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Quality of potato CV. innovator submitted refrigeration and recondition

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Abstract

The objective of this study was to determine the storage efficiency and reconditioning of potato cv. Innovator for processing. Tubers were stored at 6, 7 and 8 °C in the dark for 30, 60, 90, 120 and 150 days and reconditioned at 15 °C for 15 days. TRS and RS were reduced as storage temperature increased from 6 + 15 °C to 8 + 15 °C. Regardless of temperature and storage time, sugar contents were suitable for industry; however non-enzymatic browning remained in category 2 for up to 60, 90 and 150 days in tubers stored at 6 + 15 °C, 7 + 15 °C and 8 + 15 °C, respectively. Starch was influenced by storage time, despite the absence of temperature effect. Regardless of the temperature, sprouting started at 90 days, but the growth of shoots was directly proportional to the increase in temperature. The PPO and POD increased at the beginning of storage but did not cause darkening before the frying. Reduction in storage temperature followed by reconditioning did not delay the onset of sprouting, but reduced the size of sprouts, maintained adequate sugar levels, however it promoted non-enzymatic browning.

Keywords: sprout; reducing sugars; reconditioning.

Practical Application: Determination of temperature and ideal storage time for potato cv. Innovator.

1 Introduction

Potato plays an important role in the world economy because is one of the most consumed staple food in the diet of many countries. The processed potato market is on the rise due to changes in the population's eating habits, who seek products that are easy to be prepared. For the constant supply of raw material for the industry, the prolonged refrigerated storage of the tubers is carried out.

Potato tubers are in general stored at 8 to 10 °C (Wiberley-Bradf ord et al., 2016). The objective of the low temperature is to reduce sprouting, loss of water and infection by microorganisms (Chen et al., 2012). However, within this temperature range, there is a high incidence of diseases and sprouting (Wiberley-Bradford et al., 2016). Therefore, storage is necessary at lower temperatures.

Nevertheless, when potato tubers are stored at temperatures below 8 °C, they accumulate glucose and fructose (RS) (Wiberley-Bradf ord et al., 2016) a physiological disorder called cold-induced sweetening (CIS). The carbonyl or ketone group from RS reacts with the amino group of the amino acids, mainly with asparagine, in a non-enzymatic reaction (Maillard reaction). This reaction results in formation of the melanoidin pigments during frying, causing the darkening of the fried products (Amy et al., 2016). In addition, other reactions occur during this process leading to the formation of acrylamide (Amy et al., 2016).

Acrylamide was classified as a likely carcinogenic substance to humans by the International Agency for Research on Cancer (Pelucchi et al., 2011) and, a category 2 carcinogen by the European Union (Bethke & Bussan 2013). Studies suggest that 55% of acrylamide consumed in a typical American diet may be derived from potato products (Katz et al., 2012). In potato, there is a direct relationship between the reduction of sugar contents in raw tubers and the amount of produced acrylamide in fried products (Bethke & Bussan, 2013).

An alternative to reduce the accumulation of sugars would be the reconditioning at a higher temperature after the long term storage and before processing, in order to reverse the metabolism of carbohydrates. However, the effectiveness of reconditioning depends on the cultivar, temperature and duration of cold storage (Knowles et al., 2009).

In addition to the accumulation of sugars, low temperatures may increase the activity of oxidative enzymes peroxidase (POD) and polyphenoloxidase (PPO), due to the stress condition, causing the darkening before frying.

The objective of this study was to determine the storage efficiency and reconditioning on potato cv. Innovator for processing

2 Materials and methods

Tubers of cv. Innovator potato cultivar were obtained from the commercial production area of the region of Perdizes, Minas Gerais (19º 21' 10" S, 47º 17' 34" W and 1000 m). The tubers were planted in May and hand-harvested in September 2017. The curing was performed at 15 °C for 15 days. The temperature was reduced daily by 1 °C until reaching storage temperatures. The tubers were stored at 6, 7 and 8 °C (90 ± 2% RH) in the absence of light for 30, 60, 90, 120 and 150 days, and after each period, they were reconditioned for 15 days at 15 °C. Analyzes of total

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soluble sugars (TSS), reducing sugars (RS), non-reducing sugars (NRS), post-fry color, starch, sprouting onset, peroxidase activity (POD) and polyphenoloxidase (PPO) were performed in those periods. The end of storage was determined by sprouting of tubers.

