

Effects of muña essential oil (*Minthostachys mollis*) added in edible coating based on black maca flour (*Lepidium meyenii* Walpers) and nanoclay for shelf-life prolongation of minimally processed melon (*Cucumis melo* L.)

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Abstract

The objective of this manuscript was to evaluate the effect of muña essential oil in the coating based on black maca flour and nanoclay to prolong the shelf life of minimally processed melon. Melon cubes were stored for 12 days at 5 ± 1 °C and divided into four treatments: T1 control (without coating), T2, T3, and T4 with 0.1%, 0.2%, and 0.3% muña essential oil, respectively. Weight loss, titratable acidity, pH, soluble solids content, color, firmness, water activity, microbiological evaluations of molds and yeasts, *Salmonella spp*, and *Escherichia coli* were analyzed. Treatment 2 showed better results, in less weight loss (8.74%), firmness, and color, in addition to retarding microbial growth and prolonging the shelf life of the melon compared to T1. It concluded that the muña essential oil and maca coating was efficient, it reduced the growth of molds and yeasts and the loss of weight and firmness in fresh-cut melon.

Introduction

Inadequate conservation management of fruits and vegetables generates losses worldwide of 1.3 million tons per year (Santos et al., 2020). Microbial contamination in food generates losses and waste, especially in those that are marketed *in natura*. Minimally processed fruits have a short shelf-life because they are not subjected to any treatment during processing. For this reason, they are susceptible to rapid microbial development, changes in color, flavor, aroma, and loss of texture that impair their quality (Supapvanich, Boon-Lha, & Mhernmee, 2011; Tournas, Heeres, & Burgess, 2006).

Cucumis melo L. is a species that belongs to the *Cucurbitaceae* family (Jeffrey, 1990). The fruits of this species are polymorphic due to the great variability of size, shape, flavor, and color of the pericarp and mesocarp (Nuñez-Paleniús et al., 2008). In 2020, the countries with the highest melon production worldwide were China, Iran, Japan, the USA, and Turkey (Statistics Division of Food and Agriculture Organization of the United Nations, 2020). The presentations of the melon in the market are as whole or minimally processed fruit or as slices with peel and cubes of pulp (Falah, Nadine, & Suryandono, 2015). There are some pathogens associated with melon rinds, such as *Listeria monocytogenes* and *Salmonella enterica* that are rarely eliminated after washing and disinfection. A study showed that these pathogens proliferate rapidly in the skin and pulp of canary melons between 5 and 35°C of storage (Martinez, Osborne, Jayeola, Katic, & Kathariou, 2011; McCollum et al., 2013; Scolforo et al., 2017).

Regarding preservation methods for fruits and vegetables, there are nanostructured materials with mechanical and functional properties that allow extending the shelf-life of foods (Sothornvit, 2019). Currently, food preservation technologies are directed to the design of active packaging with the use of nanoparticles and modified atmosphere properties (Rodríguez-Rojas, Arango, Rodríguez-Vélez, & Arana-Florez, 2019). The use of functional and bioactive materials for the development of packaging and coatings is a trend in food preservation in the food industry (Jafarzadeh, Mohammadi, Salehabadi, Oladzad-abbasabadi, & Jafari, 2021).

An edible coating consists of a thin, uniform layer that forms over the entire surface of whole or minimally processed food (Zhao, 2018). The edible material can be a matrix of hydrocolloids, lipids, or a mixture of both (Pratap Singh & Packirisamy, 2022). The addition of antioxidant, antimicrobial, anti-browning agents, texture modifiers, and nutrients, among others in the polymeric matrix of the coatings, improve the nutritional and sensory characteristics and extend the shelf life of the coated fruits (Panahirad et al., 2021).

Muña (*Minthostachys mollis*) is a native Andean plant that belongs to the *Laminaceae* family and grows between 500 and 3500 meters above sea level (masl). It is aromatic, woody with pubescent leaves and flower spikes (Alkire, Tucker, & Maciarello, 1994). This plant has phenolic compounds, mainly flavanones, flavones, and derivatives of hydroxycinnamic acid. A study evaluated the ethyl acetate fraction of muña and found 10.0 mg/g of flavanones, 5.8 of flavones, and 4.7% of hydroxycinnamic acids on a dry basis (Chirinos, Huamán, Betalleluz-Pallardel, Pedreschi, & Campos, 2011). Likewise, another study found a large number of flavonoids in aqueous and ethanolic solutions in muña leaves (Alegre, Iannacone, & Carhuapoma, 2017). Other studies identified monoterpenes such as pulegone and menthone in the essential oil from leaves and flowers of muña. These compounds showed inhibitory activities against *Staphylococcus aureus* and *Candida albicans* *in vitro* studies (Benites et al., 2018; Castro-Alayo et al., 2019; Fernández et al., 2017; Huamaní et al., 2021).

