










Ideal temperature and storage period for commercial potato cultivars selected for frying

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ABSTRACT: Potatoes for industrial processing must have high dry matter, low sugar and free from damage or disease. The objective was to determine the ideal temperature and storage period of commercial cultivars for frying. Tubers of Asterix and Cronos cultivars were stored in a cold chamber (Gallant CMC4 Premium) inside plastic boxes at 6 and 8 °C with 85 to 95% humidity for 180 days. Accumulated mass loss (PMA), alcohol insoluble solids (SIA), total soluble sugars (AST), non-reducing sugars (ANR), reducing sugars (AR), polyphenoloxidase activity (PPO) and enzymatic and non-enzymatic browning were analyzed. The PMA of Asterix at 6 and 8 °C and Cronos at 6 °C was higher. The SIA of both cultivars stored at 6 °C were lower and AST, AR and ANR higher. Those parameters of Cronos and Asterix did not differ between temperature or storage period. The browning was greater in the fried sticks of Asterix and Cronos stored at 6 °C (4 to 5) for 60 and 90 days and at 8 °C (2 to 3) for 180 days, respectively. The ideal temperature and storage period for Asterix and Cronos cultivars is 8 °C for a maximum of 120 days due to non-enzymatic browning.

Key words: conservation, french fries, low temperatures, *Solanum tuberosum*.

Temperatura e período de armazenamento ideais para cultivares comerciais de batata selecionadas para fritura

RESUMO: As batatas destinadas ao processamento industrial devem ter alto teor de matéria seca, baixo teor de açúcar e estar livre de danos ou doenças. O objetivo foi determinar a temperatura e o período de armazenamento ideais para cultivares comerciais para fritura. Os tubérculos das cultivares Asterix e Cronos foram armazenados em caixas de plástico a 6 e 8 °C com umidade de 85 a 95% por 180 dias. As perdas de massa acumulada (PMA), sólidos insolúveis em álcool (SIA), açúcares solúveis totais (AST), açúcares não redutores (ANR), açúcares redutores (AR), atividade de polifenoloxidase (PPO) e escurecimento enzimático e não enzimático foram analisadas. A PMA de tubérculos da cultivar Asterix a 6 e 8 °C e a da cultivar Cronos, armazenadas a 6 °C foram maiores. Os teores de SIA foram menores e os de AST, AR e ANR maiores nos tubérculos de ambas as cultivares armazenadas a 6 °C. A temperatura e o período de armazenamento não afetaram as cultivares Cronos e Asterix. O escurecimento foi maior nos palitos fritos das cultivares Asterix e Cronos armazenados a 6 °C (4 a 5) por 60 e 90 dias e a 8 °C (2 a 3) por 180 dias, respectivamente. O período ideal de temperatura e armazenamento para as cultivares Asterix e Cronos é de 8 °C por, no máximo, 120 dias devido ao escurecimento não enzimático.

Palavras-chave: conservação, baixas temperaturas, batatas fritas, *Solanum tuberosum* L.

INTRODUCTION

Potato is the most important tuber worldwide (ZHANG et al., 2019), with 19,204,609 hectares of planted area and 386 million tons of annual production (AMJAD et al., 2017a). Potato is nutritionally benefic with components such as organic acids, fibers, minerals (phosphorus,

magnesium and potassium), proteins and vitamins B and C (HAASE, 2008).

The processed potatoes increase, mainly chips, is due to preparation and consumption convenience (CHEN et al., 2019). Potato tubers are planted in the summer and harvested in the fall (JANSKY & FARJADO, 2014) and stored for use throughout the year in Brazil (BIANCHI et al., 2014).

Technologies for potato tubers storage stabilize their quality during off-season (SOTOME et al., 2009).

Potato tubers, for industrial processing, must have high dry matter content, low sugar content and damage and disease free (SILVA et al., 2019). Low-temperature storage reduces losses from sprouting, wilting and diseases (XIAO et al., 2018). However, storage at temperatures lower than or equal to 6 °C induce amylases and phosphorylases synthesis (MALONE et al., 2006) reducing starch content by reducing sugars (glucose and fructose) and causing sweetening cold induced (XIAO et al., 2018; HAMEED et al., 2018).

