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Scientific Article

Analysis of browning in minimally processed yam related to vascular bundles

Análise do escurecimento em inhame minimamente processado relacionado aos feixes vasculares

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ABSTRACT – This study evaluated the relationship of vascular bundles and cut region with enzymatic activities of the oxidative metabolism of minimally processed yam, in order to verify how enzymatic browning occurs and its extent. Samples of yam were collected from three regions: the central region (0–1.25 cm), the intermediate region (1–3 cm), and the peripheral region (3–9 cm) of the slices of minimally processed yam, packaged in PVC film and stored at 5 °C for 15 days. The results indicated that cutting the tissue of minimally processed yam acted as a trigger for changes in phenolic content and the activities of polyphenol oxidase, peroxidase, and phenylalanine ammonia-lyase. These alterations, observed throughout the storage period, intensified the propagation of enzymatic browning in a non-homogeneous manner across the peripheral, intermediate, and central regions of the slices due to oxidation around vascular bundles randomly distributed in the yam's plant tissue. The enzymatic browning is associated with the distribution of vascular bundles and the enzyme PPO throughout all regions of the slice and its propagation occurs non-homogeneously. In minimally processed yam, enzymes involved in oxidative reactions and regulation of the oxidation of phenolic compounds are interconnected, contributing to tissue browning.

Keywords: *Dioscorea*. Phenolic compounds. Polyphenol oxidase. Postharvest.

RESUMO – Este estudo avaliou a relação entre os feixes vasculares e a região cortada com as atividades enzimáticas do metabolismo oxidativo do inhame minimamente processado, a fim de verificar como ocorre o escurecimento enzimático e sua extensão. Amostras de inhame foram coletadas de três regiões: região central (0–1,25 cm), região intermediária (1–3 cm) e região periférica (3–9 cm) das fatias de inhame minimamente processado, embaladas em filme de PVC e armazenadas a 5 °C por 15 dias. Os resultados indicaram que o corte do tecido do inhame minimamente processado atuou como um gatilho para alterações no conteúdo fenólico e nas atividades da polifenol oxidase, peroxidase e fenilalanina amônia-liase. Essas alterações, observadas ao longo do período de armazenamento, intensificaram a propagação do escurecimento enzimático de maneira não homogênea nas regiões periférica, intermediária e central das fatias, devido à oxidação em torno dos feixes vasculares distribuídos aleatoriamente no tecido vegetal do inhame. O escurecimento enzimático está associado à distribuição dos feixes vasculares e da enzima PPO em todas as regiões da fatia, e sua propagação ocorre de maneira não homogênea. No inhame minimamente processado, as enzimas envolvidas nas reações oxidativas e na regulação da oxidação dos compostos fenólicos estão interligadas, contribuindo para o escurecimento do tecido.

Palavras-chave: *Dioscorea*. Compostos fenólicos. Feixe vascular. Polifenoloxidase.

Conflict of interest: The authors declare no conflict of interest related to the publication of this manuscript.

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Data Availability: The data that support the findings of this study can be made available, upon reasonable request, from the corresponding author.

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INTRODUCTION

Due to its nutritional attributes, yam can be prepared in various ways, such as boiled, fried, or processed into different products (HONFOZO et al., 2021). Although it is commonly marketed fresh and whole, fresh-cut yam has emerged as an alternative to add value and expand commercialization (MORAIS et al., 2019; CHANG et al., 2023). Minimally processed yam is susceptible to browning following tissue disruption, which compromises visual quality, shortens shelf life, and reduces consumer acceptance and commercial value (MORAIS et al., 2022; YUAN et al., 2025).

Cutting induces stress responses in plant tissues, triggering the biosynthesis of secondary metabolites such as phenolic compounds and activating oxidative enzymes involved in browning (GUAN et al., 2021). The intensity of these responses is associated with the extent of tissue injury, since larger cut surfaces increase physiological and biochemical alterations (HU; GUAN; FENG, 2022). In fresh-cut potatoes, different cutting styles enhanced phenylalanine ammonia-lyase (PAL) activity and increased phenolic content (HU et al., 2021).

In minimally processed yam, browning intensity depends on the cutting method and is associated with increased phenolic content and the activities of polyphenol oxidase (PPO) and peroxidase (POD), key enzymes involved in oxidative reactions (SIMÕES et al., 2015; MORAIS et al., 2022). Storage at low temperatures may modulate these enzymatic activities and delay browning

development (SIMÕES et al., 2015). Furthermore, browning may propagate gradually from injured cells to adjacent tissues through chemical signaling mechanisms (COELHO JÚNIOR et al., 2019; MORAIS et al., 2022).

Besides biochemical responses, anatomical characteristics may influence browning patterns. In cassava, discoloration is associated with oxidation of cells adjacent to xylem bundles (DJABOU et al., 2017). In minimally processed peach palm, structural features were related to surface color changes intensified by processing (FONSECA et al., 2023). In yam, anatomical studies have primarily described structural aspects (DARKWA et al., 2020), with limited investigation into the relationship between tissue organization and enzymatic browning propagation. Although some studies have correlated anatomy and oxidative metabolism intensity (MORAIS et al., 2022), evidence linking vascular structures to non-homogeneous browning distribution remains scarce.

Understanding how anatomical features interact with oxidative metabolism is essential for improving quality and extending the shelf life of minimally processed yam. Identifying structural regions more susceptible to browning may contribute to optimizing cutting practices, storage conditions, and preservation strategies.

Therefore, this study aimed to evaluate the relationship of vascular bundles and cut regions with the enzymatic activities involved in oxidative metabolism in minimally processed yam, in order to clarify how enzymatic browning develops and propagates within different regions of the slice.

