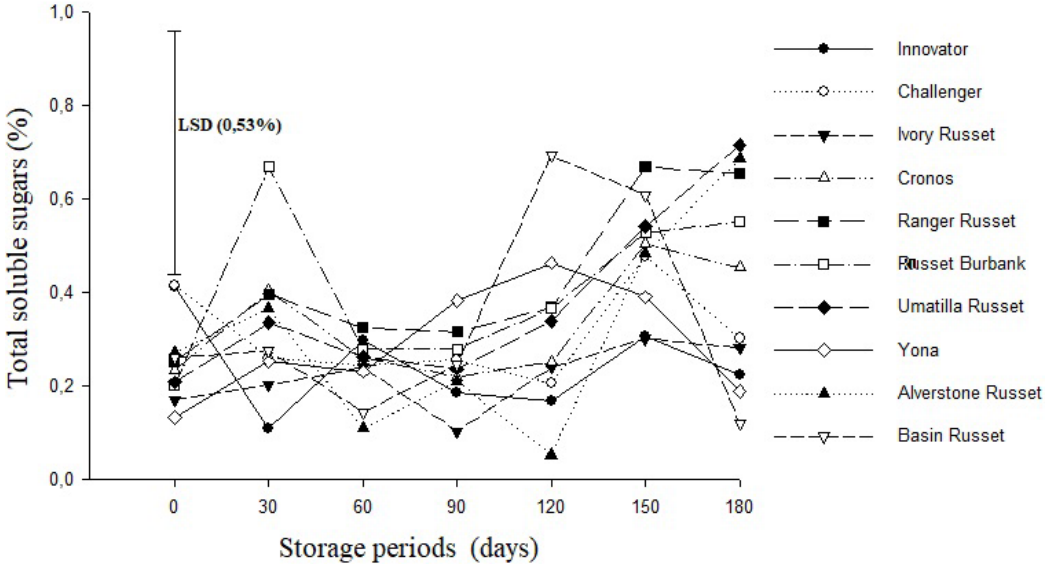
These differences between cultivars may be due to lower starch hydrolysis and greater synthesis or accumulation of sucrose from UDP-glucose and fructose-6-phosphate, associated with greater synthesis of the enzyme sucrose-phosphate synthase (Stein & Granot, 2019).

NRS were higher in Ivory Russet (0.93%), Russet Burbank (0.85%), Yona (0.94%), and Basin Russet (0.84%) cultivars,



DMS: minimum significant difference by Tukey's test (p≤0.05).

Figure 3. Alcohol-insoluble solids (AIS) (%) of potato tubers of the Innovator, Challenger, Ivory Russet, Cronos, Ranger Russet, Russet Burbank, Umatilla Russet, Yona, Alverstone Russet, and Basin Russet cultivars stored at 8°C for 180 days.



MSD: minimum significant difference by Tukey's test (p≤0.05).

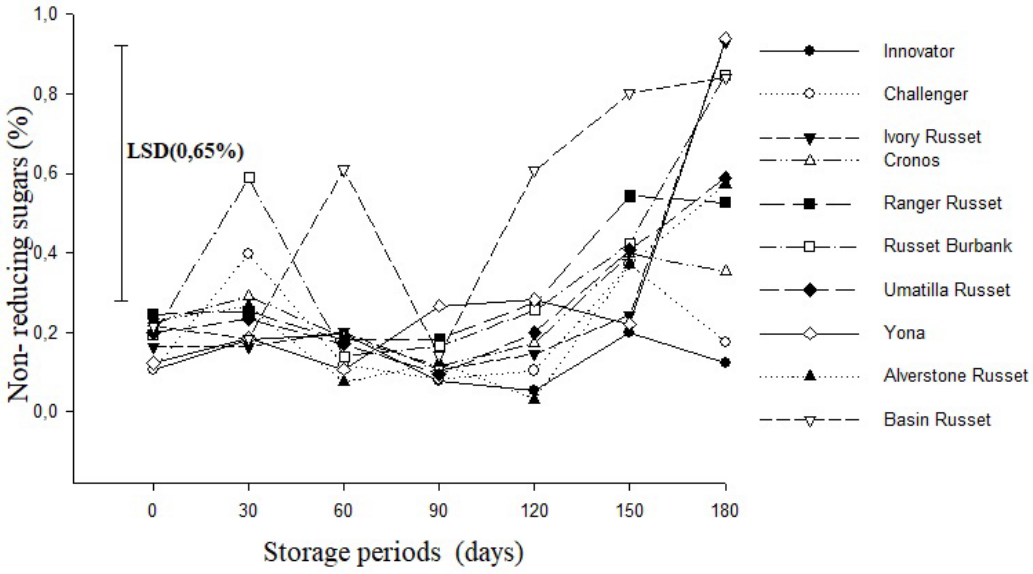
Figure 4. Total soluble sugars (TSS) (%) of potato tubers of Innovator, Challenger, Ivory Russet, Cronos, Ranger Russet, Russet Burbank, Umatilla Russet, Yona, Alverstone Russet, and Basin Russet stored at 8°C for 180 days.

differing from Innovator (0.12%) and Challenger (0.18%) after 180 days of storage at 8°C (Figure 5).