Sweetened potato is generally rejected for frying (SOWOKINOS, 2001). In the United States, the largest potato chips consumer in the world, 15% of annual potato production is discarded due to sweetening (BHASKAR et al., 2010; CLASEN et al., 2016), leading to the search for tolerant cultivars (XIONG et al., 2002; HAMERNIK et al., 2009). The browning, caused by sweetening, varies between potato cultivars (SOWOKINOS, 2001) and can be reduced by controlling the storage temperature. Asterix and Cronos are cultivars used in industrial processing due to their short cultivation cycle, elongated tubers and light flesh (SILVA et al., 2018) and supposedly resistant to cold. The objective was to determine the ideal temperature and storage period for Asterix and Cronos cultivars for frying.

MATERIALS AND METHODS

Experimental design and area characterization

The experiment was in a completely randomized design, in subdivided plots, with the plots at temperatures 6 and 8 °C and the subplots being the storage periods of 30, 60, 90, 120, 150, 180 days with five replications, each experimental unit with five tubers to assess the PMA, AST, ANR, AR and PPO. Enzymatic and non-enzymatic browning was evaluated with five replications, each with 10 toothpicks. Tubers from the commercial cultivars, Asterix and Cronos, were produced in Araxá, Minas Gerais, Brazil (19° 35' 36" S, 46° 56' 27" O, 973 m altitude) over a period with an average temperature of 20 °C and precipitation of 134 mm.

Experimental procedure and analyses

Potato tubers were harvested at 120-130 days after planting, cured for four days at 25 °C and transported to the Post-harvest Physiology Laboratory at the Universidade Federal de Viçosa in Viçosa, Minas Gerais state, Brazil. These tubers were stored

in a cold chamber (Gallant CMC4 Premium) inside plastic boxes. The soil residues were removed from the tubers without washing and they were stored at 6 or 8 °C and 85 and 95% RH, respectively. Accumulated mass loss (PMA), alcohol insoluble solids (SIA), total soluble sugars (AST), reducing (AR) and non-reducing (ANR) sugars, polyphenoloxidase activity (PPO) and enzymatic and non-enzymatic browning after 30, 60, 90, 120, 150 and 180 days of cultivar tubers storage were evaluated.

Accumulated mass loss (PMA)

Five tubers from the commercial cultivars Asterix and Cronos stored at 6 and 8 °C were weighed monthly on an analytical balance and the accumulated mass losses calculated with the equation: $PMF = (MI - MF * 100) / MI$, where: PMF= fresh weight loss per day (%); MF= fresh weight of tuber at weighing day (g); MI= initial fresh mass (g).

Alcohol insoluble solids, total soluble sugars, reducing sugars and non-reducing sugars

Five grams of fresh pulp from five tubers were weighed, immersed in 80% ethanol at 65 °C, crushed and homogenized in polytron (Ultra turrax IKA® T25 digital) and centrifuged twice by 10 minutes at 2000 g. Samples were filtered on filter paper, with each centrifugation, and the filtration volume combined into a single volume (20 mL) with ethanol in each beaker. The alcoholic extract was stored under refrigeration (8 °C) in sealed containers, to quantify the total and reducing soluble sugars.

Alcohol insoluble solids

The pellets from the step above were dried in a continuous flow oven at 65 °C for 24 h until dry mass stability, macerated in a crucible and weighed on an analytical balance (LA BONTE et al., 2000). The alcohol-insoluble solids content was determined by the residue from the total soluble sugars extraction from potato pellets.

Total soluble sugars

Total soluble sugars (AST) were quantified by the Phenol-sulfuric method (DUBOIS et al., 1956) with 250 µL of the extracts from the pipetted potato tubers and with 250 µL of 5% phenol solution added by sealed glass test tube with 10 mL capacity and vortexing, 1.25 mL of concentrated sulfuric acid added and the solution stirred again. The tubes were kept in a thermostatic bath (30 °C) for 20 minutes, stirred again, and kept at room temperature for 30 minutes. The readings were performed on a spectrophotometer

(Genesys 10S UV-VIS) at $\lambda = 490$ nm, the standard curve made with 1% sucrose solution and the AST results expressed as a percentage.

