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Effect of Cassava Starch-Based Composite Coating on the Postharvest Softening Index and Physicochemical Parameters of *Dacryodes edulis* Fruits

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A B S T R A C T

The safou (*Dacryodes edulis*) is an important seasonal fruit, but 50% of the harvest is lost due to its short shelf life of just two or three days, which reduces its economic value. This study aimed to formulate edible coatings to extend the shelf life of safou. Different blends were prepared by mixing cassava starch with various concentrations of glycerol and potassium sorbate to produce different types of gel coating. The results showed that a coating containing 20% glycerol and 5% potassium sorbate ($G_{20}S_5$) was the most effective at extending the shelf life of fresh safou fruit. Furthermore, no significant variation in physicochemical parameters such as pH, weight loss, water content, ash content, protein content, lipid content, total carbohydrate content and fibre content was observed in the coated fruit during the first nine days. Therefore, the $G_{20}S_5$ coating formulation delays the biochemical deterioration and post-harvest senescence of safou fruit for nine days while maintaining its nutritional quality at room temperature.

Introduction

Post-harvest loss, which refers to inedible state of food due to deterioration in the organoleptic quality of the food produced. This results in significant losses from harvest to consumption, which is a real problem for agricultural production (Shahbazi *et al.,* 2025). Fruit and vegetables are highly beneficial to human health and are important sources of carbohydrates, proteins, phytochemicals, vitamins, minerals, dietary fibers that are good for human health. Vitamins A (carotene), C, and E, magnesium, zinc, phosphorus, and folic acid are some of the essential constituents (Bancal & Ray, 2022). They are generally harvested with high moisture content and are highly perishable due to dehydration, which causes mechanical damage after harvest.

These post-harvest losses therefore have a negative impact on the four pillars of food security: food availability, access, utilization and stability (Jain *et al.,* 2023). The extent of post-harvest losses in fruit and vegetables varies from country to country. It depends on how the value chain is organised. in many African countries, the post-harvest losses of food cereals are estimated at 25 % of the total crop harvested (Mmereki *et al.,* 2024). Amoun them, The African pear tree (*Dacryodes edulis* (G.Don) H.J.Lam; Burseraceae) a tropical oleigenous fruit tree that possesses enormous remarkable both nutritionally and economically in Africa. in Côte d'Ivoire safou (*D. edulis*) is a fruit cultivated in Southeast (Azaguié, Azaguié-Blida and Grand-Morié) (Kadji *et al.,* 2016a). Safou pulp would be an important source of oil (Kadji *et al.,* 2016b) and thus find its place in the food, pharmaceutical, and cosmetic industries. Pulp powder may be useful in the human food industry. As climacteric fruits, safou is perishable and has a shelf life of only two to three days after harvest. Every year, producers suffer significant post-harvest losses due to the rapid softening of African pear pulp. According to Dossou *et al.,* 2018a, this softening is due to the progressive and significant degradation of the cell wall carbohydrates over time, leading to their disintegration. In addition, softened African pear is no longer marketed and represents a loss for traders. To reduce post-harvest losses, several methods have focused on preserving the freshness of safou, in previous studies. These method include the usage of polyethylene packaging, fungicide treatments, 1-methylcyclopropene (1-MCP), and ethylene inhibitors in combination with 1-MCP and benomyl to minimise post-harvest losses of *D. edulis* (Fotouo & Lekagne, 2022). However, these methods have been expensive, inappropriate, and inaccessible to farmers, customers, and consumers in the *D. edulis* value chain. Currently, coating methods are one of the safest and most viable alternatives for preserving vegetables. They have been developed to replace and reduce the use of other types of chemicals and synthetic compounds that can be harmful to consumer health. They also help to preserve phytonutrients (antioxidants, phenolics, and phenolics pigments), control physicochemical properties, and extend the shelf life of produce by reducing moisture loss, reducing spoilage, and preserving texture (Pham *et al.,* 2023) when applied to the surface of these fruits and vegetables. To contribute to the preservation of safou, a starch-based coating method was used with the aim of analyzing the effect on the physicochemical properties of safou during softening.