2.1 Determination of TSS, RS and NRS

TSS and RS were extracted from 5 g of tuber flesh mass. Then, 80% ethanol was added at 100 °C, triturated and centrifuged three times for 10 min at 1500 *g*. At each centrifugation, the samples were filtered and the combined final volume of the filtrates was standardized (Dubois et al., 1956).

TSS were quantified by the Phenol-sulfuric method (Dubois et al., 1956), using sucrose as standard. 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 water bath for 20 min at 30 °C. Reading was performed in a spectrophotometer (Genesys- 10UV, scanning) at 490 ŋm. The results were expressed in % of fresh weight.

RS were determined by the dinitrosalicylic acid (DNS) methodology described by Gonçalves et al. (2010) with adaptations using fructose as standard. The reaction was composed of 500 µL of DNS and 500 µL of the sample, subsequently placed in water at 100 °C and after 5 min, 4 mL of distilled water was added in it. The readings were performed in spectrophotometer (Genesys- 10UV, scanning) at 540 ŋm and expressed in percentage.

NRS were calculated by the difference between TSS and RS and expressed in percentage of the fresh weight.

2.2 Determination of French fry color

To determination of French fry color, the tubers were cut into sticks using a manual cutter and fried in electric fryer, with capacity for 3 L (Model: Ford®) for 3 min at 180 °C. The color of the post-fry potatoes was visually determined based on the grading scale recommended by the 'United States Standards for Grades of Frozen French Fried Potatoes' (United States Department of Agriculture, 1967) and the fast food industry color grading chart from 1 to 5.

2.3 Determination of starch and Sprouting onset

With the residue from TSS and RS extraction, the starch content was determined by the methodology described by McCready et al. (1950), the result being multiplied by the factor 0.9, because during the formation of starch there is the removal of a water molecule.

Sprouting onset was determined from the visualization of sprouted tubers

2.4 Determination of POD and PPO

Enzymatic extracts of POD, PPO were obtained from 5 g of potato flesh was mixed with 15 mL of extraction buffer (0.1 M potassium phosphate buffer at pH 6.5). The material was ground, filtered on gauze and centrifuged at 17,000 g for 30 min at 4 °C (Lagrimini et al., 1997).

Enzymatic activity of POD was determined adding 100 µL of the enzyme extract to the reaction medium containing 0.5 mL of guaiacol (1.7%), 1.5 mL of 0.1 mol L^{-1} potassium phosphate buffer (pH 7.0) and 0.5 mL of hydrogen peroxide (1.8%). Reading was performed in a spectrophotometer at 470 µm for 3 min and the data expressed in units of absorbance (UA) min^{-1} mg^{-1} protein (Lagrimini et al., 1997).

Activity of PPO was determined in the reaction medium composed by 100 µL enzyme extract, 1.5 mL of 0.1 mol L^{-1} potassium phosphate buffer (pH 7.0), 0.5 mL catechol and 0.9 mL of distilled water. The reading was performed for 3 min at 420 µm and expressed in UA min^{-1} mg^{-1} protein (Kavrayan & Aydemir 2001).

Total protein was determined by the method of Bradford (1976) using bovine serum albumin (BSA) as standard.

2.5 Statistical analysis

The experiment was conducted in split-plot design, where the plots were the temperatures (6, 7 and 8 °C + 15 °C) and in the subplots, the storage times (30, 60, 90, 120 and 150 days of storage + 15 days of reconditioning). It was used a completely randomized design, with five replications, each repetition consisting of two tubers. For the analysis of sugars, starch and enzymatic activity of POD and PPO were performed analysis of variance and regression unfolding, the R version 1.1.2 was used (Ferreira et al., 2013).

3 Results and discussion

RS and TSS decreased with increasing storage temperature from 6 + 15 °C to 8 + 15 °C, from 0.06 to 0.02% and 0.19 to 0.15%, respectively (Figure 1). RS content being the most affected by the increase in storage temperature, as observed in the present study (Figure 1). While NRS was not influenced by storage temperature (Figure 1).

The storage time of the tubers altered the TSS, NRS and RS contents, which increased from 94.6; 30 and 104.5 days of storage with values of 0.17; 0.05; 0.12% at 150 days, respectively. (Figure 2).

The combination of storage (6, 7 and 8 °C) with subsequent reconditioning at 15 °C, even after 150 days of storage, kept the RS content below industry recommended 0.12% fresh mass (Stark et al., 2003).