MATERIALS AND METHODS

Yam Harvest and Minimal Processing

Yams (*Dioscorea cayanensis* Lam.) at the physiological maturity stage, harvested 300 days after planting (ANDRES et al., 2017), were obtained from the State Supply Center (CEASA) in Aracaju, SE, Brazil. The yams were transported to the Fruit and Vegetable Laboratory (LABFRUTH) of the Department of Food Technology at the Federal University of Sergipe (UFS) and stored in a climate-controlled room at 18 ± 2 °C until minimally processed.

Minimal processing followed the protocol proposed by previous studies, with adaptations (Figure 1).

Tubers of uniform size, free from mechanical damage and visible infections, were selected. After being washed with running water, they were peeled manually and the ends were removed. The tubers were then cut into 2-cm-thick slices. The slices were sanitized (200 mg L^{-1}), rinsed, and placed in polypropylene trays (300 g), wrapped in PVC film, and stored in an upright refrigerator at 5 ± 2 °C for 15 days. Samples from the peripheral, intermediate, and central regions of the yam slices were collected on the day the experiment was set up and at 3, 6, 9, 12, and 15 days of storage (Figure 2).

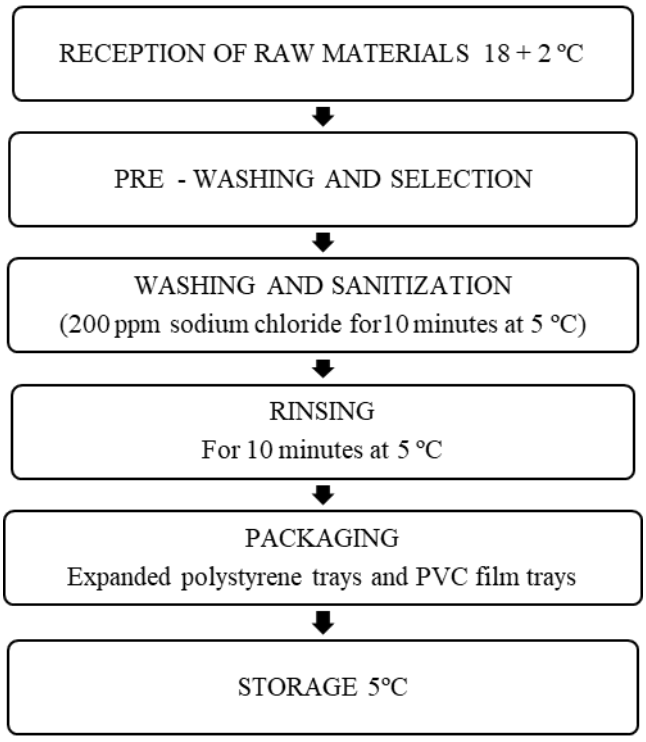


Figure 1. Flowchart of minimal yam processing (BRITO et al., 2011), with adaptations.

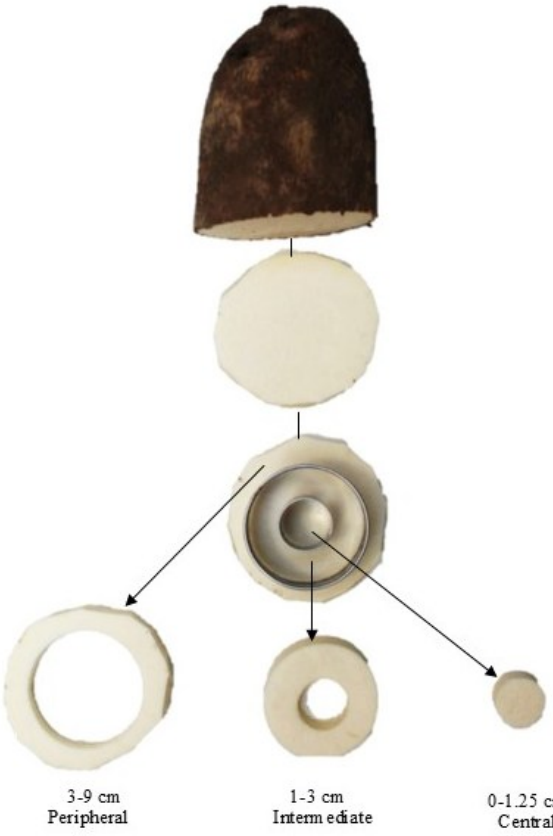


Figure 2. Delimitation of the slice of fresh-cut yam (*Dioscorea cayanensis*) into peripheral, intermediate and central regions.

Histochemical and Anatomical Evaluations

Sections from the peripheral, intermediate, and central regions (Figure 2) were fixed in FAA (70% ethanol, 5% glacial acetic acid, and 5% formaldehyde) for 72 hours and then stored in 70% ethanol (JOHANSEN, 1940). The material underwent a graded ethanol dehydration series (70%, 80%, 90%, and 100%) for two hours each. Samples were then pre-infiltrated with a solution of 50% ethanol and 100% methacrylate (Historesin-Leica) for 72 hours (JOHANSEN, 1940) and subsequently infiltrated with 100% methacrylate for 24 hours.

The material was embedded in silicone molds with a 250 µL capacity. After embedding, the blocks were sectioned into 8-µm-thick slices using a Leica RM 2235 semi-automatic microtome. Sections were stained with 0.05% toluidine blue for 20 minutes and Lugol for 5 minutes, then mounted on permanent slides with Canada balsam. The sections were photographed using a Leica DM500 optical microscope equipped with a camera and visualized on a computer using the LAS EZ® software.

Physical, Chemical, and Biochemical Analyses

Mass Loss (%): Determined as the difference between the initial mass and the mass at the end of storage, measured using a digital scale. The percentage mass loss was calculated as follows: Mass loss (%) = [(initial mass − mass at the evaluation date) / initial mass] × 100 (YOUSSEF; ROBERTO, 2014).

