Bioactive edible coatings incorporating extract from unfermented and fermented *Tamarindus indica* residues for the conservation of grapes of the cultivar 'Italia'[1]

Tacila Rayane Jericó Santos[2], *Patrícia Nogueira Matos*[2], *Luciana Cristina Lins de Aquino Santana*[2*]

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ABSTRACT

Several studies have used edible packaging for food preservation due to its composition of biodegradable polymers and natural additives. In the present work, bioactive extracts obtained from the fermented and unfermented flour of tamarind residues were incorporated into formulations of edible coatings for the conservation of grapes of the cultivar 'Italia'. The flours extracts were obtained with 80% aqueous ethanol solution. Edible coating formulations containing 10 g L^{-1} cassava starch and 5 g L^{-1} chitosan without extract or containing 10 g L^{-1} unfermented or fermented flour extract were prepared and applied to grapes stored at 25 °C for 15 days. The physical-chemical characteristics of the coated and uncoated fruits were similar during storage. The addition of fermented and unfermented flour extracts to the edible coatings improved the in vitro antioxidant activity of the grapes, especially that determined by the ferric reducing antioxidant power method, on the last day of storage, with emphasis on grapes coated with a formulation containing fermented residue extract. Extracts of tamarind residues incorporated in edible coatings promoted the acquisition of bioactive coatings with the potential to improve the antioxidant activity of grapes during 15 days of storage at 25 °C.

Keywords: chitosan; solid-state fermentation; active packaging; antioxidants; conservation.

INTRODUCTION

In recent decades, the food industry has been under pressure to adapt to increasing consumer demand for quality products free of preservatives and chemical additives. Aiming to replace conventional plastic packaging, several researchers have developed edible packaging that can be in the form of films previously made and then adhered to the product or coatings that are formed directly on the food (Díaz-Montes & Castro-Muñoz, 2021a). Chitosan is the polymer most often used for the elaboration of edible films and coatings due to their chemical and biological properties, such as formation of hydrogen bonds and hydrophobic interactions, biocompatibility, biodegradability and bioactivity (Díaz-Montes & Castro-Muñoz, 2021[a]). Chitosan can be used in association with others materials as reported by Díaz-Montes *et al.* (2021a) and (2021b), who used a dextran/chitosan blend film for bio-packaging of mushrooms (*Agaricus bisporus*) and chitosan mixed with oligodextrans (synthesized directly by *Leuconostoc mesenteroides), respectively*.

In recent years, several studies have reported an increase in the efficiency of films or edible coatings via the incorporation of bioactive substances such as essential oils,

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[1] This work is part of the doctoral thesis of the first author.
[2] Universidade Federal de Sergipe, Departamento de Tecnologia de Alimentos, Laboratório de Microbiologia de Alimentos e Bioengenharia, Programa de Doutorado em Biotecnologia (Rede Nordeste de Biotecnologia - RENORBIO), São Cristóvão, SE, Brazil. tacilarayane@hotmail.com; patynogueiram@hotmail.com; aquinoluciana@hotmail.com
*Corresponding author: luciana.santana@academico.ufs.br

extracts or pure compounds. Such substances may contain compounds with antimicrobial, antioxidant, antimutagenic, anti-inflammatory, anti-cancer, apoptotic and anti-cholesterol properties, which can improve the characteristics of coatings and consequently the quality of food and shelf life (Dehghani *et al.,* 2018; Díaz-Montes & Castro-Muñoz, 2021). In recent research, milk protein composites reinforced with bioactive compounds, nanoparticles or plasticizers have shown the potential to form films carrying antimicrobial and antioxidant compounds, pigments and flavourings, which can be used in the pharmaceutical, food and biomedical industries (Garavand *et al.*, 2022).

One of the causes of food spoilage is oxidation. However, the addition of antioxidants to foods requires high concentrations, and these can easily deteriorate. Alternatively, films or edible coatings can be carriers of antioxidant substances, thus preventing oxidation damage to food (Saberi *et al.,* 2017). Extracts of agro-industrial residues are an alternative source of natural antioxidants, and they can be incorporated in films or edible coatings.

Studies have also revealed that the antioxidant potential of extracts from agro-industrial residues can be improved after being subjected to fermentation processes. Particularly, solid-state fermentation (SSF) has been used as a tool to facilitate the release of bioactive compounds from agro-industrial residues or the production of new compounds, through extracellular enzymes produced by microorganisms during the process (Dey *et al.,* 2016; Dulf *et al.,* 2016; Handa *et al.,* 2019).