Reducing and non-reducing sugars

The reducing sugars content was determined using the dinitrosalicylic acid (DNS) method (GONÇALVES et al., 2010). Five hundred microliters of alcoholic extract containing potato tubers fragments were pipetted through a glass test tube and 500 μ L of DNS added to each one and placed in a thermostatic bath at 100 °C for 5 min. After cooling, 4 mL of distilled water was added to each tube for the final reaction mixture. The readings were performed on a spectrophotometer (Genesys 10S UV-VIS) at $\lambda = 540$ nm and the standard curve made with 0.2% fructose solution. The RA levels were expressed as a percentage. The non-reducing sugars (ANR) content was calculated by the difference between the total and reducing soluble sugars concentration and the results were expressed as percentage.

Polyphenoloxidase (PPO) activity

Five grams of fresh tuber pulp mass from each potato cultivar were immersed in 15 mL of extraction buffer (0.1 M potassium phosphate buffer, pH 6.5). This mixture was ground, filtered through gauze and centrifuged at 17,000 g for 30 minutes at 4 °C. The PPO activity was determined by adding an enzymatic extract aliquot (100 μ L) to the reaction medium containing 1.5 mL of 0.1 M phosphate buffer (pH 7.0), 0.5 mL of catechol (1.68%) and 0.9 mL of water. The PPO activity was determined in a spectrophotometer (UV-1601) with variation in absorbance for 3 minutes at $\lambda = 420$ nm at 25 °C. Results were expressed in EU $\text{min}^{-1} \text{mg}^{-1}$ protein (KAVRAYAN & AYDEMIR, 2001).

The protein of the enzymatic extract was determined with the method of Bradford (1976) using BSA (bovine serum albumin) as standard. The protein content was determined using a mixture of 100 μ L of extract and 1 mL of Bradford's reagent and the protein quantified in a spectrophotometer (Genesys 10S UV-VIS) at $\lambda = 595$ nm at 25 °C. The results were expressed in mg of protein in the enzyme extract.

Enzymatic and non-enzymatic browning

The potato tubers were peeled, cut longitudinally into 1 cm² thick sticks with a manual cutter, fried in an electric fryer with a capacity of 3L (Ford®) and immersed in soy oil for three minutes at 180 °C. The enzymatic browning of the sticks was visually evaluated before frying. The amount

of oil used for frying was sufficient to minimize the temperature drop after immersing the potato sticks. The non-enzymatic browning of the fried sticks was visually determined, based on the panel equivalent to the 'United States Standards for Grades of Frozen French Fries Potatoes' (USDA, 1967), used by the potato processing industry.