Maca (*Lepidium meyenii* Walpers) is a domestic cruciferous plant that belongs to the *Brassicaceae* family (Quirós & Aliaga, 1997). This plant has tough basal leaves that are elliptical. Its root is strong, and thick, with several lateral rootlets similar to 'Red Globe' radishes; in addition, it has a coloration between light purple to yellow. The maca plant grows in the central highlands of Peru, specifically in the Puna region between 3,500 and 4,000 masl (León, 1964). The edible part of this crop is its main root, hypocotyl, the aerial parts of this plant can also be consumed, which are a source of bioactive compounds (Jin et al., 2018; Wang & Zhu, 2019). The maca root is consumed fresh or dried, maca dried can be kept for up to two years and is used to prepare porridge (León, 1964). Maca root contains 94.5% starch and 26% amylose. Its starch has a low gelatinization temperature of 53.5°C (Fuentes et al., 2019). Maca starch has different functional and rheological properties compared to potato, corn, and cassava starches. Particularly, maca starch has a high degree of swelling and water solubility, and low shear strength. Likewise, it has a high tendency to retrogradation, gelatinization, and viscosity (Zhang, Li, Wang, Yao, & Zhu, 2017).

There is a demand for eco-friendly technologies for the preservation of fruits and vegetables. The addition of natural ingredients with antioxidant and antimicrobial properties is promising, but there are still few studies evaluating these effects. This manuscript aims to evaluate the effect of muña essential oil (*Minthostachys mollis*) added in an edible coating based on black maca flour (*Lepidium meyenii* Walpers) and nanoclay to prolong the shelf life of minimally processed melon (*Cucumis melo* L.).

Materials And Methods

Materials

Muña essential oil was acquired from Nua, an amazon company in Tarapoto from Peru, and Black maca root flour was produced from *Nuestra Salud*, a Peruvian brand bought in Arequipa, Perú.

Melons were purchased from a market chain in Dourados – MS, Brazil. The fruits were selected with a uniform maturity of 75%, with a weight between 1.5 and 2 kg, without visually physiological defects. Then the melons were transported to the Bioengineering Laboratory of the Federal University of Grande Dourados, MS, Brazil for their processing.

Minimally processed melon

The utensils that were used for processing the melons were previously sanitized with a solution of chlorine organic dichloroisocyanurate), at a concentration of 2 gL^{-1} . The melons were sanitized with an organic chlorine solution at 2 g.L^{-1} for 10 min, their peel and seeds were removed manually, and the pulp was cut into cubes with dimensions of $2.5 \times 2.5 \text{ cm}$. All the cubes were immersed in an organic chlorine solution (0.2 g.L^{-1}), the solution was drained to eliminate the extravasated cellular juice and they were separated into four batches (Basaglia et al., 2021).

Preparation of coating solution

To prepare the three coating solutions, the distilled water was heated with the black maca flour until reaching 60°C in constant agitation with a mechanical agitator, in that temperature, the nanoclay was added, dissolved, and integrated for 20 minutes. Then, the temperature was dropped to 45°C to add the muña essential oil and it was stirred for 10 more minutes. Treatment 1 (control) was only uncoated melon cubes, treatments 2, 3 and 4 contain 0.1%, 0.2% and 0.3% muña essential oil respectively, all treatments contained black maca flour (2.5%) and nanoclay (0.3%).

The melon cubes were completely submerged for 5 minutes into their treatments, after that time the liquid coating was drained for 3 minutes; the cubes were packaged in non-recycled PET polyethylene terephthalate packages.

The samples were stored in refrigeration at $5 \pm 1^\circ \text{C}$ for 12 days. The analyzes were performed in triplicate, considering day 0 for the day of processing, and after 1, 3, 5, 7, 9, and 12 days within the storage (Basaglia et al., 2021).