Materials and Methods

Collection of Materials

The safou (*Dacryodes edulis*) fruits were harvested at physiological maturity directly from the place of cultivation of producers in the Grand-Morié sub-prefecture (Agboville), Agnéby-Tiassa region, southern Côte d'Ivoire (Figure 1A).

A total of 250 units of fruits were transported from the field to the laboratory. It was wasted 50 fruits, and those 200 fruits were used for physico-chemical analyses. Native starch extracted from harvested Yavo variety cassava tubers (*Manihot esculenta*) in this study. This was obtained harvested at maturity in an experimental plot at the CSRS Bringakro research station in Côte d'Ivoire (Figure 1B).

Cassava starch extraction

Cassava (*Manihot esculenta*) starch was extracted by the method described by Amani *et al.,* 1993. Peeled tubers, cut into small pieces, were ground in a Moulinex France blender. The ground material was then taken up in a sodium chloride solution (4% w/v) to separate the proteins from the starch. It is then passed through a series of sieves with mesh sizes of 500, 250, and 100 µm, respectively. The starch milk obtained undergoes a series of decantations and washes (at least four times). The product obtained is then dried in an oven at 45 °C for 48 hours. The dry product obtained (Figure 2) is then ground, sieved, and stored in a hermetically sealed container until further analysis.

Coating production and application

The coating gel preparation was conducted in accordance with the method outlined by Mohammed *et al.,* 2022, with minor adaptations. Cassava suspension was prepared by means of the dissolution of 5 g of isolated cassava starch in 100 mL of distilled water. To this suspension, the glycerol (G) plasticizer was introduced into the mixture at varying concentrations, namely 20%, 25%, and 30% of the relative mass of starch in suspension. Subsequently, potassium sorbate (S) is incorporated into the mixture at proportions of 5, 10 and 15% by weight relative to the weight of starch. The mixture was subsequently placed in a water bath at a temperature of 70 ± 5°C, with constant stirring at a rate of 750 rpm, for a duration of 5 minutes, resulting in a slurry-like consistency suspension. A total of nine types of edible coverings were developed for each of the treatment groups (Table 1). The following designations were used: $G_{20}S_5$, $G_{20}S_{10}$, $G_{20}S_{15}$, $G_{25}S_5$, $G_{25}S_{10}$, $G_{25}S_{15}$, $G_{30}S_5$, $G_{30}S_{10}$ and $G_{30}S_{15}$. The gels obtained were then cooled to 15°C prior to the coating of the fruit. The temperature was measured using a digital thermometer (JTH10 pocket thermometer).

Determination of the effective concentration of the formulated coating gel

The safou (*Dacryodes edulis*) were divided into ten batches, with each batch containing fifteen fruits. The fruits were then subjected to a series of cleansing procedures. Initially, the items were washed with water, followed by a sanitization with a sodium hypochlorite solution at 100 ppm for a duration of 10 minutes. Subsequently, the samples were rinsed in a chlorinated water solution at a concentration of 3 ppm. The final stage of the process involved the placement of the fruits in plastic trays for desiccation at a constant temperature of 27 ± 1.2 °C. Nine of these batches were utilised for the experimental coating formulation, and one batch was designated as a control (uncosted raw safou). The coating treatment is initiated by immersing the fruit in the coating gel for a duration of 15 seconds (Figure 3). Thereafter, the excess gel was carefully drained away, and the fruits were subjected to a drying process in the laboratory for a period of 12 hours. The drying was carried out at a temperature of 27 ± 1.2 °C. Subsequently, the samples were stored for a period of nine days at the same temperature. On the ninth day, samples were collected for the purpose of determining the softening index. Fruits with a low softening index are indicative of the optimal coating gel concentration.