SSF promotes the bioconversion of conjugated forms of phenolic compounds into their soluble forms, with a consequent change in the profile of bioactive substances and an increase in their biological activity. For this, the selection of the appropriate microorganism is one of the most important criteria of the process, which can use bacteria, yeasts or fungi. Specifically, *Aspergillus niger* has been widely used in these processes due to its ability to synthesise more than 19 types of enzymes, which degrade the cell wall of solid material and release bioactive compounds present in residues that were in the bound form or synthesise new ones (Madeira Junior *et al.*, 2015; Dulf *et al.,* 2015; Dey *et al.,* 2016; Dulf *et al.,* 2017; Sadh *et al.,* 2018). In previous studies, Santos *et al.* (2020b) reporteded that ethanolic extracts obtained from fermented tamarind mixed peel and seed flours showed an increase of 67% and 650% in total phenolic and total flavonoid contents, respectively, good antioxidant activity and increased levels of gallic acid, ethyl gallate and propyl gallate, when compared with extracts obtained from unfermented flour. On this basis, these extracts, if incorporated in films or edible coatings, can improve the antioxidant potential of these materials, promoting better preservation of food.

Particularly, table grapes (*Vitis vinifera* L.) of the cultivar 'Italia' are considered important sources of antioxidant phenolic compounds; however, they are a highly perishable harvest and subject to loss of colour and firmness during storage (Souza *et al.,* 2021). Some researchers have used films or coatings containing substances to prolong the shelf life and improve the antioxidant potential of this fruit. Souza *et al.,* (2021) obtained a high phenolic content and antioxidant activity in grapes of the cultivar 'Italia' using an edible coating containing 2.0% alginate, 0.5% galactomannans, 0.5% cashew gum and 2.0% gelatine after 12 days of storage at 25 °C. Santos *et al.* (2020a) applied tamarind (*Tamarindus indica* L.) seed starch on Isabel grapes (*Vitis labrusca* × *Vitis vinifera* L.), and the quality of grapes was maintained for 12 days of storage at 12 °C and 85% relative humidity, although the antioxidant activity was not evaluated in this study. Melgarejo-Flores *et al.* (2013) applied pectin coatings containing cinnamon leaf oil to grapes. However, there was no reduction in fungal growth, and the highest antioxidant activity was observed after 15 days of storage. Sánchez-Gonzáles *et al.* (2011) applied coatings based on hydroxypropylmethylcellulose or chitosan with bergamot essential oil in table grapes, cv. Muscatel, and the antioxidant activity did not increase after 3 days of cold storage. Pastor *et al.* (2011) applied edible coatings based on hydroxypropylmethylcellulose containing an ethanolic extract of propolis in table grapes, cv. Muscatel. However, the coating treatments did not affect the antioxidant capacity of fruits, and the phenol content was reduced during storage.

Considering that no studies were found on the application of edible coatings containing antioxidant extracts from fermented fruit residues for the conservation of grapes, the present study aimed to evaluate the potential of edible coatings incorporating fermented tamarind residue flour extract to maintain cv Italia table grapes after harvest.

MATERIALS AND METHODS

Materials

Ripe tamarind fruits (brown in colour and 9 cm in size) were purchased from a commercial market in Abaré

city (Bahia, Brazil). 6-Hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), 2,2-diphenyl-1-picrylhydrazyl radical (DPPH), 2,2′-azino-bis-(3-ethylbenzthiazoline)-6-sulphonic acid (ABTS+) and ferric reduction antioxidant power (FRAP) reagent were obtained from Sigma Aldrich and Fluka Analytica (St Louis, MO, USA). Potato dextrose agar and Brain Heart Infusion broth were acquired from Kasvi (São Paulo, Brazil). The 'Italia' type grapes were purchased from the central market in Aracaju (Sergipe, Brazil) after one day of harvest.

Fungus

Aspergillus niger (IOC 3677) was acquired from the Oswaldo Cruz Institute (Manguinhos, Rio de Janeiro, Brazil) and stored in Eppendorf tubes containing Brain Heart Infusion broth and glycerol in an ultra-freezer at −80 °C. The fungus was cultivated on potato dextrose agar for 7 days at 30 °C before use.

Treatment of tamarind fruits

Tamarind fruits without physical damage were washed with water and immersed in 200 ppm chlorinated solution for 15 min. The peel and seeds were removed manually, dried at 50 °C in a greenhouse for 24 h, crushed in a Wiley-type analytical mill (Tecnal, Model 650) and passed through a 0.01 mm mesh sieve. The peel and seed flours were mixed in a 1:1 ratio to obtain a final flour from tamarind residues. Specifically for fermentation experiments, this flour was autoclaved at 121 °C for 15 min.

Method of extraction from fermented and unfermented flours

A solid-state fermentation of flour was performed in Erlenmeyer flasks (125 mL) using 5 g of flour and the volume of the spore suspension required to adjust the initial moisture of solid material to 50% (Santos *et al.,* 2020b). The spore suspension was prepared at a concentration of 2.0×10^8 spores mL^{-1} in culture medium containing distilled water, glucose (50 g L^{-1}) and yeast extract (20 g L^{-1}). The flasks were incubated at 30 °C for 72 h. This procedure was based on previous studies (Santos *et al.*, 2020b) where, at this fermentation time, an elevated concentration of antioxidant polyphenolic compounds was obtained.

Extracts from fermented and unfermented flours were obtained with 25 mL of an aqueous solution of 80% ethanol. The samples were agitated on an orbital shaker at 30 °C and 200 rpm for 1 h and filtered through filter paper (diameter of 125 mm) (Santos et al., 2020b).