Physicochemical, color, firmness, water activity and microbial analysis of yellow melon cubes

Physicochemical analysis

Weight loss

The weight loss of the minimally processed melon was calculated with the difference between the initial weight and the weight obtained at the end of each storage time evaluated until day twelve (Alikhani,

2014).

The results were expressed as a percentage of weight loss.

$$\% \text{Weight loss} = [(\text{initial mass} - \text{final mass}) / \text{initial mass}] \times 100 \quad (1)$$

pH

20 g of the sample to be analyzed was used in 100 mL of distilled water with a potentiometer (Quimis, Modelo 400 A.) (AOAC, 2000).

°Brix

For the counting of soluble solids expressed in °Brix is used a refractometer (Abbé Q767B, São Paulo, Brazil) (AOAC, 2000).

Acidity

For the titratable acidity analysis, 10 mL of the homogenized sample was taken in 100 mL of distilled water, using feloftalein and NaOH at 0.1 mol L^{-1} . The results were expressed as a percentage of citric acid (AOAC, 2000).

Color measurement

Colour analysis was measured on the surface of the melon cubes with the colorimeter Minolta, model Chroma Meter CR400 (Osaka, Japan). The colorimeter gives different parameters as L^* range 0 (black) and 100 (white), it is the difference in lightness and darkness; a^* the difference in red (+60) and green (-60); b^* the difference in yellow (+60) and blue (-60) (Basaglia et al., 2021).

Firmness

The firmness was evaluated with a texturometer (TAXT2i Plus model), the texture of the samples was obtained by uniaxial shearing, and the cutting speed was 2 mm s^{-1} with a running distance of 35 mm. The cutting force is expressed in Newton (N) (AMSA, 2015).

Water Activity

Water activity was evaluated with an Aqua Lab water activity determiner (model CX3T instrument, Decagon Devices, Inc., Pullman, WA, USA). Melon samples were finely chopped and placed in sample cups for reading.

Microbiological quality

Preparation of samples for microbial analysis

Microbiological analyzes were performed to determine the presence of molds and yeasts, *Salmonella ssp*, and *Escherichia coli*, following the methods described in APHA (2001).

For molds, yeasts, and *Escherichia coli*, 25 g of sample diluted with 225 ml of 0.1% sterile peptone water was used, and for *Salmonella*, 1% peptone water was used. Subsequently, the sample was homogenized for 2 min in a Blender Homogenizer. (BagMixer SW, Interscience, Saint-Nom-la-Bretèche, Francia). Then, serial dilutions of (10^{-1} - 10^{-7}) were made with 1ml of water and 9 ml of 0.1 % peptone for molds and yeasts and *E. coli*.

The inoculation was carried out in a sterile environment with 1 mL of sample in potato dextrose agar for 5 days and it was kept at a constant temperature of 25 °C. Counting was done in triplicate every day.

Statistical analysis

Statistical analyzes were performed with the Analysis of Variance by Tukey's method, with a 5% level of significance, and the Statistix 10 program (Analytical Software 2105 Miller Landing Rd Tallahassee, USA).

Results And Discussion

Physiochemical evaluation

Weight loss

Water loss is the main cause of weight loss in fruits and vegetables; it causes changes in their organoleptic characteristics, mainly in texture. Some coatings with essential oils showed less water loss and therefore less weight loss (Sánchez-González, Vargas, González-Martínez, Chiralt, & Cháfer, 2011).

Fig.1 shows weight loss in melon treatments for 12 days. Treatment 2 maintained his initial weight compared to the other treatments in storage days.

The coated melon pieces presented a lower percentage of weight loss compared to the uncoated melons which presented a 20.5% weight loss. T2 with muña essential oil at 0.1% presented a lower weight loss (8.7%) compared to the other treatments with coated on day 12 at 5 ± 1 °C of storage. These results report a low weight loss compared to the study by Basaglia et al. (2021) which presented a 12.59% weight loss for the treatment with 0.5% cinnamon essential oil in the chitosan coating on freshly cut pineapple pieces.

Treatments with muña essential oil and black maca flour did not show a significant loss of weight in comparison with the control. This effect is attributed to the hydrophobic characteristic of essential oils contained in the coating that limits weight/water loss on the surface of the food (Sánchez-González, Chiralt, González-Martínez, & Cháfer, et al., 2011; Yousuf, Wu, & Siddiqui, 2021). Crosslinking between hydrophobic compounds and the biopolymeric matrix decreases the number of hydroxyl groups available

for interaction with water molecules (Ahmad, Benjakul, Prodpran, & Agustini, 2012). In this study, 0.1% muña essential oil coatings reduced the weight loss in fresh-cut melons, in comparison with a study that used 2% *Mentha longifolia* L. essential oil films and showed a greater water vapor permeability reduction on peeled prawns (Shahbazi, Shavisi, Karami, Lorestani, & Dabirian, 2021).