Effect of the application of the optimal edible coating gel on the fruits physico-chemical parameters

Following the determination of the optimum coating gel formulation for the purpose of enhancing the preservation of safou, the subsequent phase involved its practical application. Consequently, the totality of the fruit batch (n = 6) was utilised to ascertain the physicochemical characteristics of the pulp. Each batch contained 25 fruits. For the purposes of this study, the initial five batches, encompassing 125 fruits, were subjected to coating, while the sixth batch of 25 uncoated fruits served as a control group. The safou fruits were then stored for 12 days at a laboratory room temperature of 27 ± 1.2°C. Samples of safou pulp were collected at three-day intervals according to six stages of fruit softening (D0, D3, D6, D9, and D1), and then the physico-chemical characteristics of the safou pulps were evaluated at the six stages. The softening index (SI) of safou fruits was measured using a K19500 penetrometer (Koehler Instrument Company, Inc., New York, USA), which was equipped with a 47.5 g piston. Measurements were taken at two points on opposite sides of the equatorial zone of each fruit. The pH was determined using a pH meter (pH-Vision 6071, Jenco Electronics Ltd, San Diego, USA) with a 10 g sample diluted in 100 ml of distilled water. The proximate parameters (carbohydrate, fat, protein and ash) of the safou were determined using the Association of Official Analytical Chemists (AOAC, 2012) method. The nitrogen content of the samples was determined using the micro-Kjeldahl method. The nitrogen value obtained was multiplied by 6.25 to convert it to crude protein. Weight difference methods were used to determine the moisture and ash content levels, while the crude fat content of the safou was determined using the AOAC procedure with petroleum ether as the solvent. Carbohydrate content was calculated using a different method and expressed as a percentage of dry matter. Loss of mass (ΔM), calculated as the difference in mass before and after storage, is given in grams according to the method described by Kassebi & Korzenszky, 2022.

Statistical analyses

All analyses reported in this study were performed in triplicate. Data were evaluated by analysis of variance (ANOVA) and Duncan's multiple range test (p = 0.05). The correlation between the different parameters was assessed by Pearson's test of independence. Statistical analyses were performed using Statistica 7.1 software (Stat Soft Inc., Tulsa, USA).

Results and Discussion

Variation of the softening index of safou as a function of the different coating gel

The softening of *Dacryodes edulis* fruits (safou) is attributable to a delicate life process, including physiological, biochemical, and metabolic changes that occur during the ripening stage or after harvest (Peng *et al.,* 2022). This phenomenon is known to result in a reduction in post-harvest life. The development of cassava starch-based composite coatings in this study was motivated by the necessity to preserve safe fruits. In the present study, the G20S5 formulation (comprising glycerol at a concentration of 20% and potassium sorbate at a percentage of 5%) yielded a low softening index (1.81 mm) for coated safou fruits, in comparison to uncoated safou (3.42 mm). The present study demonstrated that a combination of 20% glycerol concentration and cassava starch for safou coating gel was optimal for safou conservation, with a nine-day shelf life observed after harvesting. Rezaei & Motamedzadegan (2015) obtained the good mechanical and barrier properties for this same concentration (20%) of glycerol into gelatin-based edible films containing clay nanoparticles (Rezaei & Motamedzadegan, 2015). Glycerol is a clear compound that is readily soluble in water, thereby increasing the solution's viscosity and binding water in accordance with its concentration (Adjouman *et al.,* 2018) This property renders it a suitable plasticiser for use in the formulation of food-grade gels and films. The influence of glycerol on film thickness, density, moisture content, solubility, swelling capacity, and water absorption is significant (Bebartta *et al.,* 2020). The second additive used in the formulation of our gels is potassium sorbate. It is one of the most frequently employed preservatives in the production of edible films (Tarek *et al.,* 2022). It is among the most extensively studied antimicrobial agents (Dong *et al.,* 2024). Potassium sorbate, the most soluble form of sorbate, has been shown to possess significant antifungal properties (Sushant *et al.,* 2022). In this study, the optimal concentration of potassium sorbate was determined to be 0.25g per 100g of gel solution. These results are comparable to those obtained by Dave *et al.,* 2017 in a similar study on pears (*Pyrus communis* L.). The findings of this study demonstrate a positive correlation between the quality of coating gels and the concentration of potassium sorbate. Indeed, as demonstrated by some authors, the sorbate content has been shown to influence the physical properties of starch-based films (Flores *et al.,* 2007; Shen *et al.,* 2010) or a mixture of starch and chitosan (Vásconez *et al.,* 2009). Indeed, the work of Famá *et al.,* 2005 demonstrated that increasing potassium sorbate led to a decrease in the crystallinity of edible tapioca starch films, consequently increasing the gas permeability of these films. Increasing the potassium sorbate content would also influence the water vapour permeability of edible films. According to Shen *et al.,* 2010, high concentrations of potassium sorbate form fragile films, which facilitate the permeation of water vapour.

