










Control of enzymatic browning in minimally processed sweet potato

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ABSTRACT: Enzymatic browning represents one of the main challenges in the postharvest conservation of minimally processed sweet potatoes, as it affects appearance and reduces consumer acceptance. This study aimed to evaluate the effectiveness of different packaging types and alternative enzymatic inactivation techniques using natural antioxidants (citric acid and apple cider vinegar) and thermal treatment applied to off-grade sweet potato roots. Samples were stored in two types of packaging (expanded polystyrene trays wrapped with PVC film and sealed textured plastic bags) under controlled conditions of 18 °C for up to 12 days. Parameters such as pH, soluble solids, and enzymatic browning were analyzed. The results indicated that treatment with citric acid combined with textured packaging was the most effective in preserving physicochemical quality and reducing enzymatic browning during storage. Although thermal treatment promoted an increase in soluble sugar content, it resulted in greater enzymatic browning, especially when combined with trays covered with PVC film. It is concluded that the use of natural antioxidants along with appropriate packaging constitutes a viable strategy for adding value to off-grade sweet potatoes, extending shelf life, and reducing postharvest losses.

Keywords: *Ipomoea batatas*; minimal processing; enzymatic oxidation; postharvest preservation.

Controle do escurecimento enzimático em batata-doce minimamente processada

RESUMO: O escurecimento enzimático representa um dos principais desafios na conservação pós-colheita de batatas-doces minimamente processadas, pois afeta a aparência e reduz a aceitação pelo consumidor. Este estudo teve como objetivo avaliar a eficácia de diferentes tipos de embalagens e de técnicas alternativas de inativação enzimática, utilizando antioxidantes naturais (ácido cítrico e vinagre de maçã) e tratamento térmico, aplicados a raízes de batata-doce fora de padrão. As amostras foram armazenadas em dois tipos de embalagens (bandejas de poliestireno expandido envolvidas com filme de PVC e sacos plásticos texturizados selados) sob condições controladas de 18 °C por até 12 dias. Foram analisados parâmetros como pH, sólidos solúveis e escurecimento enzimático. Os resultados indicaram que o tratamento com ácido cítrico, combinado à embalagem texturizada, foi o mais eficaz na preservação da qualidade físico-química e na redução do escurecimento enzimático durante o armazenamento. Embora o tratamento térmico tenha promovido um aumento no teor de açúcares solúveis, resultou em maior escurecimento enzimático, especialmente quando combinado com bandejas cobertas com filme de PVC. Conclui-se que o uso de antioxidantes naturais, aliado a embalagens adequadas, constitui uma estratégia viável para agregar valor à batata-doce fora de padrão, prolongar a vida útil e reduzir as perdas pós-colheita.

Palavras-chave: *Ipomoea batatas*; processamento mínimo; oxidação enzimática; conservação pós-colheita.

1. INTRODUCTION

The sweet potato (*Ipomoea batatas* (L.) Lam), belonging to the family Convolvulaceae, stands out as the seventh most important food crop worldwide. It is recognised as a superfood due to its high nutritional density, being rich in antioxidants, vitamins, and minerals, which contribute to the prevention and management of chronic diseases (MOHAMMED, 2022; ORTELAM et al., 2022). Originally

from Tropical Central America, this tuberous root is cultivated in more than 100 countries, playing an essential role in global food security (NIGUSSIE et al., 2022).

In addition to its importance in human consumption, sweet potato has several applications, such as in animal feed, ethanol production, and ornamental use (SOUZA et al., 2022). Its cultivation is widely spread, particularly due to its richness in carbohydrates, vitamins, and minerals -

characteristics that reinforce its potential as a functional food, mainly because of the presence of bioactive compounds such as carotenoids and anthocyanins (LAURIE et al., 2022).

In Brazil, sweet potato holds significant socioeconomic importance, being predominantly cultivated by small-scale farmers, especially for subsistence purposes (COSTA et al., 2022). However, substantial losses occur along the production chain, from harvest to commercialisation, often due to non-compliance with market standards required for fresh sale, such as irregular shape, size outside specifications, or slight mechanical damage. Conversely, these tubers may be utilised through minimal processing, which includes steps such as selection, washing, sanitisation, peeling, cutting, and packaging, to provide ready-to-eat products while preserving as much as possible their natural characteristics of freshness, flavour, texture, and nutritional value (MORETTI, 2011).