Firmness: Measured using a Digital Fruit Firmness Tester (Brand TR, Model 53205), equipped with an 8-mm-long probe. The yam slices were fixed on the platform, and firmness was determined as the maximum force required to penetrate 8 mm into the slice. Results were expressed in Newtons (N) (ZHAO et al., 2020).

Total Soluble Solids (°Brix): Measured using a digital refractometer (HI 96801, Hanna Instruments). Cell juice (1 mL) was extracted from 1 g of yam samples diluted in 10 mL of water and transferred to the refractometer. Results were expressed in °Brix (IAL, 2008).

pH: Determined using 5 g of homogenized samples diluted in 50 mL of distilled water (IAL, 2008). Reading was performed with a digital pH meter.

Total Acidity (TA): Determined by titration. Fifty milliliters of the pH solution were used, with 1% phenolphthalein as an indicator, and titrated with standardized 0.1 N NaOH (IAL, 2008). TA was expressed as a percentage (%) of citric acid.

Browning Index (BI) (PEPA et al., 2021) **and Whiteness Index (WI)** (BOLIN; HUXSOLL, 1991): Evaluated using the GroundEye® image analysis system. Non-destructive evaluation involved overlaying markers of different diameters onto the slice surface, dividing it into peripheral, intermediate, and central regions (Figure 2). Slices were transferred to the GroundEye® tray for image capture and analysis. The blue background and markers were removed before analysis, resulting in segmented regions (Figure 3).

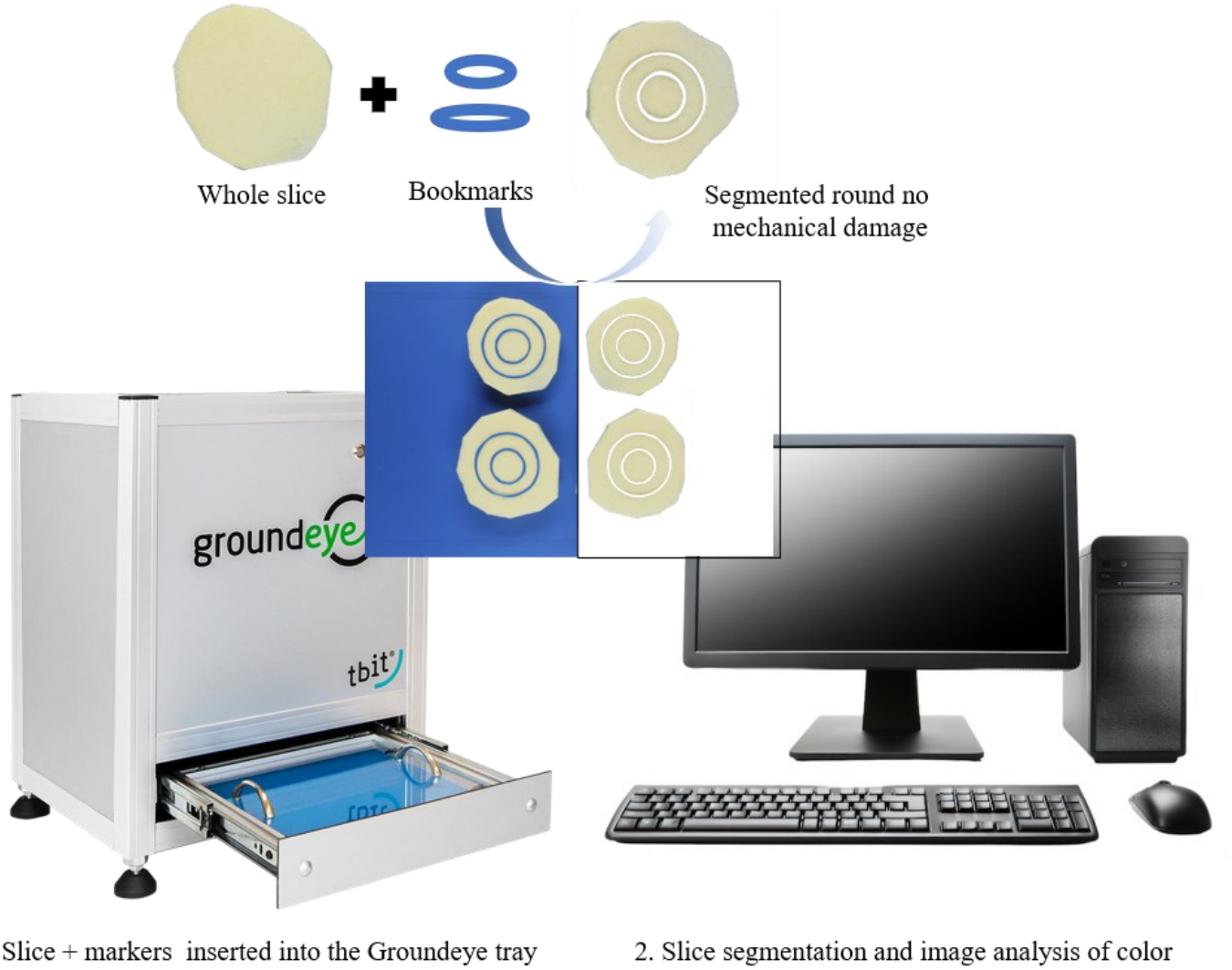


Figure 3. Image analysis of the slice of fresh-cut yam (*Dioscorea cayanensis*) in peripheral, intermediate and central regions. Source: Image captured on GroundEye® image analysis equipment.

For BI and WI, data obtained from the GroundEye® system included parameters: "*L**" (lightness: light/dark), "*a**" (chromaticity: green (-) to red (+)), "*b**" (chromaticity: blue (-) to yellow (+)).