Impact of the optimal formulation coating ($G_{20}S_5$) on the physicochemical parameters of safou

The softening index is a practical method of assessing fruit ripeness, which is essential for determining shelf life and market value. The findings reveal that the softening index of coated safous varied minimally between the initial days (0.85 ± 0.03 mm) and day 6 (0.87 ± 0.02 mm) (Figure 5). However, significant variation ($p \leq 0.05$) was observed from day 9 (1.81 ± 0.02 mm) to day 12 (2.93 ± 0.06 mm). The softening of safou is due to the degradation of constituent molecules in the fruit's cell walls, such as cellulose, hemicellulose, and pectin, by enzymes such as pectin methyl esterase, polygalacturonase, and cellulase (Moreira *et al.,* 2022) during ripening (Dossou *et al.,* 2018b), which favours subsequent disassembly of the cell wall (Shi *et al.,* 2023). Treatment extended the shelf life of safou from three to nine days. Edible coatings are commonly used to extend the shelf life of fresh produce (Yaashikaa *et al.,* 2023). These coatings suppress respiration and control moisture loss, among other functions (Devi *et al.,* 2024). They provide an effective barrier that controls the exchange of gases between fresh produce and the surrounding atmosphere. This slows down respiration and delays ripening and softening during post-harvest storage (Devi *et al.,* 2024). No loss of mass in the coated safous was observed until day three of softening. From day 6 onwards, a loss of mass of 0.7 ± 0.03% was observed, which increased significantly by day 12 to 4.5 ± 0.02% (figure 6). According to Dadzie & Amoah, 2019, mass loss generally increased for both coated and uncoated fruits throughout the storage period; however, the rate of weight loss was higher for uncoated fruits than for coated fruits. These results suggest that the coatings functioned as semi-permeable barriers, restricting the movement of oxygen, carbon dioxide, and moisture. Consequently, breathing intensity, water loss and oxidation were reduced (Gupta *et al.,* 2022).

The fundamental mechanism of mass loss in fresh produce is indeed linked to vapour diffusion, driven by water vapour pressure (Umeohia & Olapade, 2024). As demonstrated by Lufu *et al.,* 2019, this phenomenon is also linked to respiration, which in turn causes a reduction in the mass of fruit and vegetables.

Table.1 Experimental matrix of coating gel formulations

Formulation	Water (mL)	Starch (g)	Glycerol (g)	Potassium sorbate (g)
$G_{20}S_5$ (glycerol 20% + Potassium sorbate 5%)	100	5	1	0.25
$G_{20}S_{10}$ (glycerol 20% + Potassium sorbate 10%)	100	5	1	0.5
$G_{20}S_{15}$ (glycerol 20% + Potassium sorbate 15%)	100	5	1	0.75
$G_{25}S_5$ (glycerol 25% + Potassium sorbate 5%)	100	5	1.25	0.25
$G_{25}S_{10}$ (glycerol 25% + Potassium sorbate 10%)	100	5	1.25	0.5
$G_{25}S_{15}$ (glycerol 25% + Potassium sorbate 15%)	100	5	1.25	0.75
$G_{30}S_5$ (glycerol 30% + Potassium sorbate 5%)	100	5	1.5	0.25
$G_{30}S_{10}$ (glycerol 30% + Potassium sorbate 10%)	100	5	1.5	0.5
$G_{30}S_{15}$ (glycerol 20% + Potassium sorbate 15%)	100	5	1.5	0.75

G: Glycerol; S: Potassium sorbate, n=255 units of fruits.