Data analysis

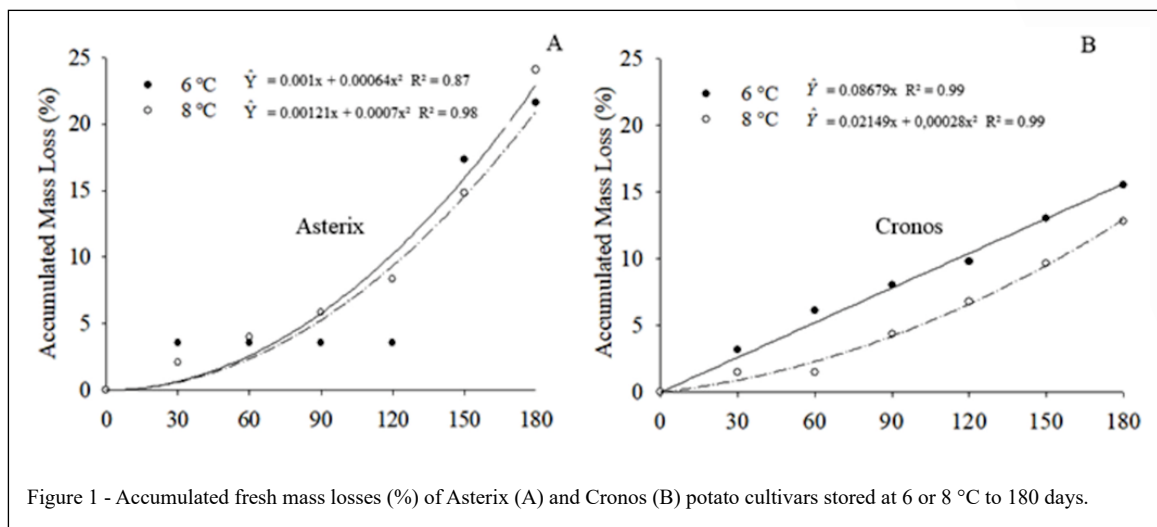
The experimental design was completely randomized in subdivided plots with the plots at the temperatures 6 and 8 °C and the subplots being the storage periods of 30, 60, 90, 120, 150, 180 days with five replications, with five tubers per experimental unit.

The data were submitted to analysis of variance and regression using the SAEG 9.1 Statistical Analysis System (SAEG, 2007). The choice of the regression model was based on the significance of the regression coefficients using the t test at a 5% probability level and on the determination coefficient ($R^2 = \text{SQReg}/\text{SQtrat}$).

RESULTS AND DISCUSSION

The accumulated loss of fresh mass of the Asterix at 6 and 8 °C and the Cronos at 6 °C tubers was higher. The fresh weight loss increased with the storage time (Figure 1). The greater accumulated fresh mass losses of Cronos stored at 6 °C is explained by the lower relative humidity (10% lower) in the storage chamber and may be associated with a periderm thickness of this cultivar as an early one (HELTOFT et al., 2017). The similar accumulated loss between 6 and 8 °C for the late cultivar Asterix is due to its greater periderm thickness (HELTOFT et al., 2017) reducing the effect of low relative humidity at 6 °C (SILVA et al., 2019). The mass loss of tuber over the storage period is due to reserve consumption by respiration converting polysaccharides into sugars (SUTTLE et al., 2004; FINGER et al., 2018).

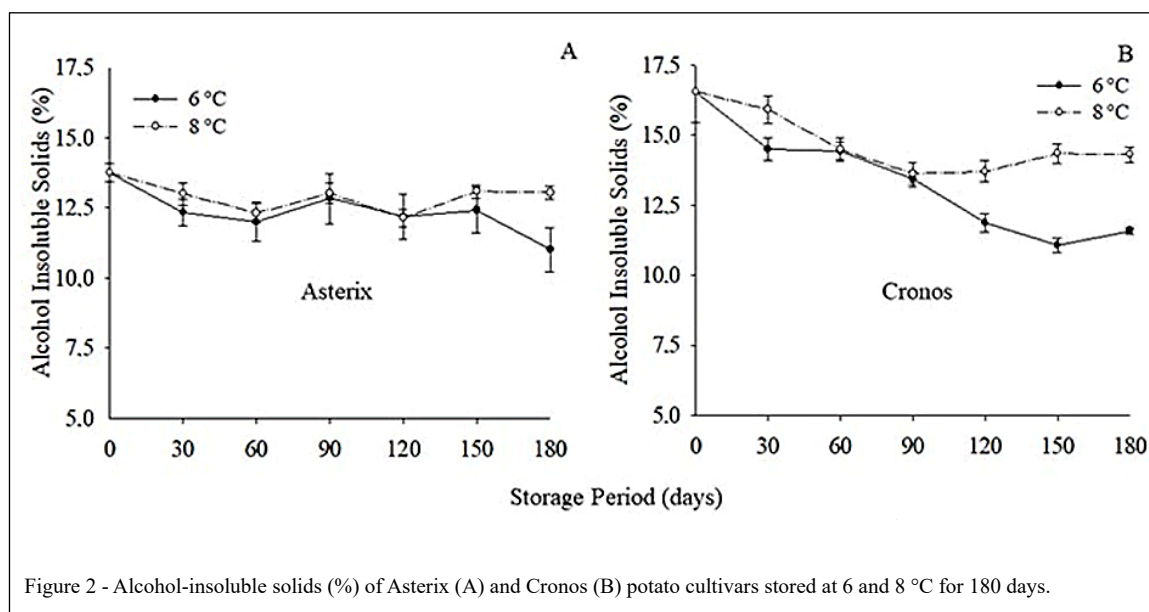
The alcohol insoluble solids (SIA) content was lower in the Asterix tubers after 180 and higher in the Cronos at 150 days of storage at 6 °C, respectively (Figure 2). The lower SIA levels in the Asterix tubers at 180 days at 6 °C are due to the greater starch degradation by amylases, phosphorylases and glycolysis enzymes lability caused by cold (MALONE et al., 2006). The greater starch degradation in the Cronos tubers stored at 6 °C after 150 days and its greater amylases and phosphorylases less degradation compared to Asterix (MALONE et al., 2006). Tubers with a higher starch content, such as those of Asterix, generally, have