These parameters were used to calculate the Browning Index (BI) and Whiteness Index (WI) using the following equations:

Browning Index (BI):

$$BI = [100(X - 0.31)] / 0.172$$

where:

$$X = (a^* + 1.75L^*) / (5.645L^* + a^* - 3.02b^*)$$

Whiteness Index (WI):

$$WI = 100 - [(100 - L^*)^2 + (a^*)^2 + (b^*)^2]^{1/2}$$

The visual analysis of minimally processed yam was performed using a Likert scale for the analyzed regions (peripheral, intermediate, and central), considering five points based on the intensity of the darkened and/or whitened area (Table 1).

Table 1. Likert scale for visual analysis of fresh-cut yam. Photo captured on GroundEye® image analysis equipment.

Images	Scores	Criteria
	5	Round with white surface, without any sign of darkening. Appearance and odor characteristic of fresh yam. Excellent for consumption and commercialization.
	4	Round with white surface, without signs of darkening. Appearance of some whitish streaks. Appearance and odor characteristic of fresh yam. Excellent for consumption and commercialization.
	3	Round with white surface, showing small points of darkening. There is an increase in the whitish area. Acceptance limit for consumption and commercialization.
	2	Round with white surface, showing small points of darkening distributed unevenly throughout the slice. Surface area of the entire slice filled with whitish streaks. Appearance unsuitable for consumption and commercialization.
	1	Round with an intensely whitish and/or darkened surface. Totally unsuitable for consumption and commercialization.

Extraction and Assays of Polyphenol Oxidase (PPO) and Peroxidase (POD) Activities

The enzymatic extract for PPO and POD assays was obtained by homogenizing 1.0 g of yam tissue from minimally processed samples in 6.0 mL of pre-chilled sodium phosphate buffer (0.2 M, pH 6.0). The homogenate was centrifuged at 10,000 × g for 21 minutes at 4 °C (SIMÕES et al., 2015).

POD Activity: The assay was performed by adding 300 µL of the supernatant to 1.0 mL of sodium phosphate buffer (0.2 M, pH 6.0), followed by the addition of 100 µL of guaiacol (0.5%) and 100 µL of hydrogen peroxide (0.08%). Absorbance was measured at 470 nm (SIMÕES et al., 2015). POD activity was calculated using the molar extinction coefficient for guaiacol (26,600 M^{-1} cm^{-1}) and expressed as µmol s^{-1} kg^{-1} of fresh weight.

PPO Activity: The assay involved adding 30 µL of the supernatant to a reaction mixture containing 1.5 mL of catechol and 1.3 mL of sodium phosphate buffer (0.2 M, pH 6.0). PPO activity was determined by the increase in absorbance at 425 nm at 30 °C. It was calculated using the molar extinction coefficient for catechol (3,400 M^{-1} cm^{-1}) and expressed as µmol s^{-1} kg^{-1} of fresh weight (SIMÕES et al., 2015).

For both assays, six readings were taken at 30 second intervals using a Libra spectrophotometer.

Phenylalanine Ammonia-Lyase (PAL) Activity (EC 4.3.1.5)

PAL activity was determined following the method described by Ke and Saltveit (1986), with adaptations. The enzymatic extract was prepared by homogenizing 2 g of yam tissue in 5 mL of pre-chilled 50 mM sodium borate buffer (pH 8.5) containing 5 mM β-mercaptoethanol and 1.25 g of polyvinylpyrrolidone (PVP). The homogenate was centrifuged at 25,000 × g for 20 minutes at 4 °C.

For the assay, 3 mL of the supernatant was placed in a thermostatic bath at 40 °C and kept for 2 minutes. Subsequently, 330 µL of 100 mM L-phenylalanine was added, and absorbance at 290 nm was recorded immediately and after 1 hour under the same conditions. A standard curve based on trans-cinnamic acid formation was used, and results were expressed as µmol of cinnamic acid h^{-1} g^{-1} of fresh weight.

Determination of Total Phenolic Content

Total phenolics were quantified using the Folin-Ciocalteu reagent, following the method described by Boroski et al. (2015), with adaptations. One gram of yam tissue (from peripheral, intermediate, and central regions) was homogenized in 10 mL of distilled water and filtered using filter paper.

The assay was performed in the dark by mixing 250 µL of the extract with 150 µL of Folin-Ciocalteu reagent, followed by 300 µL of sodium carbonate. The mixture was homogenized, and absorbance at 725 nm was measured using a UV-Vis spectrophotometer. A standard curve based on gallic acid was used, and results were expressed in mg of gallic acid equivalents per kg of fresh weight.

Experimental Design and Statistical Analysis

The experiment followed a completely randomized design (CRD) with a factorial scheme of 3 × 6, corresponding to three regions of the yam slice (Figure 2) and six storage periods (0, 3, 6, 9, 12, and 15 days) under refrigeration. Each treatment had four replicates. Results were analyzed using analysis of variance (ANOVA). Mean separations were conducted using the F-test, and means were compared by Tukey's test at a significance level of $p < 0.05$. Data were expressed as mean ± standard deviation.

RESULTS AND DISCUSSION

Histochemical-Anatomical Characterization of Yam

Different anatomical structures were observed in the studied regions (Table 2; Figure 4).

Starch granules (Figure 4d), tannins (Figure 4a), calcium oxalate crystals in the form of raphides (Figure 4b), and vascular bundles (Figure 4a) were identified. Additionally, vascular cambium was detected (Figure 4a) in the peripheral region. Anatomically, yam is mainly composed of parenchyma cells and irregularly distributed xylem and phloem bundles (Figure 4a) throughout the ground tissue. Raphide crystals (Figure 4b) and tannins (Figure 4a) were also occasionally found in the tissues.

Table 2. Histochemical-anatomical comparison between the peripheral, intermediate and central regions in slices of fresh-cut yam (*Dioscorea cayanensis*).