Formulations of edible coatings

The coating formulations were prepared according to Araújo *et al.* (2018) with modifications, containing 10 g L^{-1} cassava starch and 5 g L^{-1} chitosan (F1); 10 g L^{-1} cassava starch, 5 g L^{-1} chitosan and 10 g L^{-1} unfermented flour extract (F2); and 10 g L^{-1} cassava starch, chitosan and 10 g L^{-1} fermented flour extract (F3). The chitosan solution was prepared by dissolving 1.0 g of chitosan in 100 mL of aqueous acetic acid solution (0.26 mol L^{-1}) containing glycerol (12.8 g L^{-1}). This solution was lightly shaken (Tecnal magnetic stirrer – TE 0851) for 30 min at room temperature to avoid the formation of bubbles. Then, cassava starch (2 g) was dissolved in 100 mL of aqueous glycerol solution (6.4 g L^{-1}). This solution was heated in a water bath under stirring, not exceeding 70 °C for 30 min. After cooling, the starch solution was added to the chitosan solution, followed by homogenisation and addition of 10 g L^{-1} fermented or non-fermented extract.

Application of edible coatings to grapes

Grapes of uniform size and colour and without injuries were visually selected. Then, the fruits were sanitised by immersion in sodium hypochlorite solution (0.2 g L^{-1}) for 15 min, rinsed with water and dried at room temperature on plastic trays for 1.5 h. A total of 90 grapes were immersed in each formulation and then dried at room temperature for 2 h. The grapes were placed on polyethylene trays and maintained for 0, 3, 6, 9, 12 and 15 days in biochemical oxygen demand chambers (SP Labor, Brazil) with internal forced air circulation by micro-ventilators, at 25°C and 86% – 89% relative humidity (Figure 1). For each day of storage of each formulation, the physical and chemical characteristics of 15 grapes were analysed. Uncoated grapes were used as the control. These experiments were performed in two repetitions.

Quality parameters

The following analyses were performed for coated and uncoated grapes. The weight loss was calculated as the difference between the initial weight (time 0) and the final weight (storage time) divided by the initial weight and multiplied by 100 (Pastor *et al.,* 2011). From the juice of 150 g of macerated grapes (15 grapes) were determined the pH and the total soluble solids (TSS) using a digital refractometer. The results were expressed as g sucrose 100 g^{-1} (Guerra *et al.,* 2015). The titratable acidity (TA) was