Regardless of storage temperature, tubers were classified into category 2 at 30 and 60 days of storage (Figure 3). At 90 days of storage, tubers stored at 6 + 15 °C had a darker color, classification 3, while those stored at 7 + 15 and 8 + 15 °C remained in category 2, but the tips of the chips were darker. (Figure 3). At 120 days, the tubers at 6 + 15, 7 + 15 and 8 + 15 °C were classified into categories 3, 3 and 2, respectively (Figure 3). At 150 days, the tubers at 6 + 15 °C had a very dark color, classified in category 4, while at 7 + 15 and 8 + 15 °C at 3 and 2, respectively (Figure 3).

Although sugar contents remained adequate for processing, the coloring after frying was adequate only until 60, 90 and 150 days at temperatures of 6 + 15, 7 + 15 and 8 + 15 °C, respectively.

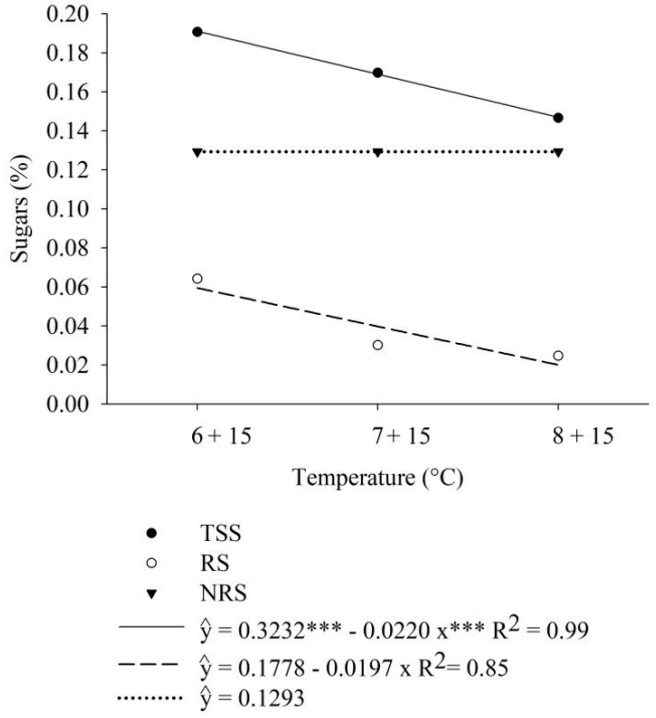

Figure 1. Total soluble sugars (TSS), reducing sugars (RS) and non-reducing sugar (NRS) of potato cv. Innovator stored at 6, 7 and 8 °C and subsequent reconditioned at 15 °C for 15 days. ***, significant at 0.1% probability.

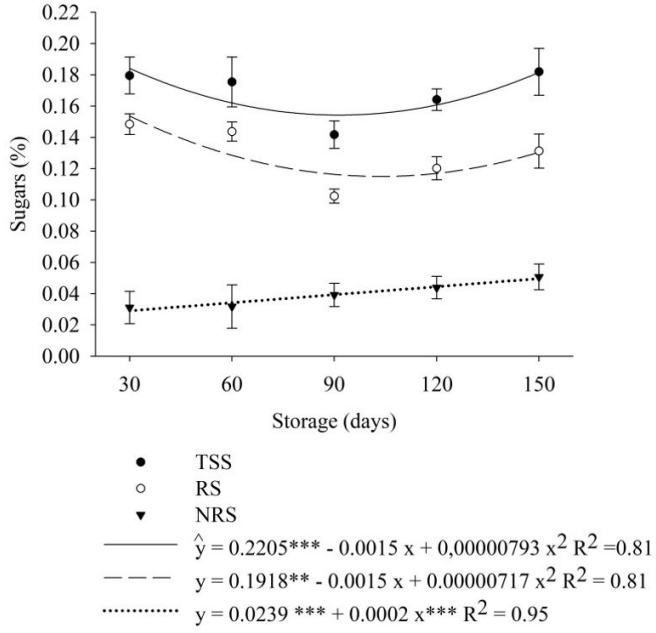

Figure 2. Total soluble sugars (TSS), reducing sugars (RS) and non-reducing sugar (NRS) of potato cv. Innovator stored at 6, 7 and 8 °C for 30, 60, 90, 120 and 150 days and subsequent reconditioned at 15 °C for 15 days. **, ***, significant at 1% and 0.1% probability, respectably.