One of the main challenges in utilising minimally processed sweet potato is related to the mechanical stress caused by cutting, which induces the formation of dark pigments on the surface due to the oxidation of phenolic compounds catalysed by the enzymes polyphenol oxidase (PPO) and peroxidase (POD). This enzymatic oxidation process compromises the visual appearance of the product, reducing its market acceptance and decreasing its shelf life (RU et al., 2020).

In addition to initial mechanical damage, post-processing factors such as temperature, storage time, type of packaging, and the interaction between these elements also directly influence the color stability of the pulp (ZHANG et al., 2019). The progression of oxidation, including in the peel, can alter the concentration and integrity of the pulp pigments, favoring fading. Simultaneously, moisture absorption by the tissues interferes with colorimetric parameters, reducing luminosity (L^*) and increasing the intensity of the reddish hue (a^*), as observed in the Keledok Jingga cultivar subjected to different temperature conditions (SANCHEZ et al., 2020).

Thus, strategies to minimise these effects are essential to ensure product quality and durability. Among the alternatives are the use of suitable packaging, chemical substances with anti-browning effects, and the application of heat treatment for enzymatic inactivation (ALMEIDA et al., 2020; MARANGONI et al., 2022). Moreover, modified atmosphere and refrigeration, when combined with appropriate packaging, contribute to delaying the respiratory process of sweet potato, thereby extending its post-processing quality (GUERRA et al., 2020; CASTRO et al., 2023). Weight loss during storage also represents a critical factor, being directly associated with sensory changes such as flavour, colour, and texture, which negatively affect consumer acceptance (YANG et al., 2022).

Furthermore, citric acid and heat treatment are widely used in the preservation of fruits and vegetables to prevent enzymatic browning, representing effective, economically feasible, and sensorially accepted alternatives for consumers (WU et al., 2023; LI et al., 2024).

In this context, the development of effective strategies for the preservation of sweet potato is essential for reducing losses and ensuring a high-quality final product. The present study aimed to evaluate the efficiency of packaging and alternative techniques for enzymatic inactivation in minimally processed sweet potato.

2. MATERIAL AND METHODS

Sweet potatoes were harvested from the Experimental Area of Crop Science and taken to the Plant Physiology Laboratory at the Auroras Campus, both belonging to the Universidade da Integração Internacional da Lusofonia Afro-Brasileira (UNILAB), in Redenção, Ceará, Brazil. The tuberous roots were first washed with running water to remove soil residues from the field. Subsequently, the material underwent a second washing with running water and neutral detergent, followed by sanitisation through immersion in a sodium hypochlorite solution at 200 mg L⁻¹ for 15 minutes. The utensils used were also sanitised in a solution of the same proportion, according to good hygienic practice recommendations in the food industry (CASTRO, 2008).

For minimal processing, tuberous roots that did not meet the commercial classification standards for sweet potato were used (MORETTI, 2011). Thus, roots weighing less than 79 g, with irregular shapes, non-standard calibres, or slight mechanical injuries were selected for enzymatic inactivation. Sweet potatoes with salmon-coloured skin and white flesh were used, ensuring that the slices were obtained only from parts free of pests, diseases, or mechanical defects. The tuberous roots were manually peeled and then cut transversely to the main axis into slices 2.0 mm thick. The ends were discarded, and only the median portion of the root was used. After cutting, the transverse sections were immersed in a sodium hypochlorite solution at 200 ppm.

The experiment was conducted in a completely randomised design in a 4 × 5 factorial scheme, assessing four types of enzymatic inactivators in relation to storage periods. Each experimental unit consisted of a package containing four slices, with each treatment consisting of three replicates. The treatments consisted of immersion for one minute in a citric acid solution (6 mL of lemon juice diluted in 300 mL of water) (CORDEIRO, 2018); immersion for one minute in an apple cider vinegar solution at pH 3 (6 mL diluted in 300 mL of water); and heat treatment by heating at 50 °C for three minutes, efficient in the quality of minimally processed sweet potato according to Cordeiro (2018).

After applying the treatments, the excess surface solution on the sweet potato slices was removed with paper towels, and the samples were packed in different types of packaging: expanded polystyrene (EPS) trays covered with 12 µm thick polyvinyl chloride (PVC) and textured plastic bags that were sealed using an Oster® FoodSaver vacuum sealer, model V2240. The samples were stored in the refrigerator, under controlled conditions of 18°C, for a period of 12 days. Four sweet potato slices per package were evaluated, thus constituting one experimental unit per storage period (0, 3, 6, 9 and 12 days), with three replications.