The TSS and NRS varied between cultivars as a function of the adaptation of carbohydrate metabolism to the refrigerated condition at 8°C. Each cultivar altered its metabolism in one way (Wiberley-Bradford *et al.*, 2016), demonstrating the importance of sugar analyses for understanding the genotypes that acclimatize better at low temperatures.

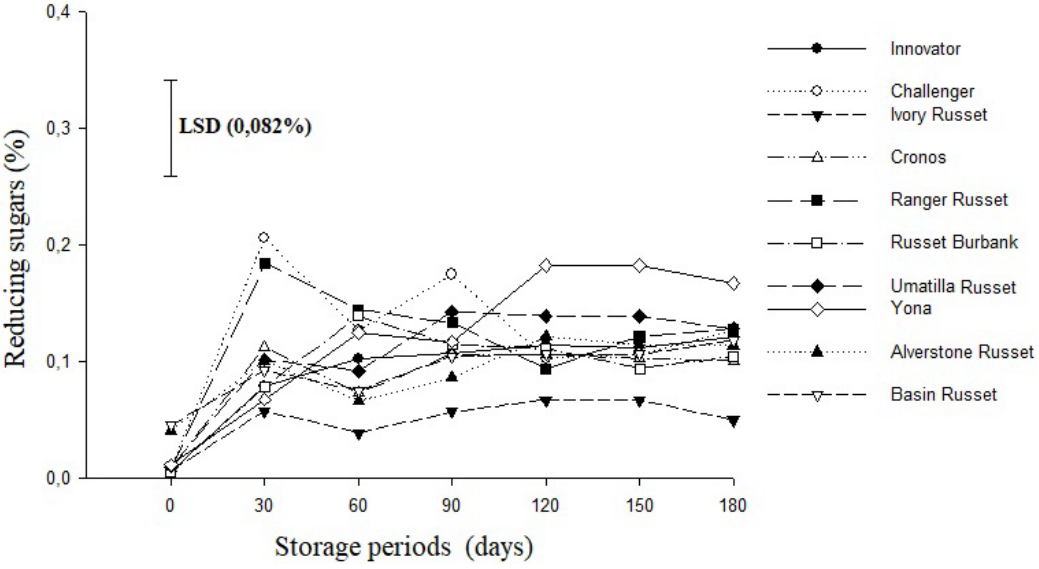
The Challenger (0.21%) and Ranger Russet (0.18%) cultivars showed higher RS contents than the other cultivars at 30 days of storage (Figure 6), being classified in categories 2 and 3 in terms of darkening, respectively (Figure 7).

At 60 and 90 days, the Challenger cultivar maintained a higher RS content, an average of 0.17% compared to Ivory Russet with 0.05% (Figure 6), with both cultivars classified as a 3 in relation to browning (Figure 8). While at 120, 150, and 180 days, the Yona cultivar showed an average RS content of



DMS: minimum significant difference by Tukey's test ($p \leq 0.05$).

Figure 5. Non-reducing sugars (NRS) (%) of potato tubers of Innovator, Challenger, Ivory Russet, Cronos, Ranger Russet, Russet Burbank, Umatilla Russet, Yona, Alverstone Russet, and Basin Russet stored at 8°C for 180 days.



MSD: minimum significant difference by Tukey's test ($p \leq 0.05$).