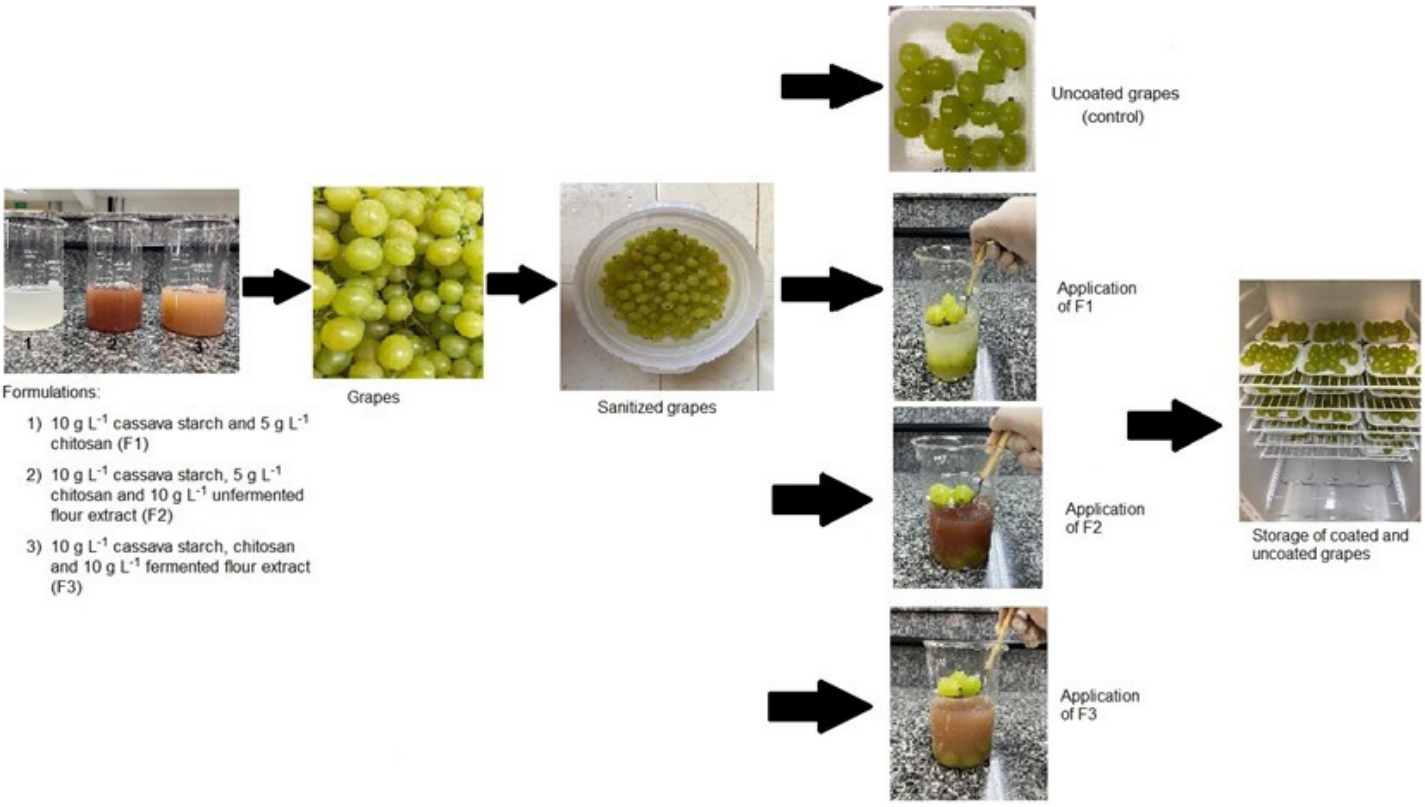

Figure 1: Some steps of applying the coatings to the grapes.

measured using 2 mL of macerated grapes homogenised with 50 mL of distilled water. Then, the samples were titrated with 0.1 N NaOH, and the results were expressed as g citric acid 100 g^{-1} (Zenebon *et al.,* 2008). All the experiments were performed in triplicate.

Antioxidant activity (AA)

A total of 15 grapes were macerated for each storage period, and the AA of the obtained liquid was analysed by the ABTS (Nenadis *et al.,* 2004), DPPH (Kwon *et al.,* 2006) and FRAP (Thaipong *et al.,* 2006) methods. The ABTS assay was performed with 30 µL of liquid and 3.0 mL of the ABTS+ radical. The sample was homogenised in a vortexer for 6 min, and the absorbance was read at 734 nm in a spectrophotometer (Spectrum SP-2000 UV, Tucumán, Argentina). A calibration curve was obtained using different concentrations of Trolox (100 to 1600 µmol Trolox mL^{-1}). The results were expressed in µmol of Trolox mL^{-1}. For the DPPH assay, 250 µL of liquid was mixed with 1.25 mL of DPPH, and after 5 min the absorbance was read at 517 nm in a spectrophotometer (Spectrum SP-2000 UV, Tucumán, Argentina). The calibration curve was obtained with concentrations of Trolox between 50 and 250 µmol of Trolox mL^{-1}, and the results were expressed in terms of µmol Trolox mL^{-1}. An aqueous 96% ethanol solution was used as the control, substituting for the sample. For the FRAP assay, 90 µL of liquid was mixed with 270 µL of distilled water and 2.7 mL of the FRAP reagent. The sample was homogenised in a vortexer and kept at 37 °C in a water bath for 30 min; the absorbance was measured at 595 nm (Spectrum SP-2000 UV, Tucumán, Argentina). The calibration curve was obtained with concentrations of Trolox from 100 to 1200 µmol Trolox mL^{-1} and the results expressed in µmol Trolox mL^{-1}. All experiments were performed in triplicate.

Statistical analysis

The experiments were performed in a completely randomized design (CRD) with two repetitions. Physico-chemical analysis and antioxidant activity were carried out in a factorial scheme, with formulations x time (4x6). The results of all experiments were subjected to analysis of variance (ANOVA), and means were compared by Tukey's test at a 5% level of significance ($p < 0.05$), using Sisvar software 5.6.

RESULTS AND DISCUSSION

The visual appearance showed that grapes coated with 10 g L^{-1} cassava starch, 5 g L^{-1} chitosan and 10 g L^{-1} extract from fermented residue were better preserved than the others on 15th day of storage (Figures 2 and 3). The weight loss of the grapes ranged from 4.1 to 37.8 g kg^{-1}. On each day of storage, there was no significant difference ($p > 0.05$) between the grapes coated with the different formulations and the control (Table 1), with the exception of the 12th day, on which the grapes coated with the formulation containing the extract of unfermented residue showed a significantly greater mass loss (33.1 g kg^{-1}) than the others ($p < 0.05$).

A comparison of each formulation between day 0 and the last day of storage revealed that, for all grapes, the mass loss increased with increasing storage time. The loss of mass in fruits is associated with the loss of water through the surface of fruit slices. In this process, the rate of water loss depends on the water pressure gradient in the fruit tissue and in the surrounding atmosphere, as well as on the storage temperature (Radi *et al.,* 2017). This result meant that the formulations did not influence the water loss process of the grapes during storage. Pastor *et al.* (2011) applied edible coatings based on hydroxypropylmethylcellulose containing an ethanolic extract of propolis to table grapes, cv. 'Muscat'. These authors obtained greater weight loss, between 20 and 40 g kg^{-1}, in 3, 6, 9 and 12 days of storage than that obtained in the present work for the same storage times. Destiana *et al.* (2021) and Souza *et al.* (2021) also obtained greater weight loss (between 0 and 200 g $kg^{-1}$and between 0 and 300 g kg^{-1}, respectively) in red grapes coated with aloe vera edible coating containing different concentrations of glycerol and grapes of the cultivar 'Italia' coated with an edible coating composed of alginate, galactomannans, cashew gum and gelatine, respectively.