lower SIA levels at the end of the storage (AMJAD et al., 2017b). The enzymes activity that degrade starch into sucrose (ANR) is greater in tubers stored at 6 °C reducing the frying sticks quality during storage (SUN et al., 2018).

The levels of total soluble (AST), non-reducing (ANR) and reducing (AR) sugars were higher in the tubers, of both cultivars, stored at 6 °C with a peak at 30 days of storage and reduction in the other periods (Figure 3). The increase in the AST, ANR and RA content of the tubers at 6 °C up to 30

days of storage is due to the sucrose accumulation (SOWOKINOS et al., 2018), the reduction in the ANR and the increase in RA in the tubers of Asterix and Cronos stored at 6 °C after 30 days is due to the increase in invertase activity, cleaving, sucrose in fructose and glucose (RICHARDSON et al., 1990). The lower the storage temperature (6 °C), the greater the stress condition and the sugars accumulation that can function as cell cryoprotectants. The 30-day storage period was sufficient to alter the sugar metabolism. The increase in the AST concentration



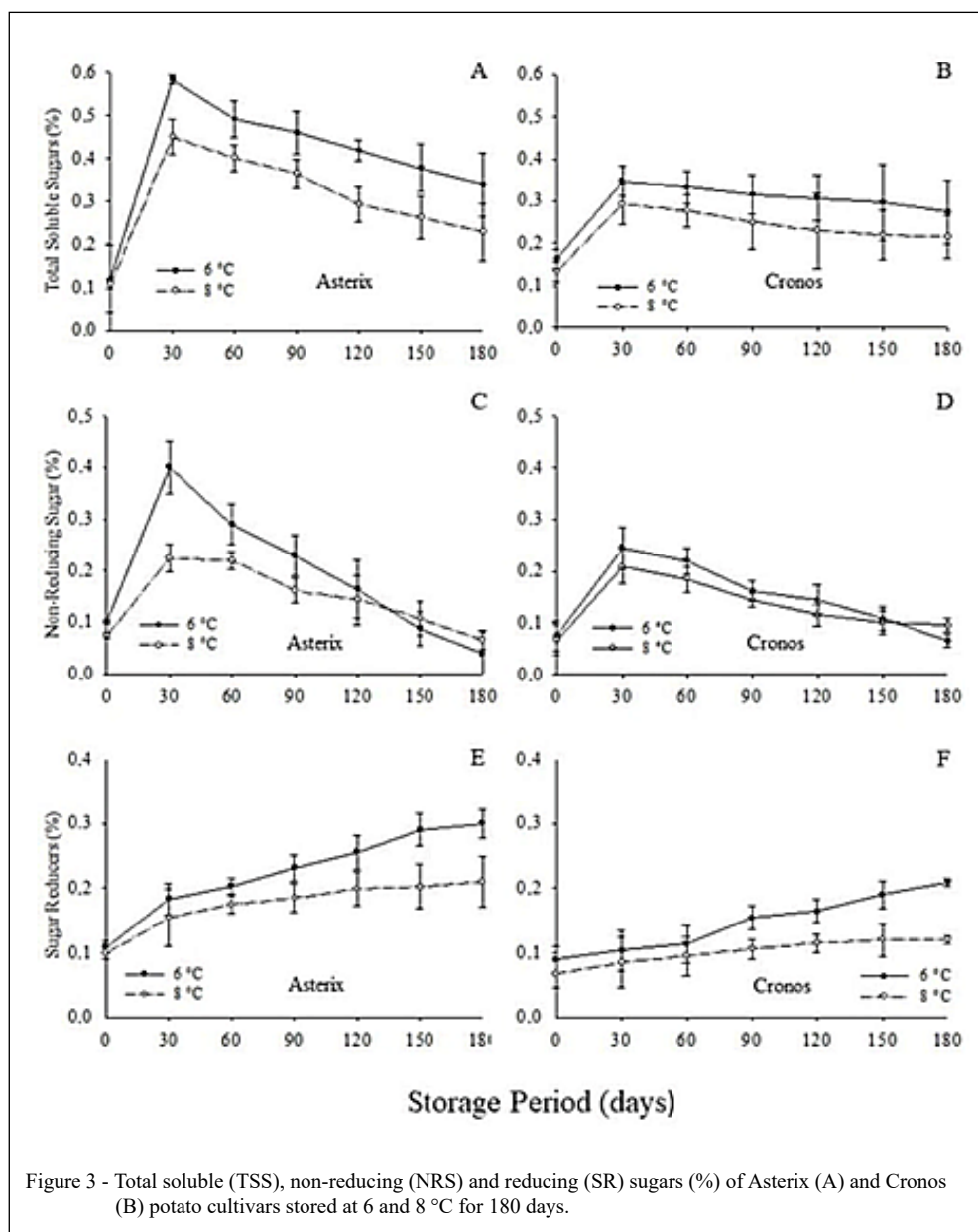
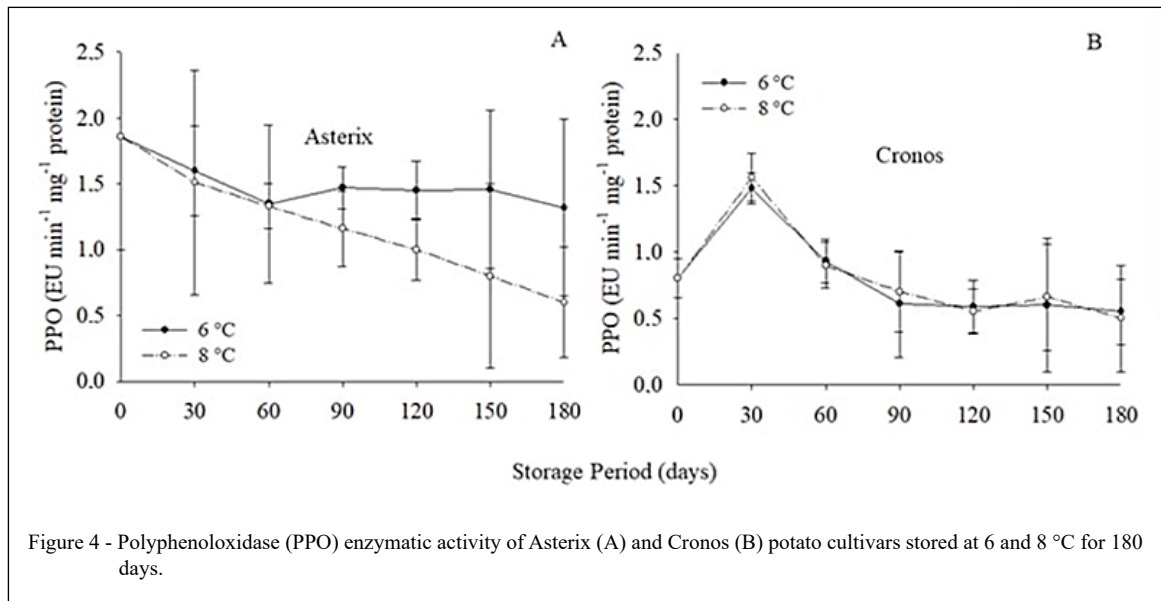