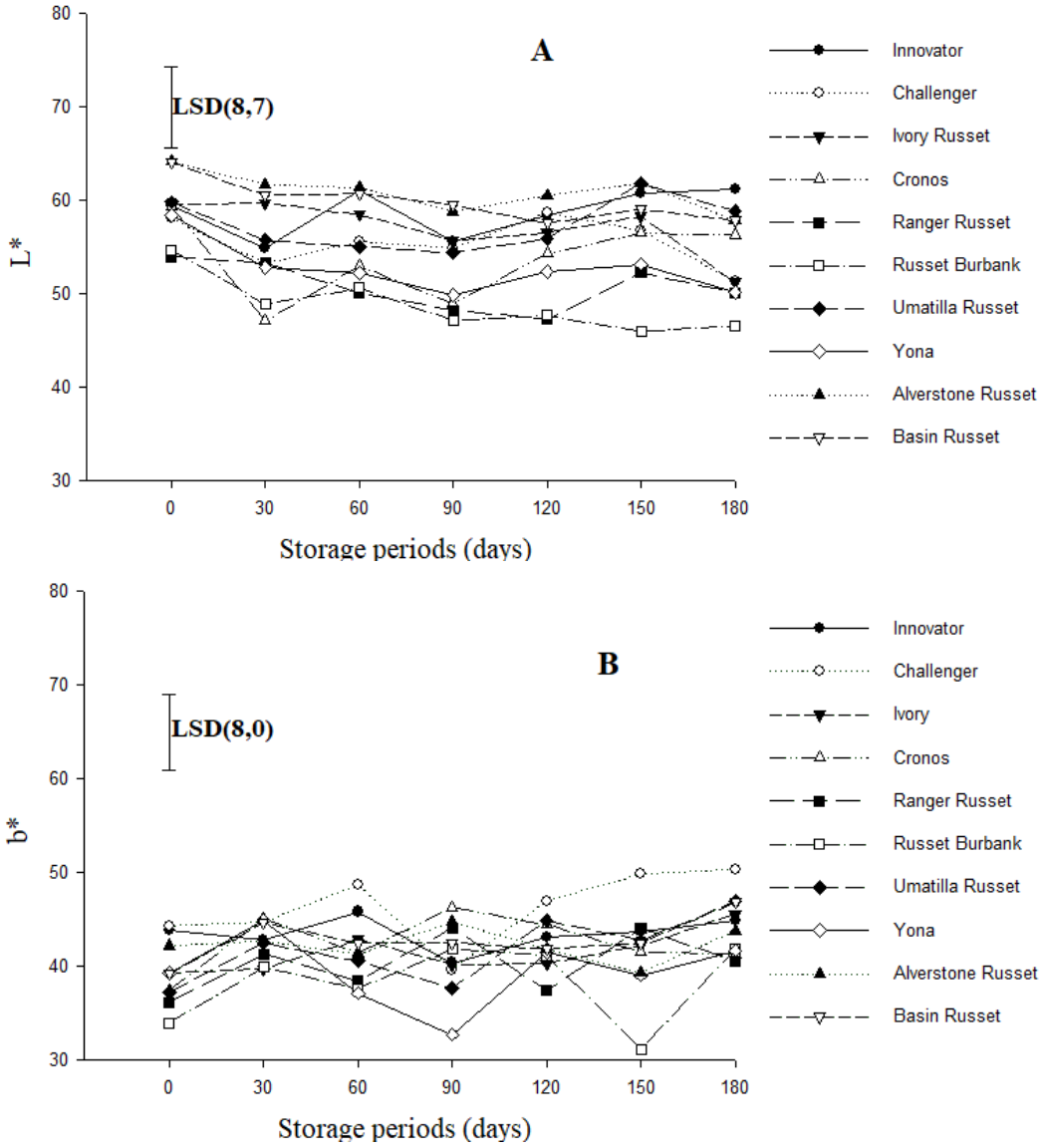
Figure 6. Reducing sugars (RS) (%) of potato tubers of Innovator, Challenger, Ivory Russet, Cronos, Ranger Russet, Russet Burbank, Umatilla Russet, Yona, Alverstone Russet, and Basin Russet stored at 8°C for 180 days.

0.18% (category 3) and showed a higher concentration, differing from Ivory Russet with 0.05% (category 3).

The RS contents of the evaluated cultivars were in the range of 0.005–0.206%, with Ranger Russet, Russet Burbank, Umatilla Russet and Yona presenting values above 0.12% from 30 to 180 days (Figure 6), which is indicated as the maximum value for the potato chip processing industry (Stark *et al.*, 2003). These cultivars were classified in category 3 during almost the entire storage period (Figure 8).

The Ivory Russet cultivar stood out with the lowest RS values, 0.006–0.07% from 30 to 180 days, respectively; however, the lowest RS content was not reflected in the color of the toothpicks, which were also categorized as grade 3 after 60 days of storage (Figure 8).

The cultivars Alverstone Russet (64.16) and Basin Russet (64.12) showed mean values of L* higher than Ranger Russet (47.26), Russet Burbank (47.16), and Yona (49.9) on most of the evaluated days (Figure 7A), indicating greater browning



DMS: minimum significant difference by Tukey's test ($p \leq 0.05$).