Processing industries reject tubers in the above USDA 2 categories (Knowles et al., 2009). RS promote darkening during frying because their carbonyl or ketone group reacts with the amino group of amino acids, such as asparagine, in a non-enzymatic

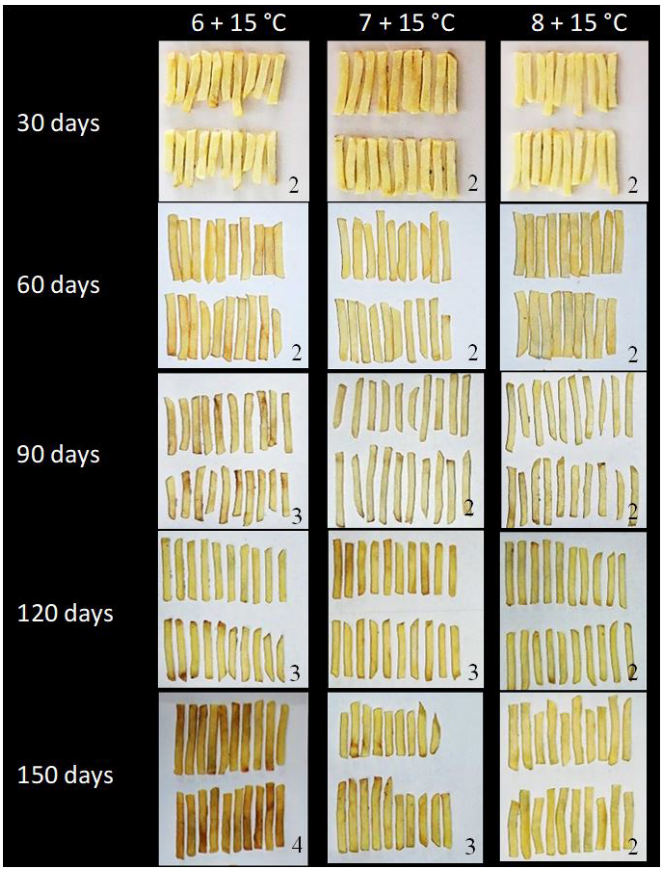

Figure 3. Post-frying coloring of potato sticks cv. Innovator stored at 6, 7 and 8 °C for 30, 60, 90, 120 and 150 days and subsequent reconditioned at 15 °C for 15 days. The numbers below each photo represent the classification according to USDA and the fast food industry, ranging from 1 to 5.

reaction (Maillard reaction) leading to the formation of melanoid pigments (Amy et al., 2016). However, sugars are not the only factors that affect the color of the sticks, but are also related to the concentration of amino acids and total polyphenols (Freitas et al., 2012).

Abong et al. (2009), by testing eight commercial cultivars and three commercial clones in Kenyan, found that reconditioning for three weeks at 15 °C after being stored at 4 °C for three months did not effectively reduce browning after frying. All the potatoes were dark brown in color and unpleasant in taste, being classified as unacceptable by the industry. Indicating that the positive response to reconditioning is dependent on temperature (Kumar et al., 2004) and storage time (Knowles et al., 2009). Thus, in order to extend the acceptance period for toothpicks to the industry, higher temperature and reconditioning time can be used, reducing amino acid concentration and plifenol content. In addition to the storage conditions the positive response is influenced by the cultivar used, study with 'Diamond', 'Hermes', 'Lady Rosetta' and 'Spunta' stored at 4 or 5 °C for 30, 60, 120 and 150 days followed by Rebuild at 16 °C for 0, 15 and 30 days showed improvement in the terrors of AR, AST and coloration after frying. For Hermes cultivar, 15 days of reconditioning were sufficient, while for Lady Rosetta cultivar 30 days, while