Structure	Regions of the yam ring		
	Peripheral	Intermediate	Central
Starch	Present	Present	Present
Raphide crystals	Present	Present	Present
Vascular bundle	Present	Present	Present
Tannins	Present	Present	Present
Vascular cambium	Present	Absent	Absent

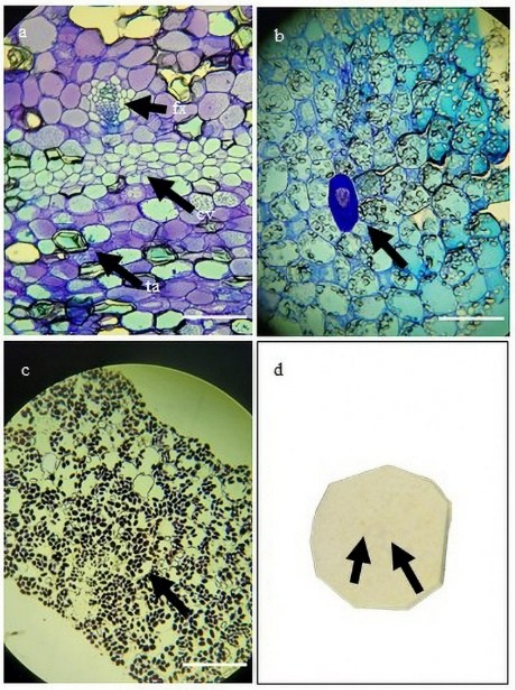


Figure 4. General view with different structures in the slice - (a) Cross section of vascular bundle (fx) - Tannins (ta) - Vascular cambium (vc) - (b) Raphide crystal - (c) Starch (d) Brown spots visualized macroscopically in the slice. Micro-photos of cross-section of the peripheral, intermediate and central regions of the slice of minimally processed yam (*Dioscorea cayanensis*) in the initial stage. Images (a – b) were stained with toluidine blue (0.05%) and image (c) was stained with Lugol to show starch content. The bar corresponds to 500 µm.

The anatomical characterization of minimally processed yam conducted by Morais et al. (2022) indicates that slices without periderm are composed mainly of starch parenchyma cells and some additional cambium with disorganized xylem and phloem, differing from the present study, where these structures were observed across all regions. Previous anatomical studies on *Dioscorea rotundata* revealed the presence of scattered vascular bundles, calcium oxalate raphide crystals, tannins near the vascular bundles, and idioblasts filled with granular brown substances in ground tissue, findings consistent with those observed here (DARKWA et al., 2020). Understanding yam anatomy is essential for correlating structural features with the chemical and biochemical processes occurring in minimally processed yam.

Visual Quality and Non-Homogeneous Distribution of Enzymatic Browning

Mass loss occurred consistently during storage, reaching approximately 3% (Figure 5e).
Titratable acidity in the slices across different regions remained constant throughout the storage period (Figure 5a). Similarly, pH (Figure 5b) and soluble solids content (Figure 5c) did not change during storage. The firmness (Figure 5d) of the slices also remained stable over the storage period.
There was no significant difference in browning index (Figure 6a) among treatments. Although no significant differences were observed among the regions for the browning index (Figure 6a), a temporal trend was observed during storage, with browning decreasing until day 12 and increasing thereafter.