The soluble solids content was determined according to AOAC (1997) from the macerated pulp of the samples, using cotton to obtain the liquid extract, and quantified with an analogue refractometer (model RHB32, scale 0–32% °Brix), with results expressed in °Brix. The pH was determined using a digital pH meter (model MPA210). The evolution of pulp browning (ΔE) was evaluated by sensory analysis, by five trained panelists, using a structured 5-point scale (1 = no browning; 2 = slight; 3 = moderate; 4 = intense; 5 = very intense), under standardized lighting. The assigned scores

were converted into a percentage of browning (0–100%) using the following equation:

$$\Delta E (\%) = [(score - 1) / (5 - 1)] \times 100 \quad (01)$$

The results were expressed as the average of the tasters' evaluations. The data were subjected to the Shapiro-Wilk normality test to verify adherence to a normal distribution. For data not following a normal distribution, a transformation of $\sqrt{X + 0.5}$ was applied. When significant effects were observed for the factors or their interaction, Tukey's test at 5% probability was used for mean comparison. When significant effects of storage periods were observed, regression analysis was also applied to evaluate the behaviour of the variables over storage time. Statistical analyses were performed using R software (R Development Core Team, 2024). Graphs were prepared using SigmaPlot software (version 15.0).

3. RESULTS

The natural pH of minimally processed sweet potato, represented by the control treatment (Figure 1), showed an increasing trend throughout the storage period in trays covered with plastic film. In contrast, under heat treatment, pH values remained unstable over time. Heat treatment in sweet potato is also employed to improve preservation and disease resistance during storage. The effects of this treatment on pH depend on the intensity and type of thermal processing applied.

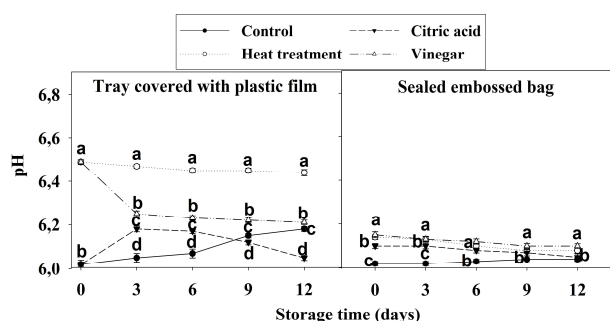


Figure 1. pH of minimally processed sweet potato stored in sealed embossed plastic bags and expanded polystyrene (EPS) trays covered with PVC plastic film. Means followed by different letters differ significantly according to Tukey's test at 5% probability.

Figura 1. pH de batata-doce minimamente processada em embalagem de saco plástico gofrado selado e bandejas de poliestireno expandido (EPS), cobertas com filme plástico PVC. Médias seguidas por letras diferentes diferem entre si, pelo teste de Tukey a 5% de probabilidade.

Changes were also observed with the application of vinegar, which resulted in a reduction on the third day of evaluation and subsequently remained unchanged. A differential behaviour was also noted in sweet potato treated with citric acid, with an increase on the third day followed by a decline on the ninth day.

Sweet potato stored in embossed plastic bags responded better to pH variations, even after the application of treatments and over the evaluation period. However, the pH of sweet potato subjected to heat treatment differed statistically from the other treatments, showing higher values. Nevertheless, the application of treatments in sweet potato stored in both types of packaging was not sufficient to

compromise the activity of oxidative enzymes, whose optimum pH is 6.0 or close to neutrality.

For the determination of soluble solids (Figure 2), the control treatment showed a constant increase throughout the storage period in expanded polystyrene (EPS) trays covered with PVC plastic film. The increase in soluble sugars in sweet potato during storage is a common characteristic, since enzymes act on starch degradation, thereby increasing the sweetness of the tuber. However, associated with this starch degradation is the enzymatic browning process, which leads to product quality loss.

Storage in embossed plastic bags favoured the reduction of soluble solids in sweet potato subjected to heat treatment and vinegar, with no significant differences between them on the third day of evaluation. Values continued to decrease over time, whereas soluble solids in citric acid-treated samples increased from the sixth day onwards, being higher than the other treatments on the final day of evaluation.