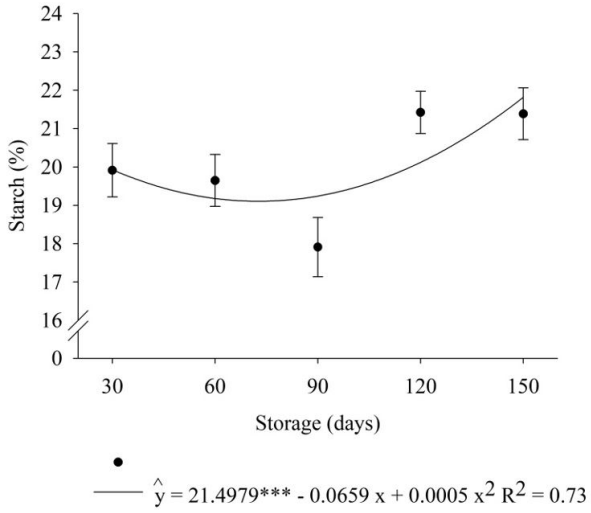

Figure 4. Starch contents in potato cv. Innovator stored at 6, 7 and 8 °C for 30, 60, 90, 120 and 150 days and subsequent reconditioned at 15 °C for 15 days. ***, significant at 0.1% probability.

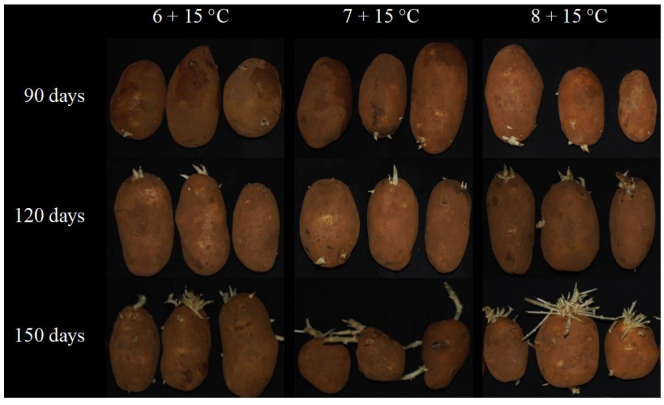

Figure 5. Sprouting onset Innovator cultivar tubers stored at 6, 7 and 8 °C for 90, 120 and 150 days and subsequent reconditioning at 15 °C for 15 days.

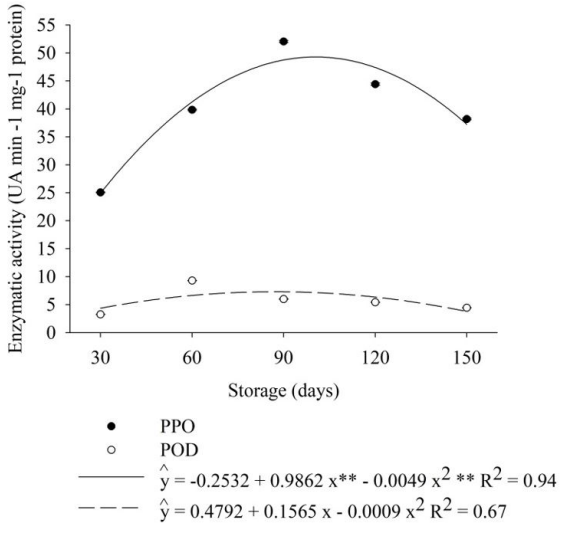

Figure 6. Polyphenoloxidase (PPO) and peroxidase (POD) enzymatic activity of Innovator potato tubers stored at 6, 7 and 8 °C for 30, 60, 90, 120 and 150 days and subsequent reconditioning at 15 °C for 15 days. **, significant at 1% probability.

'Diamond' and 'Spunta' remained below standard in these evaluated reconditioning periods (Kyriacou et al., 2009).

Starch contents were influenced by storage time increasing from 65.9 days, ranging from 19.3 to 21.9% at 30 and 150 days of storage, respectively (Figure 4), despite the absence of temperature effect. The potato chips industry requires tubers with starch content greater than 15% for good crispness (Kita, 2002). The cultivars Eliza, Pearl and Atlantic when stored at 2 °C for 10 days and reconditioned at 15 °C for 10 or 20 days, showed no changes in starch content (Chapper et al., 2004). Emphasizing that the effectiveness of reconditioning is dependent on the cultivar.

Regardless of temperature, sprouting began at 90 days of storage (Figure 5), correlating with increasing TSS (Figure 2) and darkening during frying (Figure 3). During sprouting, tubers require more sugars to act as a respiratory substrate for sprout growth and development (Bisognin et al., 2008). The increase in storage temperature was directly proportional to the size of the sprouts, making the tubers physically unsuitable for toothpick processing (Figure 5). Storage at 6 °C with subsequent reconditioning at 15 °C slowed the size of the sprouts, becoming smaller at 150 days compared to 8 + 15 °C, in which the size of the sprouts made tubers physically unsuitable for stick potato processing. (Figure 5), the effects of temperature on the physiological aging of tubers are already known, and temperature reduction is one of the best ways to retard the physiological aging of tubers (Muthoni et al., 2014).