Table.2 Effect of coating gel (G20S5) on physico-chemical parameters of safou *Dacryodes edulis* during post-harvest softening

Parameters (%)	Raw uncoated safou (Days 0)	Coated safou from starch-based edible coatings $G_{20}S_5$				
		Days 0	Days 3	Days 6	Days 9	Days 12
pH	4.1 ± 0.01^a	4.1 ± 0.01^a	4.1 ± 0.03^a	4.1 ± 0.02^a	4.3 ± 0.02^b	4.5 ± 0.01^c
Moisture	41.55 ± 0.13^a	41.56 ± 0.26^a	41.56 ± 0.23^a	41.57 ± 0.14^a	41.64 ± 0.12^a	44.14 ± 0.14^b
Proteins	3.35 ± 0.34^a	3.34 ± 0.15^a	3.34 ± 0.13^a	3.36 ± 0.34^a	3.47 ± 0.16^a	5.26 ± 0.21^b
Lipids	37.26 ± 0.42^a	37.26 ± 0.2^a	37.26 ± 0.17^a	37.25 ± 0.22^a	37.12 ± 0.4^a	35.12 ± 0.43^b
Ashes	2.97 ± 0.03^a	2.97 ± 0.01^a	2.97 ± 0.05^a	2.97 ± 0.01^a	2.97 ± 0.03^a	2.99 ± 0.02^b
Fibers	2.74 ± 0.01^a	2.73 ± 0.0^a	2.73 ± 0.03^a	2.72 ± 0.03^a	2.72 ± 0.04^a	1.53 ± 0.06^b
Carb.	12.13 ± 0.18^a	12.14 ± 0.07^a	12.14 ± 0.12^a	12.14 ± 0.14^a	12.08 ± 0.12^a	10.96 ± 0.21^b

Carb.: Carbihydrates, averages with different letters on the same line are statistically significant ($p < 0.05$).

Figure.1 *Dacryodes edulis* (A) and *Manihot esculenta* tuber var Yavo (B)