Regarding TSS, AT and pH, there were no significant differences between grapes with and without coatings ($p > 0.05$) per day of storage. Analysis of each formulation individually also verified that the TSS and AT values did not differ during storage ($p > 0.05$). The pH of grapes with and without coatings was significantly higher on the 12th day of storage, compared with all other storage times ($p < 0.05$). Pastor *et al.* (2011) and Destiana *et al.* (2021) also did not observe a significant effect of coatings on the TSS content or pH of table grapes coated with a hydroxypropylmethylcellulose coating containing an ethanolic extract of propolis or of red grapes coated with glycerol and aloe vera edible coating, respectively. Due to their low respiration rate, insignificant changes occur in grapes during storage (Destiana *et al.,* 2021). Souza *et al.* (2021) obtained an initial increase in TSS content followed by constant values until 12 days of storage and no difference among pH values in grapes of the cultivar 'Italia' coated with an edible coating composed of alginate, galactomannans, cashew gum and gelatine. In general, the type of edible coating does not significantly affect the pH of grapes because the variation in this parameter is associated with the natural variability of the fruits (Kim *et al.,* 2014; Melo *et al.,* 2018). However, these authors obtained decreasing TA during the shelf life of grapes for all treatments, due the metabolism of organic acids, mainly malic acid, in the Krebs cycle (Souza *et al.,* 2021).

Analysis of the AA determined by the ABTS method at each storage time found that on day 0 the uncoated grapes showed higher AA (958.00 µmol Trolox g^{-1}) and on the third and sixth days, significantly higher values were obtained for grapes coated with a formulation containing the fermented residue extract (F3) (725.50 and 715.92 µmol Trolox g^{-1}, respectively), compared with all other samples ($p < 0.05$) (Table 2).

From the 9th to the 15th days, there was a significantly higher AA in grapes coated with the formulation without the extract (F1) (between 848.00 and 979.25 µmol Trolox g^{-1}, respectively), compared with the values obtained for the other grapes ($p < 0.05$). The lower AA values in the grapes coated with formulations containing extracts (F2 and F3) at the end of storage may be due to the degradation of certain phenolic antioxidant compounds present in the extracts caused by a higher rate of respiration of fruits (Day, 2001). Comparison of each formulation over the storage period found that the AA contents of coated grapes increased up to the 12th day, decreasing on the 15th day, with the lowest value obtained in the grapes coated with F3

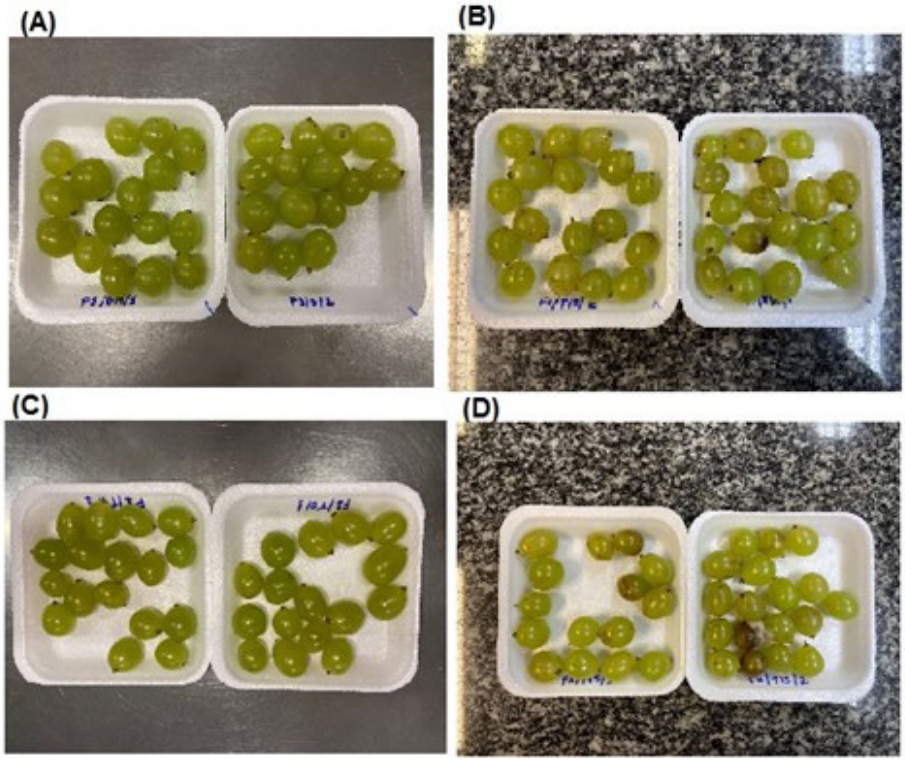

Figure 2: Storage of grapes at 25 °C. (A) uncoated grapes on day 0, (B) uncoated grapes on day 15, (C) grapes coated with 10 g L^{-1} cassava starch and 5 g L^{-1} chitosan on day 0, (D) grapes coated with 10 g L^{-1} cassava starch and 5 g L^{-1} chitosan on day 15.