The enzymatic activity of PPO and POD was not influenced by storage temperature followed by reconditioning, but had the effect of storage time, where PPO and POD increased to 100.6 and 86.9 days, with a maximum activity of 49.36. and 7.28 min^{-1} mg^{-1} protein respectively (Figure 6). The increase in enzymatic activity is due to the stress condition caused by exposure to low temperatures in which the tubers were subjected. Under stress conditions, reactive oxygen species are formed to prevent cellular damage by activating enzymatic and non-enzymatic defense systems, such as POD and PPO activity. Both PPO and can lead to darkening before frying, PODs use H_2O_2 as oxidant and phenolic compounds as electron donors (Barbosa et al., 2014) leading to melanin formation. Despite the initial increase in oxidative enzyme activity, no browning was observed on the sticks before frying.

4 Conclusion

Reduction in storage temperature followed by reconditioning did not delay the onset of sprouting, but reduced the size of sprouts, maintained adequate sugar levels, however it promoted non-enzymatic browning.

References

Abong, G. O., Okoth, M. W., Karuri, E. G., Kabira, J. N., & Mathooko, F. M. (2009). Evaluation of selected Kenyan potato cultivars for processing into french fries. Journal of Animal and Plant Sciences, 2, 141-147.

Amy, E., Bradforda, W., Busseb, J. S., & Bethkea, P. C. (2016). Temperature-dependent regulation of sugar metabolism in wild-type and low-invertase transgenic chipping potatoes during and after cooling

for low-temperature storage. *Postharvest Biology and Technology*, 115, 60-71. http://dx.doi.org/10.1016/j.postharvbio.2015.12.020.

Barbosa, M. R., Silva, M. M. A., Willadino, L., Ulisses, C., & Camara, T. R. (2014). Geração e desintoxicação enzimática de espécies reativas de oxigênio em plantas. *Ciência Rural*, 44(3), 453-460. http://dx.doi.org/10.1590/S0103-84782014000300011.

Bethke, P. C., & Bussan, A. J. (2013). Acrylamide in Processed Potato Products. *American Journal of Potato Research*, 90(5), 403-424. http://dx.doi.org/10.1007/s12230-013-9321-4.

Bisognin, D. A., Freitas, S. T., Brackmann, A., Andriolo, J. L., Pereira, E. I. P., Muller, D. R., & Bandinelli, M. G. (2008). Envelhecimento fisiológico de tubérculos de batata produzidos durante o outono e a primavera e armazenados em diferentes temperaturas. *Bragantia*, 67(1), 59-65. http://dx.doi.org/10.1590/S0006-87052008000100007.

Bradford, M. M. (1976). A rapid and sensitive method for the quantification of microgram quantities of protein utilizing the principle of protein-dye biding. *Analytical Biochemistry*, 72(1-2), 248-254. http://dx.doi.org/10.1016/0003-2697(76)90527-3. PMid:942051.

Chapper, M., Loureiro, M. E., Mosquim, P. R., Araújo, W. L., Pereira, A., Finger, F. L., & Simões, N. A. (2004). Mudanças metabólicas após recondicionamento a 15 ºC de tubérculos de batata armazenados a baixa temperatura. *Horticultura Brasileira*, 22(4), 700-705. http://dx.doi.org/10.1590/S0102-05362004000400007.

Chen, X., Song, B., Liu, J., Yang, J., He, T., Lin, Y., Zhang, H., & Xie, C. (2012). Modulation of gene expression in cold-induced sweetening resistant potato species *Solanum berthaultii* exposed to low temperature. *Molecular Genetics and Genomics*, 287(5), 411-421. http://dx.doi.org/10.1007/s00438-012-0688-6. PMid:22526428.

Dubois, M., Gilles, K. A., Hamilton, J. K., Rebers, P. A., & Smith, F. (1956). Colorimetric method for determination of sugars and related substances. *Analytical Chemistry*, 28(3), 350-356. http://dx.doi.org/10.1021/ac60111a017.

Ferreira, EB., Cavalcanti, PP., Nogueira, DA (2013). *ExpDes.pt: Experimental Designs pacakge (Portuguese). R package version 1.1.2*. Vienna: R Development Core Team.