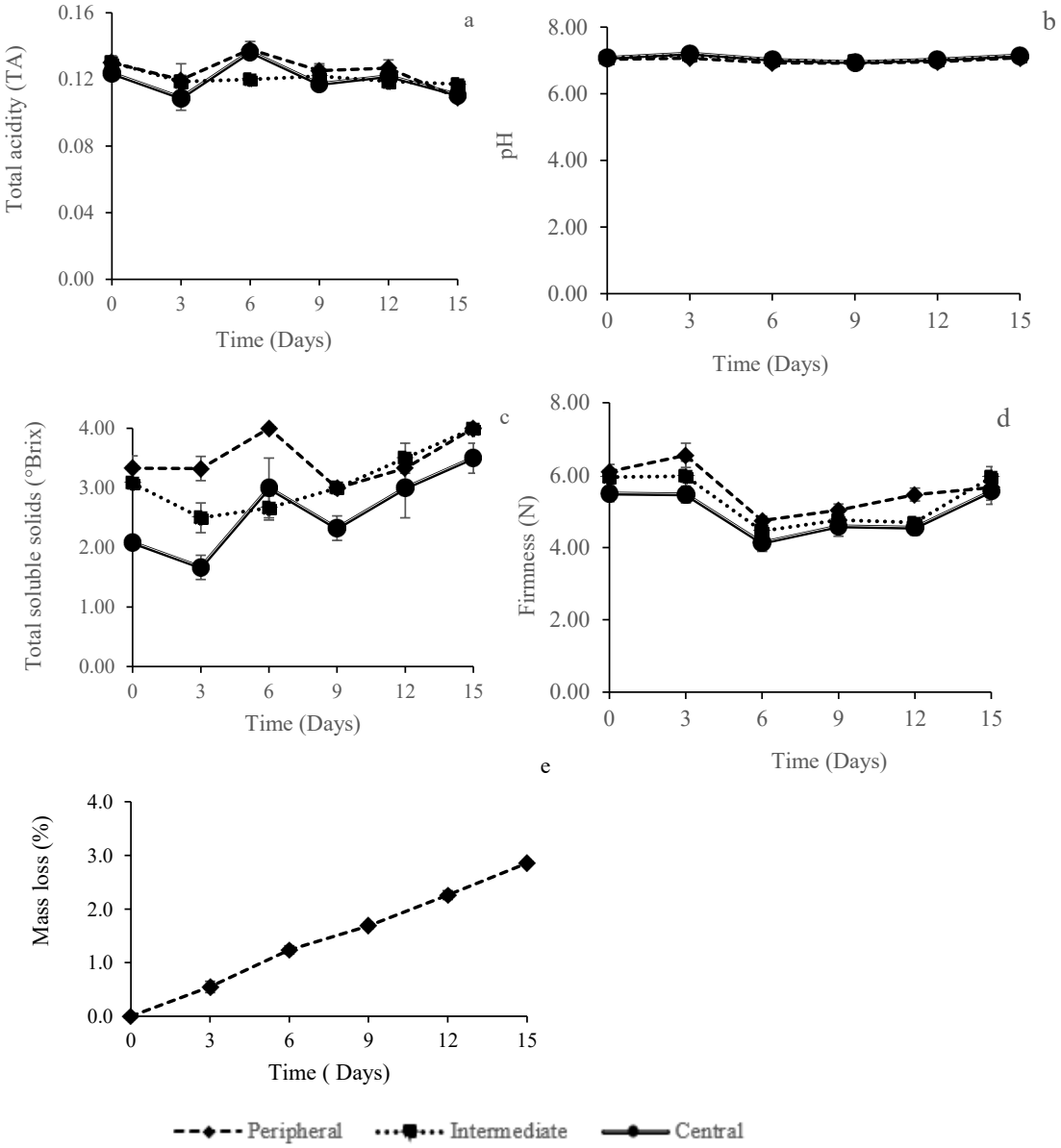


Figure 5. Acidity (a), pH (b), Soluble solids content (ºBrix) (c) Firmness (N) (d), and Mass loss (e). Physicochemical analyses in different regions of the fresh-cut yam slice. Bars represent standard error of the mean.

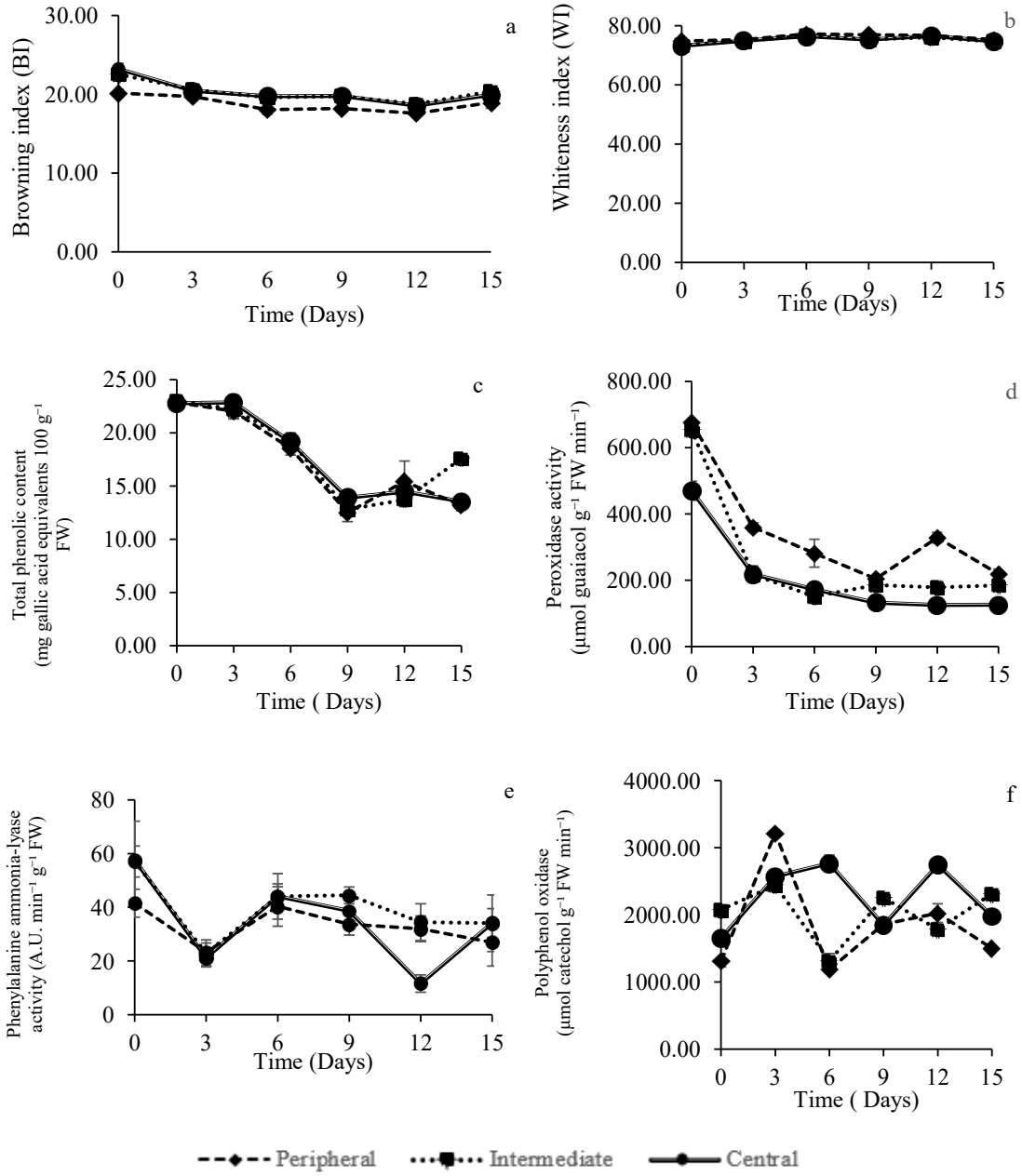


Figure 6. Darkening index (a), Whitening index (b), Total phenolic content (mg gallic acid equivalents 100 g^{-1} FW) (c), Peroxidase activity – POD (µmol guaiacol g^{-1} FW min^{-1}) (d), Activity of phenylalanine ammonia-lyase – PAL (U.A min^{-1} g^{-1} FW) (e) and Activity of polyphenoloxidase – PPO (µmol catechol g^{-1} FW min^{-1}) (f). Biochemical analyses in different regions of the fresh-cut yam slice. Bars represent standard error of the mean.