Figure.2 Extracted Cassava starch

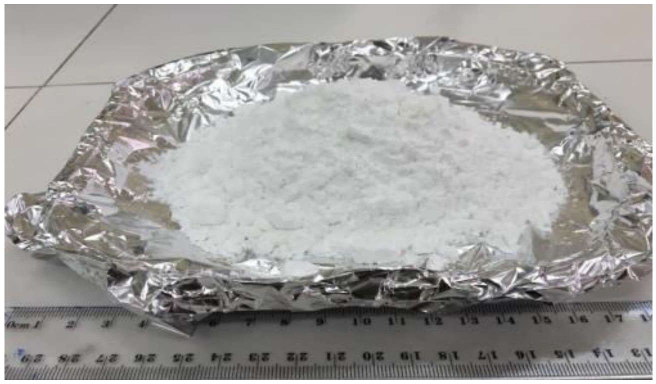


Figure.3 Coating of *Dacryodes edulis* with translucent cassava starch-based gel

Figure.4 *Dacryodes edulis* softening index variation

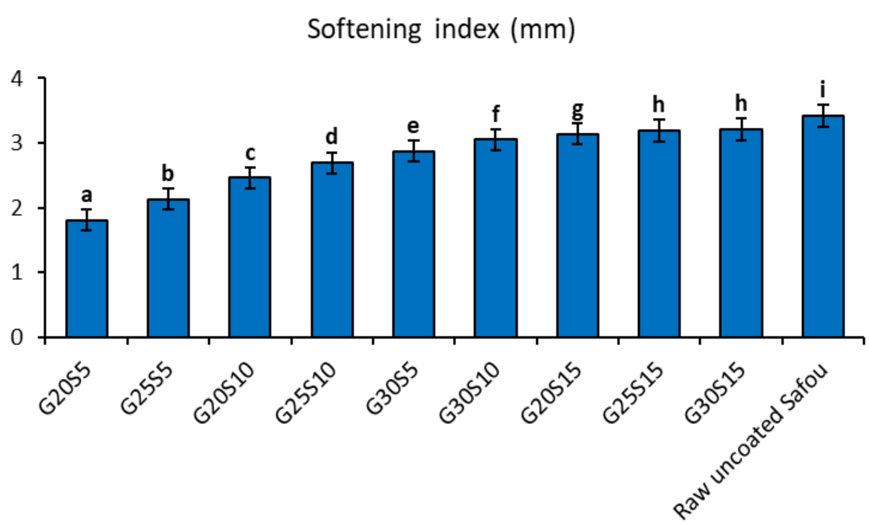


Figure.5 Evolution of the softening indexes of *Dacryodes edulis* fruits

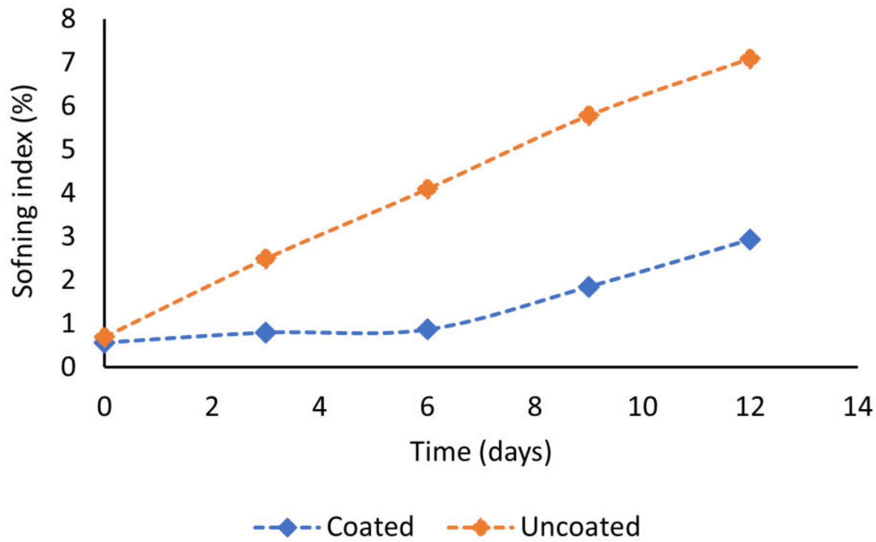
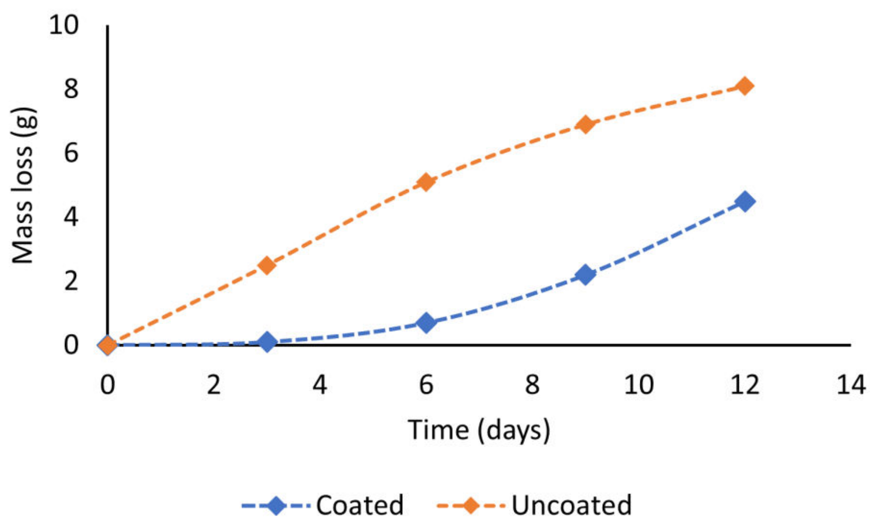


Figure.6 Evolution of the mass losses of *Dacryodes edulis* fruits



The reduced mass loss of coated safou could be attributed to the additional barrier against diffusion through the stomata. In fruit, the primary mechanism of water loss is through the skin. According to Falquetto-Gomes *et al.,* 2024, obstructing the stomata by coating surfaces with a protective layer can reduce water loss. Starch-based coatings have been shown to effectively limit safous's mass loss. This is supported by somes studies in which various authors have coated different types of fruit, tomatoes (*Solanum lycopersicum*) (Adjouman *et al.,* 2018) and guavas (*Psidium guajava* L.) (Moreira *et al.,* 2022). The acidity of fruit is an important factor in determining its quality and acceptability (Etienne *et al.,* 2013). In this study, the pH value remained consistent from the first day (4.1 ± 0.01) to day 6 (4.1 ± 0.02). However, there was a significant variation ($p \leq 0.05$) increase in the pH value from day 9 (4.3 ± 0.02) to day 12 (4.5 ± 0.01). The pH value of fruit and vegetables increases as they ripen, but this varies depending on the cultivar and storage conditions (Hailu & Bekele, 2024). The pH value of fruit and vegetables is linked to the presence of organic acids (Zhang *et al.,* 2023). During post-harvest storage, acid metabolism resulting from ripening continues to convert starch and acids into sugars, thereby increasing the pH of fruit and vegetables (Pott *et al.,* 2020). The present study results regarding safou coated with a cassava starch-based gel are corroborated by prior research indicating that coatings can regulate post-harvest alterations in physicochemical properties (Adjouman *et al.,* 2018; Das *et al.,* 2013; Dos Reis *et al.,* 2015). An increase in pH results from an increase in the respiration rate, which causes the degeneration of organic acids (Anany *et al.,* 2009).