Freitas, S. T., Pereira, E. I. P., Gomez, A. C. S., Brackmann, A., Nicoloco, F., & Bisognin, D. A. (2012). Processing quality of potato tubers produced during autumn and spring and stored at different temperatures. *Horticultura Brasileira*, 30(1), 91-98. http://dx.doi.org/10.1590/S0102-05362012000100016.

Gonçalves, C., Rodriguez-Jasso, R. M., Gomes, N., Teixeira, J. A., & Belo, I. (2010). Adaptation of dinitrosalicylic acid method to microtiter plates. *Analytical Methods*, 2(12), 2046-2048. http://dx.doi.org/10.1039/c0ay00525h.

Katz, J. M., Winter, C. K., Buttrey, S. E., & Fadel, J. G. (2012). Comparison of acrylamide intake from Western and guideline based diets using probabilistic techniques and linear programming. *Food and Chemical Toxicology*, 50(3-4), 877-883. http://dx.doi.org/10.1016/j.fct.2011.11.006. PMid:22107988.

Kavrayan, D., & Aydemir, T. (2001). Partial purification and characterization of polyphenoloxidase from peppermint (*Mentha piperita*). *Food Chemistry*, 74(2), 146-154. http://dx.doi.org/10.1016/S0308-8146(01)00106-6.

Kita, A. (2002). The influence of potato chemical composition on crisp texture. *Food Chemistry*, 76(2), 173-179. http://dx.doi.org/10.1016/S0308-8146(01)00260-6.

Knowles, N. R., Driskill, J. R. Jr., & Knowles, L. O. (2009). Sweetening responses of potato tubers of different maturity to conventional and non-conventional storage temperature regimes. *Postharvest Biology and Technology*, 52(1), 49-61. http://dx.doi.org/10.1016/j.postharvbio.2008.08.015.

Kumar, D., Singh, B. P., & Kumar, P. (2004). An overview of the factors affecting sugar content of potatoes. *Annals of Applied Biology*, 145(3), 247-256. http://dx.doi.org/10.1111/j.1744-7348.2004.tb00380.x.

Kyriacou, M. C., Siomos, A. S., Ioannides, I. M., & Gerasopoulos, D. (2009). The chip-processing potential of four potato (*Solanum tuberosum* L.) cultivars in response to long-term cold storage and reconditioning. *Journal of the Science of Food and Agriculture*, 89(5), 758-764. http://dx.doi.org/10.1002/jsfa.3509.

Lagrimini, L. M., Gingas, V., Finger, F. L., Rothstein, S., & Liu, T. T. Y. (1997). Characterization of antisense transformed plants deficient in the tobacco anionic peroxidase. *Plant Physiology*, 114(4), 1187-1196. http://dx.doi.org/10.1104/pp.114.4.1187. PMid:12223765.

McCready, R. M., Guggolz, J., Silviera, V., & Owens, H. S. (1950). Determination of starch and amylase in vegetable. *Analytical Chemistry*, 22(9), 1156-1158. http://dx.doi.org/10.1021/ac60045a016.

Muthoni, J., Kabira, J., Shimelis, H., & Melis, R. (2014). Regulation of potato tuber dormancy: a review. *Australian Journal of Crop Science*, 8(5), 754-759.

Pelucchi, C., La Vecchia, C., Bosetti, C., Boyle, P., & Boffetta, P. (2011). Exposure to acrylamide and human cancer-a review and metaanalysis of epidemiologic studies. *Annals of Oncology : Official Journal of the European Society for Medical Oncology*, 22(7), 1487-1499. http://dx.doi.org/10.1093/annonc/mdq610. PMid:21239401.

Stark, J. C., Olsen, N., Kleink, O. P., Ge, F., & Love, S. L. (2003). Tuber quality. In: J. C. Stark S. L. Love (Eds.), *Potato production systems*. Aberdeen: University of Idaho. p. 329-343.

United States Department of Agriculture – USDA. (1967). *United states standards for grades of frozen french fried potatoes*. Washington: USDA. p. 16.

Wiberley-Bradford, A. E., Busse, J. S., & Bethke, P. C. (2016). Temperature dependent regulation of sugar metabolism in wild-type and low-invertase transgenic chipping potatoes during and after cooling for low-temperature storage. *Postharvest Biology and Technology*, 115, 60-71. http://dx.doi.org/10.1016/j.postharvbio.2015.12.020.