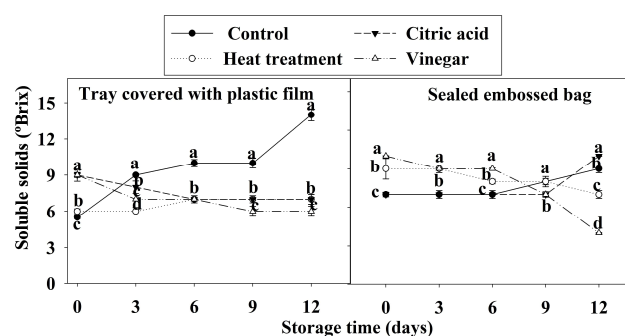


Figure 2. Soluble solids of minimally processed sweet potato stored in different sealed embossed plastic bags. Means followed by different letters differ significantly according to Tukey's test at 5% probability.

Figura 2. Sólidos solúveis de batata-doce minimamente processada em diferente embalagem de saco plástico gofrado selado. Médias seguidas por letras diferentes diferem entre si, pelo teste de Tukey a 5% de probabilidade.

The storage environment in trays covered with plastic film and in embossed plastic bags promoted enzymatic browning of sweet potato over time, with stronger responses observed for the control and heat treatment (Figures 3 and 4).

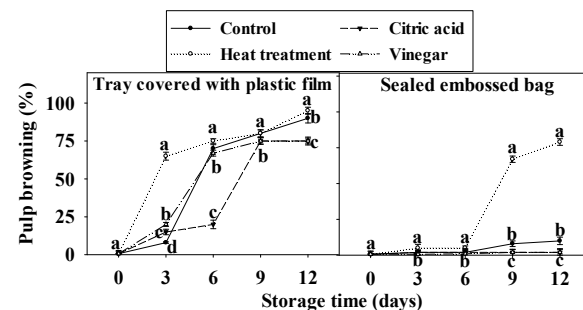


Figure 3. Evolution of sweet potato pulp browning (%) of minimally processed sweet potato stored in expanded polystyrene (EPS) trays covered with PVC film according to inactivation techniques. Means followed by different letters differ significantly according to Tukey's test at 5% probability.

Figura 3. Evolução do escurecimento da polpa da batata-doce (%) minimamente processada em bandejas de poliestireno expandido (EPS) cobertas com filme de PVC, em função das técnicas de inativação enzimática. Médias seguidas por letras diferentes diferem entre si, pelo teste de Tukey a 5% de probabilidade.

4. DISCUSSION

The control of pH, °Brix content, and enzymatic browning is essential to ensure the quality and preservation of sweet potato. The pH of stored sweet potato generally ranges between 5.9 and 6.0, varying according to cultivar and storage conditions (KROCHMAL-MARCZAK et al., 2020), which aligns with the results observed in the initial evaluation of the roots. pH directly influences carbohydrate transformations, firmness, and colour intensity, often having a greater impact than postharvest storage time itself (SGROPPO et al., 2010). Additionally, it affects the solubility of structural components such as pectins and hemicelluloses, thereby influencing the final texture of the product (ARACHCHIGE et al., 2021).

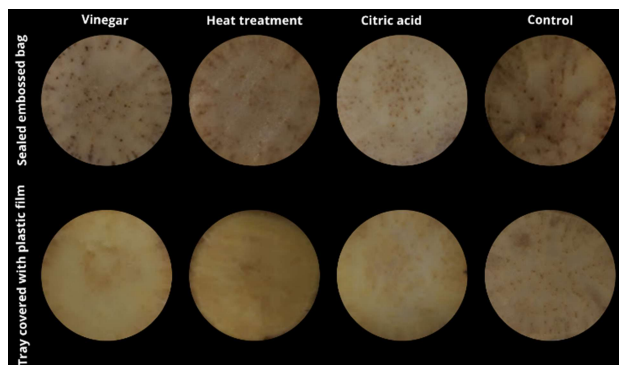


Figure 4. Visual appearance of minimally processed sweet potato stored in expanded polystyrene (EPS) trays covered with PVC film and in sealed embossed plastic bags at the end of 12 days of evaluation.

Figura 4. Aparência visual da batata-doce minimamente processada armazenadas em bandejas de poliestireno expandido (EPS), cobertas com filme de PVC e em saco gofrado selado ao final dos 12 dias de avaliação.