However, during the storage period, browning decreased until day 12 and then increased afterward. Contrarily, the whitening index (Figure 6b) increased until day 6, remained constant until day 12, and then decreased. Conversely, the whiteness index (Figure 6b) increased until day 6, remained relatively stable until day 12, and then decreased.

Contrary to this study's results, prior research (SIMÕES et al., 2015) reported a higher mass loss (8%) under the same storage temperature. This discrepancy may stem from differences in packaging material, as nylon multilayer packaging resulted in greater mass loss compared to PVC packaging (SIMÕES et al., 2015), which limited loss to 3% here.

The low mass loss observed at 5 °C likely maintained product quality, aided by a starch deposition layer on the slice surface, which acted as a physical barrier against dehydration (SIMÕES et al., 2015). Starch deposition on the slice surface (Figure 4d) was similarly observed in other studies (MORAIS et al., 2019) and was attributed to the extrusion of cellular contents caused by cutting (SIMÕES et al., 2015).

Visual analysis (Figure 7) revealed no differences among regions in terms of browning (Figure 7a) or whitening (Figure 7b).

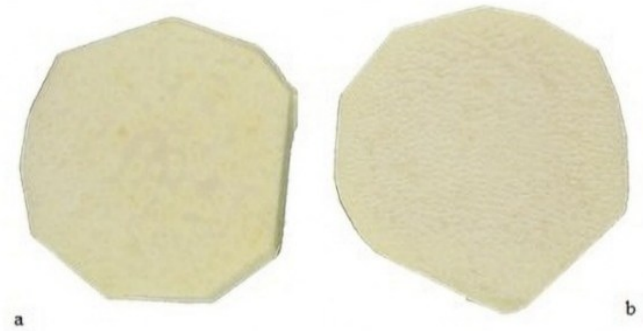


Figure 7. Visual analysis of the peripheral, intermediate and central regions of fresh-cut yam during 15 days of storage. Enzymatic browning (a); whitish streaks (b). Bars represent standard error of the mean. Slices of minimally processed yam.

Until day 12, all regions scored three or higher, which is considered the threshold for consumer acceptance. After day 12, browning intensified, resulting in a lower score (Figure 7). It is noteworthy that, due to the naturally white color of yam, whitening had minimal impact on the visual evaluation (Figure 7b).

The whitening on the surface of yam slices may result from the deposition or migration of starch released from the tissues after cutting and during storage, a phenomenon related to the structural and physicochemical properties of the starch present in the tuber (LOVERA et al., 2020).

Although noticeable, whitening did not significantly affect the visual assessment of yam quality, which remained acceptable up to 12 days of storage at 5 °C.

Enzymatic Browning and Enzymatic Activities

Peroxidase (POD) activity (Figure 6d) increased immediately after processing and decreased until day 6, after which it remained stable until the end of storage.

Phenylalanine ammonia-lyase (PAL) activity (Figure 6e) showed no variation between peripheral, intermediate, and central regions. During storage, its activity decreased by day 3, increased after day 6, and stabilized thereafter.

Polyphenol oxidase (PPO) activity (Figure 6f) remained consistent across peripheral, intermediate, and central regions of minimally processed yam. Although PPO activity stayed constant throughout storage, browning only became evident after day 12.

Enzymatic browning initially occurred around the vascular bundles (Figure 8a) as non-homogeneous brown spots dispersed across the surface of the slices (Figure 4d).

Peroxidase (POD) activity increased immediately after processing, likely due to cellular disruption from peeling and cutting (ZHANG et al., 2018), which led to oxidative stress and phenolic oxidation (GUAN et al., 2024). This behavior aligns with studies on carrots (SURJADINATA; JACOBO-VELÁZQUEZ; CISNEROS-ZEVALLOS, 2021), and red cabbage (GUAN et al. 2023), where injuries triggered reactive oxygen species (ROS) generation, enhancing antioxidant enzyme activities, including POD (GUAN et al., 2023).

The constant activity of polyphenol oxidase (PPO) (Figure 6) during storage contrasts with the late onset of browning (12th day), suggesting a possible role for the reduction in phenylalanine ammonia-lyase (PAL) activity (Figure 6e) in limiting the biosynthesis of phenolic compounds and delaying browning. Similar findings in broccoli suggest that browning involves the active induction of PAL and the synthesis of phenolic compounds, rather than pre-existing phenolics (GUAN et al., 2021).

The non-homogeneous enzymatic browning observed around vascular bundles corroborates prior studies on *Phalaenopsis* explants, where PPO activity localized near vascular bundles triggered oxidative browning (XU et al., 2015). These bundles were filled with tannins during browning, linking vascular damage to phenolic oxidation (XU et al., 2015).

Tissue Susceptibility

It was observed in the present study that enzymatic browning occurs not only in the tissue near the cut region but also around the vascular bundles, which are distributed non-uniformly throughout the parenchymal tissue of minimally processed yam (Figure 4d). These results are consistent with those found in studies reporting that internal tissues exhibit reduced phenolic metabolism and oxidative susceptibility (MORAIS et al., 2022). The browning intensity in yam slices varies by region (COELHO JÚNIOR et al., 2019), with superficial tissues near injuries showing greater oxidative responses compared to internal tissues. Therefore, the depth and location of the cut significantly influence the browning intensity in minimally processed yam slices (MORAIS et al., 2022).