Figure 7. Parameter (A) L* and (B) b* of potato sticks after frying at 180°C for 4 min of the cultivars Innovator, Challenger, Ivory Russet, Cronos, Ranger Russet, Russet Burbank, Umatilla Russet, Yona, Alverstone Russet, and Basin Russet stored at 8°C for 180 days.

of the toothpicks, which was not visually detected, since all cultivars were categorized as darkening grade 3 during almost all storage (Figure 8).

The Challenger cultivar showed a b* of 48.7, 49.8, and 50.3 at 60, 150, and 180 days, respectively, being higher than the b* values of Ranger Russet (38.4), Russet Burbank (37.6), Umatilla Russet (40.5), and Yona (37.1) at 60 days, and then the cultivars Cronos (41.5 and 41.3), Russet Burbank (31.2 and 41.8), and Yona (39.1 and 41.7) at 150 and 180 days (Figure 7B); therefore, Challenger was the cultivar that presented the most yellowish color sticks, an indication of quality for the industry.

For the market, color is fundamental to quality analysis. Consumers are increasingly demanding sticks that are light golden in color, with no dark spots or lines, as a parameter. Visual analysis, despite being predominant in industries, has low accuracy due to being subjective. In this study, when evaluating the visual color, all cultivars were categorized as grades 2 and 3, which are accepted by the pre-fried potato processing industry, with emphasis on the Innovator cultivar, which remained for 180 days in grade 2 (Figure 8).

However, through the L* parameter, the cultivars Alverstone Russet and Basin Russet presented sticks with a lighter color and Challenger with a more yellowish hue (Figure 7).

In a study with the Asterix, Corsica, Edison, Lionheart, and Markies cultivars, the sticks showed adequate color with L* above 45 and b* greater than 40 (Pereira *et al.*, 2020a). In the genotypes Alibaba, Arsenal, Antartica, and Babylon, values of L* above 49.32 and b* greater than 48.3 were considered adequate (Pereira *et al.*, 2020b), while in the cultivars Donato and BRS F 132, L* was above 55.8 and b* was greater than 44.5 (Pereira *et al.*, 2022).

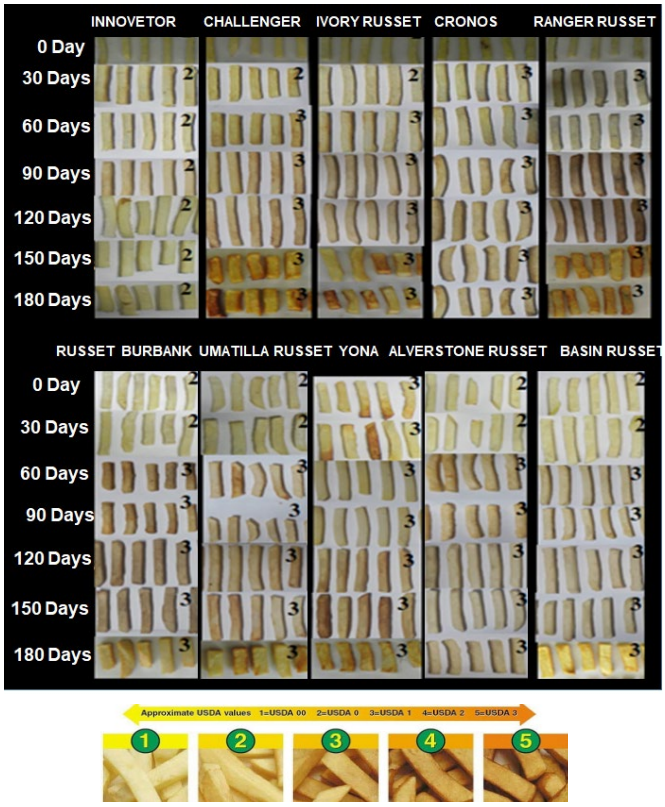


Figure 8. Coloration of potato sticks after frying at 180°C for 4 min of the Innovator, Challenger, Ivory Russet, Cronos, Ranger Russet, Russet Burbank, Umatilla Russet, Yona, Alverstone Russet, and Basin Russet cultivars stored for up to 180 days at 8°C.

These results highlight the importance of colorimetric studies and show that the reference values are specific for each cultivar, with the present study indicating L* values above 64.1 and b* values above 50.3.

Conclusion

Among the evaluated cultivars, the best parameters for the pre-fried potato processing industry were obtained in the Innovator, Alverstone Russet, and Basin Russet cultivars.

The cultivar Innovator would be the best indication for the processing industry, because it has a lighter color, less tuber sprouting during the storage period, and more advanced studies with it.

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