Changes in pH during storage can affect texture, colour, the stability of bioactive compounds, and overall product quality (Sgroppo et al., 2010), as observed in this study regarding the color changes resulting from pulp browning. Shi et al. (2022) highlighted that plastic packaging, particularly that with higher barriers to moisture and gas exchange, can create a microenvironment that accelerates acidification over time, mainly due to reduced gas exchange and accumulation of acidic metabolites. Moreover, the roughness and structure of embossed plastic can influence moisture retention and gas exchange dynamics, accelerating fermentative processes and promoting pH reduction. Sohany et al. (2021) concluded that the lower permeability of embossed plastic to oxygen and water vapour promotes acidification by limiting the dissipation of CO₂ and other volatile acids produced by the food's metabolism. In addition, acidic solutions or citric acid treatments can reduce enzymatic activity, inhibiting browning and extending the shelf life of minimally processed products.

pH is negatively correlated with soluble solids content, as the activity of starch-degrading enzymes is lower at near-neutral pH (FERNANDES et al., 2010). This aligns with the natural postharvest increase in °Brix observed in potatoes, which occurs due to the conversion of starch into soluble sugars by enzymes such as β -amylase and invertases, whose activity is enhanced at pH values away from neutrality.

The use of suitable packaging, such as embossed bags, can help regulate moisture and gas exchange, reducing the risk of rot and maintaining soluble solids content. Treatments

such as citric acid and heat can reduce soluble solids by modifying the starch in sweet potato, increasing water retention capacity, altering crystalline structure, and promoting the formation of resistant starch, particularly when combined with heat treatment (LI et al., 2024). Li et al. (2024) observed that citric acid inhibits enzymatic activity related to the increase in soluble solids and consequent browning of sweet potato.

Yuan et al. (2024) investigated the influence of packaging and temperature on the sweetness of sweet potatoes and found that soluble sugar content increased, with sucrose and fructose being 1.72 and 1.46 times higher, respectively, than in the control after 8 days of storage. The reduction in soluble solids during storage is likely due to substrate consumption in respiratory metabolism, a feature of catabolic senescence reactions (BEERLI et al., 2004). These findings align with Neeraj; Dalal (2019), who highlighted the potential of embossed bags to preserve soluble solids by reducing moisture and excessive gas exchange.

Mechanical injuries during harvest can trigger metabolic changes in the tuber, affecting postharvest quality. Enzymatic browning occurs primarily due to improper handling during postharvest storage and is often linked to increased polyphenol oxidase activity (PAN et al., 2020).

Heat treatment can increase phenolic compound content and antioxidant activity, particularly in purple cultivars, and can also alter the profile of phenolic acids (PAN et al., 2020). Rodrigues et al. (2019) reported that immersing sweet potatoes in water at 40 °C effectively reduced the incidence of soft rot while maintaining the tubers' physicochemical properties over 20 days of storage. However, although heat treatment was more effective in preserving minimally processed sweet potato stored in embossed plastic bags, it was less efficient in trays covered with plastic film, where enzymatic browning was intensified.

Therefore, heat treatment applied to tubers stored in trays may have been insufficient to inactivate enzymatic activity. In addition, residual heat and condensed moisture could facilitate oxidation and the migration of phenolic compounds to the tuber surface, intensifying enzymatic browning. Polyphenol oxidase (PPO) activity reaches its maximum at approximately 30 °C and decreases progressively as temperature increases (LIU et al., 2012). Thermal treatment at 50 °C for three minutes has been reported as effective in controlling enzymatic browning and maintaining water content in minimally processed sweet potato slices, thereby contributing to postharvest quality preservation (CORDEIRO, 2018). However, under the conditions of the present study, exposure of the roots to 50 °C for three minutes was not sufficient to inhibit pulp browning, suggesting that the effectiveness of the thermal treatment may vary according to genotype and its specific physiological characteristics.

Citric acid treatment was effective in delaying browning, particularly from the sixth day, compared to other treatments. Li et al. (2024) highlighted that citric acid preserves tuber quality by regulating antioxidant capacity and reducing lipid peroxidation, with its effectiveness being concentration-dependent.

Zou et al. (2018) showed that exposing sweet potato samples to 140 °C for 10 seconds in purple sweet potato nectar did not significantly alter pH, which remained stable during 28 days of refrigerated storage. Conversely, Wu et al. (2023) reported that treating sweet potato at 35 °C for 24

hours prevented soft rot (*Erwinia carotovora* ssp.) without significantly affecting pH, while improving disease resistance and nutritional stability during storage.

5. CONCLUSIONS

The combination of citric acid treatment and storage in sealed embossed bags may serve as an effective strategy for controlling pulp browning and maintaining the quality of minimally processed sweet potato. The use of alternative techniques, such as natural antioxidants and modified-atmosphere packaging, is suitable for adding value and reducing postharvest losses of sweet potato roots.

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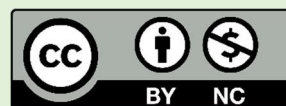
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