For example, in minimally processed peach palm (FONSECA et al., 2023), it was found that the tissue in the superficial region is metabolically more active, and the color change occurs randomly along the surface, as well as in the median and basal regions of the stem. In cassava, discoloration occurs due to the oxidation of cells adjacent to the xylem as a defense strategy, forming the so-called dark band of xylem vessels. This phenomenon may be associated with the formation of tylosis occlusions within secondary vessels in the third tissue layer composed of phellogen and phelloderm, cambium and phloem, secondary vessels, and storage parenchyma cells (DJABOU et al., 2017).

The browning observed in the superficial region of the slices and intensely near the epidermis and around the

vascular bundles may result from the action of PPO (polyphenol oxidase) located throughout the pulp and distributed non-uniformly, as seen, for example, in apples (OLIVEIRA et al., 2018) and peach palms (FONSECA et al., 2023).

The present study provides insights into the anatomical and biochemical factors influencing browning and quality in minimally processed yam. These findings highlight the importance of anatomical features, enzymatic activities, and storage conditions in determining the visual and functional quality of minimally processed yams, emphasizing the role of controlled processing and storage strategies in extending product shelf life.

According to the results of this study, a diagram (Figure 8) was proposed to provide a complementary hypothesis to the mechanism of physical and physiological responses involved in the enzymatic browning of minimally processed yam, complementing what was previously proposed (COELHO JÚNIOR et al., 2019).

It is suggested that browning in the superficial region, resulting from oxidative reactions, not only leads to a gradient beginning in the tissue closest to the wound but also occurs intensely around vascular bundles, characterizing non-uniform enzymatic browning due to its random distribution. Handling, environmental conditions, and storage may trigger wound-related signaling processes that coordinate local and systemic responses in plant tissues. These responses may involve signaling molecules associated with wound perception and oxidative stress, ultimately affecting phenolic metabolism and the activity of oxidative enzymes, as proposed by Coelho Júnior et al. (2019). In the present study, the specific signaling molecules involved were not identified; therefore, this mechanism is proposed as a hypothesis based on the observed anatomical and biochemical responses.

Additionally, it is suggested that yam can be cut into different shapes, and biochemical analyses can be performed in different regions of the sliced product (peripheral, intermediate, and central), as there are no significant differences between these parts.

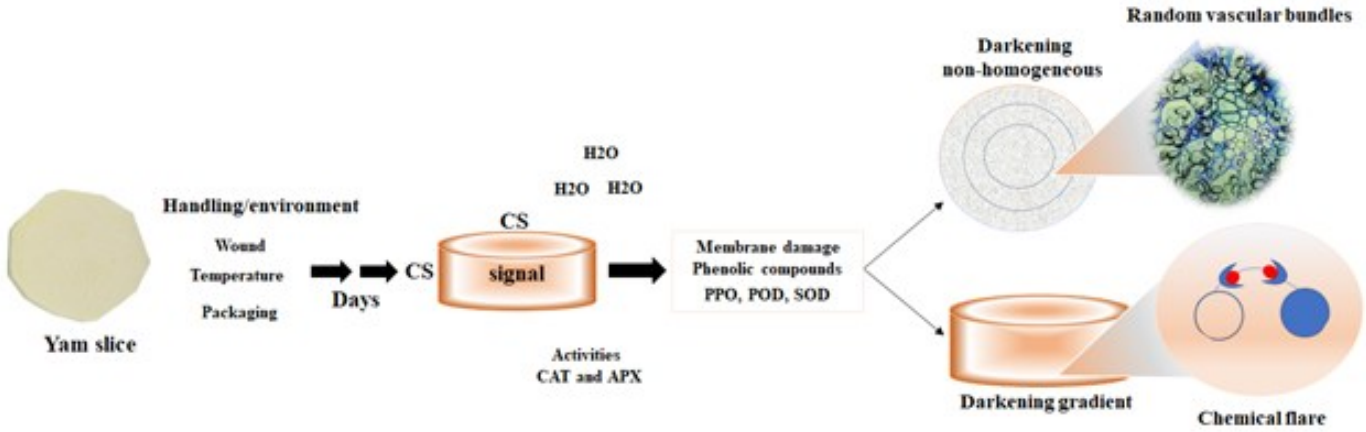


Figure 8. Mechanism for non-homogeneous enzymatic browning in fresh-cut yam slices in addition to the mechanism proposed by Coelho Júnior et al. (2019).

During the storage period, the yam slice is vulnerable to factors arising from handling and/or environment, such as wound, temperature and type of packaging. These factors in combination can result in the production of a chemical signal (unknown) and its transduction, causing damage to the membrane and an increase in the content of phenolic compounds and the activity of oxidative enzymes (PPO and POD). These events result in the propagation of enzymatic browning not only in a gradient manner (from outside to inside), but also non-homogeneous darkening characterized by intense darkening around randomly distributed vascular bundles. At the end of storage, the surface region shows brown spots distributed throughout the entire length of the yam's fundamental tissue.

Understanding the browning process and the anatomical characteristics of fresh-cut yam is essential for developing technologies aimed at improving the quality and shelf life of minimally processed products.

Cutting and refrigerated storage are viable strategies to maintain the quality of minimally processed yam, with positive implications for the food industry by reducing economic losses and extending the shelf life of products. However, further studies are needed to explore the molecular mechanisms involved in enzymatic browning more deeply and to develop more effective methods to control this phenomenon. The analysis of different yam varieties and the application of other preservation technologies could also broaden the knowledge about the minimal processing of these tubers.

CONCLUSION

Yam slices are composed mainly of starch, parenchyma cells and some additional cambium with disorganized xylem and phloem.

The enzymatic browning is associated with the distribution of vascular bundles and the enzyme PPO throughout all regions of slice, and its propagation occurs non-homogeneously. The enzymes involved in oxidative reactions and regulating the oxidation of phenolic compounds are interconnected, contributing to tissue browning.

These results are important for improving the quality of minimally processed yam, providing a solid foundation for future research and practical applications in the food industry.

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