Figure 3 - Total soluble (TSS), non-reducing (NRS) and reducing (SR) sugars (%) of Asterix (A) and Cronos (B) potato cultivars stored at 6 and 8 °C for 180 days.

during storage occurs by breaking down the starch into ANR (sucrose), which is converted into AR (glucose and fructose) by invertase (RICHARDSON et al., 1990). The lower sugar accumulation in tubers stored at 8 °C is due to the lower invertase activity as reported for the potato cultivar Lady Roseta (AMJAD et al., 2017b; SUN et al., 2018).

The polyphenoloxidase (PPO) activity in the tubers of the Asterix and Cronos cultivars was similar between periods and storage temperatures (Figure 4). Enzymatic browning was not observed

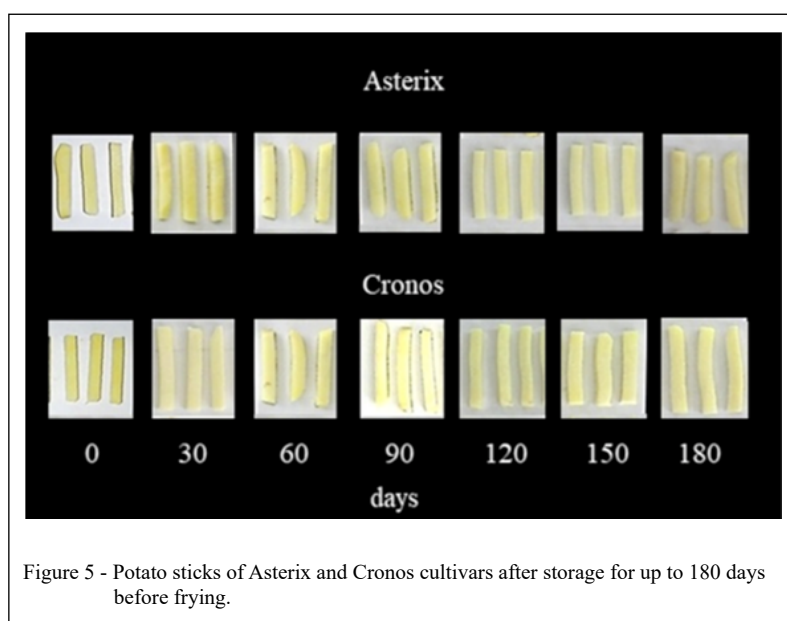
after cutting and processing potato tubers stored at 6 and 8 °C for up to 180 days (Figure 5). The similar PPO activity of potato cultivars at temperatures and storage periods is due to the short period between cutting and frying (<2 minutes) (HOU et al., 2014), which prevents browning, due to the complete oxidation of the substrates by PPO, 10 minutes after the cut (SINGH & WADHWA, 2017). Reducing the exposure time of enzymes to phenolic substrates and O₂ decreases the chances of increasing PPO activity (FUGATE et al., 2016). Therefore, the



time between cutting and frying is essential to avoid enzymatic browning.