(619.67 µmol Trolox g^{-1}). The increase in AA can be attributed to the formation of Maillard compounds associated with enzymatic browning, which can contribute to the formation of antioxidant compounds, due to the increase in peroxidase and polyphenol oxidase activity observed in grapes during post-harvest storage (Karadeniz *et al.,* 2000; Meng *et al.,* 2008). On the other hand, uncoated fruits showed a reduction in AA during storage, featuring greater oxidation of these fruits.

Regarding the DPPH method, no significant differences in AA were observed between the coated and uncoated grapes between the 6th and 12th days. On the last day of storage, the coated grapes showed the highest AA values and did not differ statistically from each other ($p > 0.05$), due to the presence of antioxidant compounds in the extracts added to the coatings as well as the presence of chitosan, which can exert antioxidant capacity mainly due to the activity of hydroxyl and amino groups (Xie *et al.,* 2001). Analysis of each formulation revealed an increase in AA only between the 3rd and 6th days, followed by a reduction until the 15th day of storage.

Grapes showed higher AA values for the FRAP method (between 1650.58 and 2661.34 µmol Trolox g^{-1}), especially those coated with a formulation containing fermented residue extract (F3), which showed significantly higher AA on the last day of storage (2350.59 µmol Trolox g^{-1}), compared with all other samples ($p < 0.05$). In previous studies, Santos *et al.* (2020b) identified the presence of higher levels of phenolic compounds (gallic acid, catechin, epicatechin gallate, epigallocatechin gallate, protocatechuic acid), as well as the presence of ethyl gallate and propyl gallate in the fermented residue extract, when compared with the unfermented residue extract. Probably, these compounds were responsible for the highest AA found in grapes coated with formulation F3. For grapes coated with the formulation without extract (F1) and with extract of unfermented residue (F2), there was an increase in AA, which reached a maximum on the 12th day of storage. The highest AA values of grapes were obtained by the FRAP method. This result indicated the probable presence of compounds in the formulations with a greater capacity to reduce ferric iron (Fe^{3+}). In all the analysed methods, there was an improvement in the AA of the coated grapes in relation to the uncoated ones.

For all the analysis methods, there was an improvement in the AA of the coated grapes in relation to the uncoated ones. The antioxidant effect of phenolic compounds present in fermented and unfermented residue extracts can cause

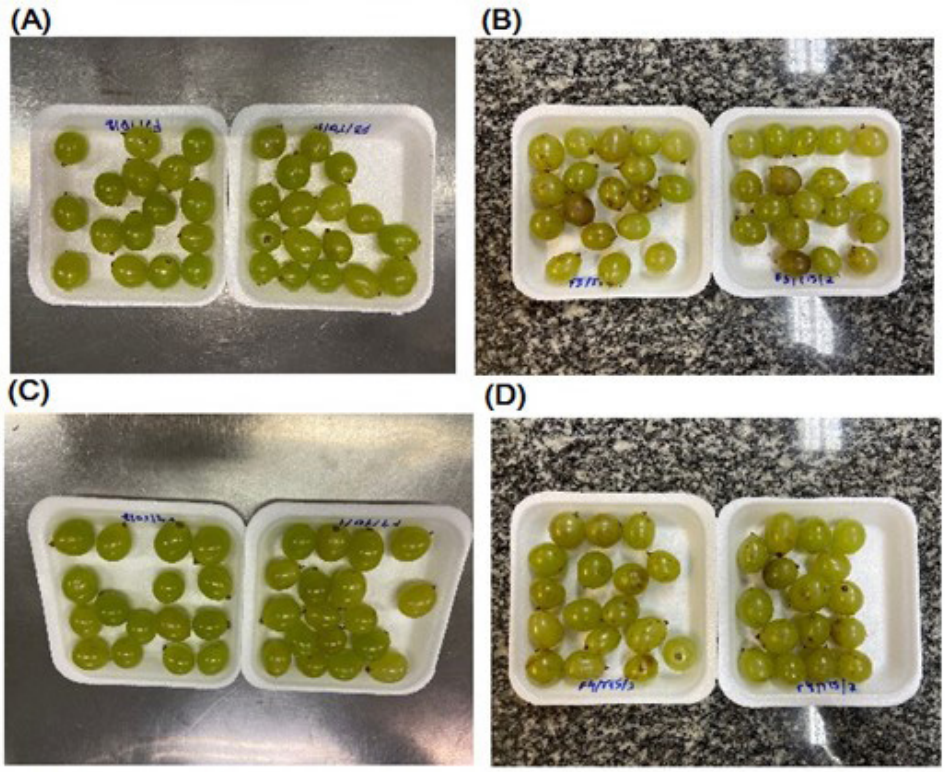

Figure 3: Storage of grapes at 25 °C. (A) grapes coated with 10 g L^{-1} cassava starch, 5 g L^{-1} chitosan and 10 g L^{-1} extract from unfermented residue on day 0, (B) grapes coated with 10 g L^{-1} cassava starch, 5 g L^{-1} chitosan and 10 g L^{-1} extract from unfermented residue on day 15, (C) grapes coated with 10 g L^{-1} cassava starch, 5 g L^{-1} chitosan and 10 g L^{-1} extract from fermented residue on day 0, (D) grapes coated with 10 g L^{-1} cassava starch, 5 g L^{-1} chitosan and 10 g L^{-1} extract from fermented residue on day 15.