These acids are substrates for enzymatic reactions, which leads to their depletion and thus an increase in pH (Drincovich *et al.,* 2016). There is no significant variation in water content between day 0 (41.56 ± 0.26%) and day 9 (41.64 ± 0.14%). However, a significant increase was observed at day 12 (44.14 ± 0.14%). The protein content was 3.34% ± 0.15% on day 0 and remained stable until day 9 (3.47% ± 0.16%), when the fruit softened. However, the protein content increased significantly on day 12 (5.26 ± 0.21%), by which time the fruit was fully soft. The same variation was observed for the oil content, which remained constant from day 0 (37.26 ± 0.2%) to day 9 (37.12 ± 0.4%), before decreasing significantly on day 12 (32.62 ± 0.43%). The ash content remained constant from day 0 (2.97 ± 0.01%) to day 9 (2.97 ± 0.03%). However, a significant increase was observed on day 12 (2.99 ± 0.02%). The fibre content decreased significantly only between days 9 and 12 (from 2.72 ± 0.04% to 1.53 ± 0.06%). The total carbohydrate content remains statistically constant from day 0 (12.14 ± 0.07%) to day 9 (12.08 ± 0.14%). It then decreased significantly on day 12 (10.96 ± 0.21%).

After harvesting, fruits and vegetables undergo physiological and biochemical processes that result in a deterioration in quality (Lv *et al.,* 2024). During respiration, carbohydrates, organic acids, proteins and fats are metabolised (Pott *et al.,* 2020). The lipids they contain undergo oxidative degradation during post-harvest storage due to the action of oxygen, moisture and enzymes (Gidado *et al.,* 2025). Then using edible coatings is a promising way to preserve fruit quality (Blancas-Benitez *et al.,* 2022). In this study, the treatment applied to safou made it possible to maintain constant levels of nutrients (carbohydrates, lipids, protein, fibre and ash) for up to nine days after harvest. This result is supported by the findings of several other studies (Adjouman *et al.,* 2018; Ashraf *et al.,* 2025; Reis *et al.,* 2025). Edible coatings have demonstrated efficacy in prolonging the shelf life of various agricultural products. The utilisation of edible coatings has been demonstrated to curtail deleterious biochemical alterations, thereby prolonging the shelf life of fruit and vegetables (Do Nascimento *et al.,* 2023). These substances act as barriers to water loss and gas exchange, thereby controlling the transfer of moisture, oxygen, carbon dioxide, lipids, and aromatic components. The effect of this is similar to that promoted by storage under controlled or modified atmosphere

In conclusion, this study confirms that the technology developed to preserve safou fruit *(Dacryodes edulis)* in a fresh state using an edible composite coating has resulted in the creation of several formulations with different concentrations of glycerol and potassium sorbate. The study showed that the $G_{20}S_5$ gel formulation (comprising 20 per cent glycerol and 5 per cent potassium sorbate) was the most effective at delaying softening. Finally, the application of the $G_{20}S_5$ gel formulation to safou fruit helped to preserve the physicochemical properties of the pulp for up to 9 days after harvest.

Author Contributions

Djédjé Blétro Patrick Gérard: Conceived the original idea, designed the model, and wrote the manuscript; Kouadio Marcellin Konan: Designed the model and the computational framework and analysed the data; Koné Fankroma Martial Thierry: Visualization, Supervision; Dabonné Soumaïla: Visualization, Supervision.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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