Non-enzymatic browning occurred in the Asterix tubers stored at 6 °C for 60 days and those of the Cronos for 90 days (Figure 6). Fried tuber sticks, from cultivars Asterix and Cronos, stored at 6 °C, received grades 4 at 60 and 150 days and 5 at 180 days, respectively, and 2 and 3, from 30 days

of storage, for both cultivars stored at 8 °C (Figure 6). The increase of the AR levels, induced by cold, explains the non-enzymatic fried sticks browning of the tubers stored at 6 °C (BALAGIANNIS et al., 2019). The greater activity of the amidolytic enzymes can explain the onset of non-enzymatic browning in the tubers of the cultivars Asterix and Cronos at 6 °C stored for 60 and 90 days, respectively (MALONE



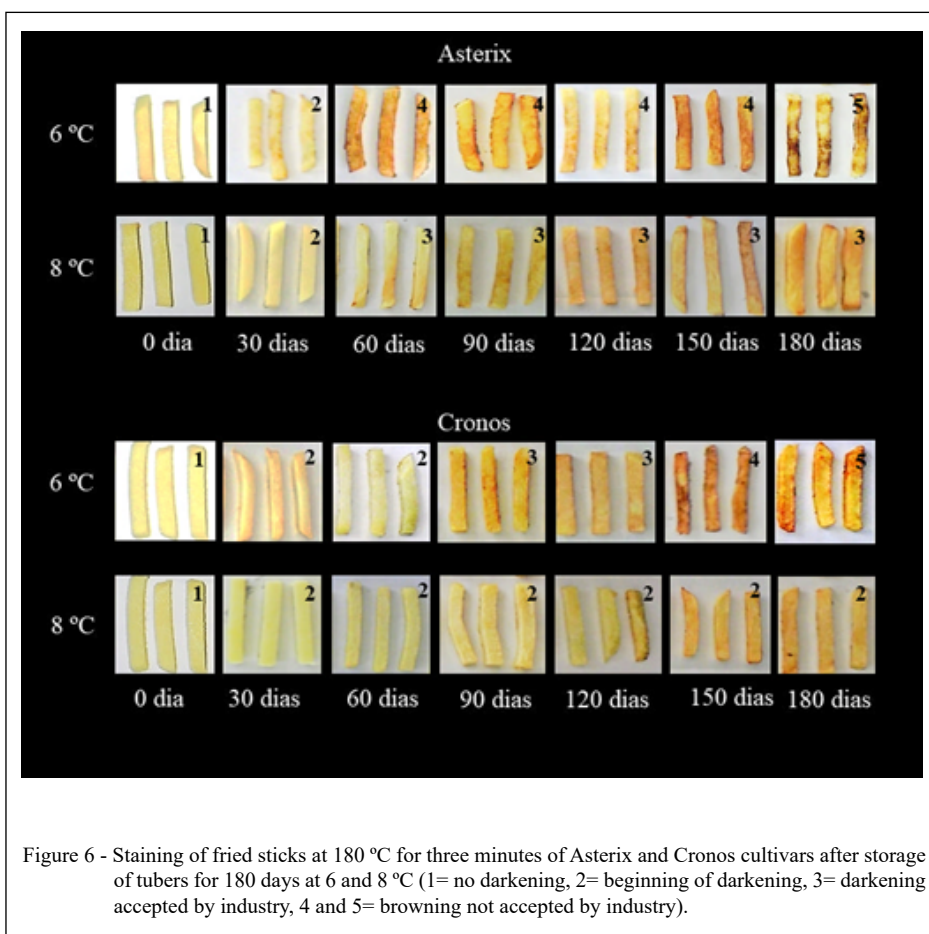


Figure 6 - Staining of fried sticks at 180 °C for three minutes of Asterix and Cronos cultivars after storage of tubers for 180 days at 6 and 8 °C (1= no darkening, 2= beginning of darkening, 3= darkening accepted by industry, 4 and 5= browning not accepted by industry).

et al., 2006; AMJAD et al., 2017b). Part of the starch in the tubers is converted during storage into sucrose and; subsequently, into glucose and fructose, darkening tubers at 6 °C during (BUSSE et al., 2019). The grades 4 at 60 to 150 days and 5 at 180 days of the tubers of the cultivars Asterix and Cronos, respectively, stored at 6 °C, are due to the RA greater accumulation in these periods (RICHARDSON et al., 1990).

CONCLUSION

Tubers of Asterix and Cronos cultivars should be stored at 8 °C for up to 120 days due to their non-enzymatic browning.

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DECLARATION OF CONFLICT OF INTERESTS

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved the final version.

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