Table 1: Physical-chemical analysis of coated and uncoated grapes during 15 days of storage at 25 °C

Parameters	Formulations	Time of storage (days)					
		0	3	6	9	12	15
Weight loss (g kg^{-1})	Control	$0.0^{aC} \pm 0.0$	$5.8^{aBC} \pm 0.2$	$6.0^{aBC} \pm 0.0$	$9.5^{aBC} \pm 0.0$	$13.3^{aB} \pm 2.4$	$30.9^{aA} \pm 2.2$
	F1	$0.0^{aD} \pm 0.0$	$4.1^{aC} \pm 0.2$	$7.3^{aBC} \pm 0.0$	$10.0^{aBC} \pm 0.0$	$18.3^{aAB} \pm 0.0$	$37.8^{aA} \pm 1.9$
	F2	$0.0^{aD} \pm 0.0$	$4.6^{aBC} \pm 0.8$	$7.2^{aB} \pm 0.0$	$9.6^{aB} \pm 0.0$	$33.1^{Ab} \pm 1.1$	$32.6^{aA} \pm 0.0$
	F3	$0.0^{aD} \pm 0.0$	$4.1^{aC} \pm 0.3$	$6.0^{aC} \pm 0.0$	$12.0^{aB} \pm 0.0$	$15.7^{aB} \pm 0.0$	$30.8^{aA} \pm 2.5$
Total soluble solids (TSS) (g $100g^{-1}$)	Control	$11.50^{aA} \pm 0.71$	$11.93^{aA} \pm 0.12$	$12.70^{aA} \pm 0.42$	$11.8^{aA} \pm 0.69$	$12.80^{aA} \pm 0.85$	$11.90^{aA} \pm 1,27$
	F1	$12.50^{aA} \pm 0.71$	$11.87^{aA} \pm 0.42$	$11.6^{aA} \pm 0.53$	$12.29^{aA} \pm 1.23$	$12.00^{aA} \pm 1.41$	$10.70^{aA} \pm 0,99$
	F2	$11.80^{aA} \pm 0.69$	$11.87^{aA} \pm 0.42$	$11.6^{aA} \pm 0.72$	$12.53^{aA} \pm 0.61$	$12.10^{aA} \pm 0.14$	$11.93^{aA} \pm 0,83$
	F3	$12.90^{aA} \pm 0.42$	$12.18^{aA} \pm 0.71$	$13.10^{aA} \pm 0.14$	$12.04^{aA} \pm 0.14$	$12.00^{aA} \pm 0.00$	$12.62^{aA} \pm 1,17$
Titratable acidity (TA) (g tartaric acid 100 g^{-1})	Control	$0.67^{aA} \pm 0.01$	$0.58^{aA} \pm 0.01$	$0.58^{aA} \pm 0.05$	$0.58^{aA} \pm 0.05$	$0.53^{aA} \pm 0.04$	$0.56^{aA} \pm 0.08$
	F1	$0.63^{aA} \pm 0.02$	$0.57^{aA} \pm 0.00$	$0.66^{aA} \pm 0.09$	$0.52^{aA} \pm 0.03$	$0.49^{aA} \pm 0.03$	$0.56^{aA} \pm 0.03$
	F2	$0.63^{aA} \pm 0.00$	$0.56^{aA} \pm 0.07$	$0.66^{aA} \pm 0.06$	$0.60^{aA} \pm 0.18$	$0.51^{aA} \pm 0.01$	$0.51^{aA} \pm 0.00$
	F3	$0.59^{aA} \pm 0.03$	$0.61^{aA} \pm 0.04$	$0.57^{aA} \pm 0.01$	$0.57^{aA} \pm 0.04$	$0.56^{aA} \pm 0.06$	$0.53^{aA} \pm 0.04$
pH	Control	$3.79^{aB} \pm 0.03$	$3.86^{aB} \pm 0.08$	$3.82^{aB} \pm 0.07$	$3.83^{aB} \pm 0.04$	$4.02^{aA} \pm 0.25$	$3.87^{aB} \pm 0.09$
	F1	$3.76^{aBC} \pm 0.09$	$3.91^{aB} \pm 0.20$	$3.80^{aB} \pm 0.18$	$3.89^{aB} \pm 0.03$	$4.08^{aA} \pm 0.27$	$3.73^{aBC} \pm 0.09$
	F2	$3.87^{aB} \pm 0.14$	$3.94^{aA} \pm 0.28$	$3.78^{aB} \pm 0.12$	$3.90^{aB} \pm 0.06$	$4.02^{aA} \pm 0.26$	$3.81^{aB} \pm 0.04$
	F3	$3.78^{aB} \pm 0.14$	$4.02^{aA} \pm 0.42$	$3.89^{aB} \pm 0.12$	$3.88^{aB} \pm 0.06$	$4.03^{aA} \pm 0.35$	$3.87^{aB} \pm 0.06$

Means followed by a different lowercase letter in the same column or an uppercase letter in the same row are significantly different ($p < 0.05$) according to Tukey's test. Control: grapes without edible coating, F1: grapes coated with 10 g L^{-1} cassava starch and 5 g L^{-1} chitosan, F2: grapes coated with 10 g L^{-1} cassava starch, 5 g L^{-1} chitosan and 10 g L^{-1} extract from unfermented residue, F3: grapes coated with 10 g L^{-1} cassava starch, 5 g L^{-1} chitosan and 10 g L^{-1} extract from fermented residue.

Table 2: Antioxidant activity of coated and uncoated grapes during 15 days of storage at 25 °C

Parameters	Formulations	Time of storage (days)					
		0	3	6	9	12	15
ABTS(µmol Trolox·g−1)	Control	958.00aA ± 59.40	581.34abC ± 5.89	686.33^{a}bBC ± 38.89	626.33bcC ± 0.00	863.84bB ± 15.32	723.83bBC ± 21.21
	F1	605.08cB ± 68.94	605.09^{a}bB ± 20.63	663.42bB ± 19.45	918.42^{a}A ± 80.73	979.25aA ± 1.77	848.00aAB ± 31.82
	F2	618.00cC ± 77.78	540.92bCD± 64.23	625.09bC ± 10.02	674.67bB ± 21.21	862.17bA ± 40.07	662.59cB ± 48.91
	F3	700.92bB ± 50.08	725.5aB ± 30.65	715.92^{a}B ± 10.02	695.09bB ± 2.95	810.09bA ± 64.23	619.67cC ± 0.00
DPPH(µmol Trolox·g−1)	Control	124.14cF ± 7.2	579.19bB ± 124.35	657.93aA ± 4.59	258.60^{a}E ± 6.08	456.13^{a}C ± 8.66	304.42bD ± 20.39
	F1	448.74bB ± 15.03	652.7aA ± 39.24	626.13aA ± 10.83	269.26^{a}C ± 27.23	449.82aB ± 5.35	290.66aC ± 29.21
	F2	553.34aB ± 50.58	656.4aA ± 54.40	655.23aA ± 1.53	222.52abE ± 48.10	446.31aC ± 5.73	301.00aD ± 29.66
	F3	574.96aB ± 48.8	611.98aA ± 13.76	645.05aA ± 20.00	277.78^{a}D ± 66.15	448.61^{a}C ± 68.74	301.06^{a}D ± 29.78
FRAP(µmol Trolox·g−1)	Control	2661.34^{a}A ± 196.10	1758.09cC ± 165.58	1864.38^{a}C ± 21.15	1850.00bC ± 212.13	2168.92bB ± 186.80	2175.50bB ± 248.19
	F1	1650.58cD ± 15.91	1895.58bC ± 114.90	1897.25^{a}C ± 127.87	2023.50^{a}B ± 31.82	2234.67^{a}A ± 190.45	2223.92bA ± 39.48
	F2	1987.67bC ± 208.60	1795.58cD ± 143.19	1775.00bD ± 176.78	2072.59^{a}B ± 102.65	2166.42bA ± 92.51	2060.09cB ± 84.97
	F3	2047.67bC ± 27.10	2163.92^{a}B ± 80.73	1872.67^{a}D ± 102.53	1833.00bD ± 188.09	1961.00cC ± 165.00	2350.59aA ± 197.40

Means followed by a different lowercase letter in the same column or an uppercase letter in the same row are significantly different ($p < 0.05$) according to Tukey's test. Control: grapes without edible coating, F1: grapes coated with 10 g L^{-1} cassava starch and 5 g L^{-1} chitosan, F2: grapes coated with 10 g L^{-1} cassava starch, 5 g L^{-1} chitosan and 10 g L^{-1} extract from unfermented residue, F3: grapes coated with 10 g L^{-1} cassava starch, 5 g L^{-1} chitosan and 10 g L^{-1} extract from fermented residue.

a significant delay in the oxidation of grapes and inhibit reactions involving free radicals (Apak *et al.,* 2007).

CONCLUSIONS

Chitosan edible coatings containing extract of fermented and unfermented tamarind residue (peel and seed flour) were used to preserve table grapes of the cultivar 'Italia'. The grapes were evaluated for physico-chemical characteristics and AA during storage for 15 days at 25 °C. The pH, TSS or AT values of the coated and uncoated fruits were similar during storage. The AA of the grapes improved, with emphasis on the last storage method for grapes coated with a formulation containing fermented residue extract. The coatings with and without extract showed the potential to improve the AA of the grapes during 15 days of storage at 25 °C, the extract from the fermented residue being an additional option to enhance the antioxidant effect of edible packaging. For application purposes, future studies are needed to evaluate the toxicity of the extracts.

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