Arnon-Rips et al., (2019) developed film and coating based on two different biopolymers, chitosan and carboxymethyl cellulose (CMC), and, the addition of citral as a coarse and nanoemulsion on fresh-cut melon. The nanoemulsion coating with encapsulated citral showed great stability, organization, and density, so that, it presented a higher water vapor barrier that decrease the water/weight loss of fresh-cut melons. This research supports the results obtained in the present work because the application of nanoclay in the development of a coating decreased the weight loss of minimally processed melons.

pH, °Brix, and acidity

Minimally processed fruits and vegetables with a pH higher than 6 are susceptible to the development of bacteria, yeast, and molds. For this reason, the values of pH are important against microbial deterioration (Rahman, 2015).

Treatments with muña essential oil maintained the pH of melon cubes during storage days, in comparison with the control which showed a decreased pH. Koh, Noranizan, Nur-Hanani, Karim, & Rosli (2017) studied fresh-cut melons coated with a polymeric polysaccharide matrix and repetitively pulsed light. The results showed a slight decrease in the pH of the pulp. It could be attributed to the metabolism of microbial growth and the accumulation of CO₂ in the barrier formed by the coating.

A study applied Ferulic acid (FA) at concentrations from 2.5–15 g L⁻¹ on fresh-cut apples and melon. Results showed pH values from 3.9±0.1 to 3.7±0.1 at treatments with FA solutions and there was no difference significantly between concentrations (Nicolau-Lapeña et al., 2022). The effect of FA is similar to muña essential oil in fresh-cut melons. Another study evaluated the physicochemical qualities of freshly cut pineapples coated with sodium alginate at different concentrations of citral nanoemulsion and pH remained between 3.9 and 4.5 in all the treatments (Prakash, Baskaran, & Vadivel, 2020).

Table 1 pH, °Brix, and acidity of melon coating based on black maca flour and nanoclay with muña essential oil in different concentrations at 5±1 °C, for 12 days.

Parameters	Days	Treatments			
		T1	T2	T3	T4
pH	0	6.40±0.01 ^{bcdA}	6.34±0.01 ^{aA}	6.51±0.01 ^{aA}	6.49±0.01 ^{aA}
	1	6.50±0.02 ^{abcA}	6.35±0.01 ^{aB}	6.52±0.04 ^{aA}	6.50±0.01 ^{aA}
	3	6.63±0.05 ^{abA}	6.38±0.09 ^{aB}	6.45±0.08 ^{aB}	6.49±0.03 ^{aAB}
	5	6.73±0.18 ^{aA}	6.40±0.03 ^{aB}	6.37±0.07 ^{aB}	6.46±0.11 ^{aAB}
	7	6.33±0.06 ^{cdA}	6.40±0.07 ^{aA}	6.34±0.05 ^{aA}	6.45±0.05 ^{aA}
	9	6.2±0.09 ^{dAB}	6.40±0.05 ^{aA}	5.90±0.31 ^{aB}	6.35±0.04 ^{aA}
	12	5.86±0.11 ^{dA}	6.45±0.08 ^{aA}	5.62±0.52 ^{aA}	5.29±0.23 ^{aA}
Brix°	0	7.60±0.5 ^{aAB}	7.33±1 ^{aA}	6.00±1 ^{aAB}	5.60±0.5 ^{aB}
	1	7.67±0.58 ^{aA}	7.33±1.15 ^{aA}	6.0±1 ^{aA}	5.67±0.58 ^{aA}
	3	8.33±0.58 ^{aA}	7.33±1.53 ^{aAB}	6.33±0.58 ^{aAB}	6.0±0.0 ^{aB}
	5	9.25±1.85 ^{aA}	7.33±1.04 ^{aAB}	6.5±0.5 ^{aAB}	6.0±0.71 ^{aB}
	7	8.88±0.25 ^{aA}	7.53±0.85 ^{aAB}	6.67±0.29 ^{aB}	6.5±0.5 ^{aB}
	9	7.5±0.58 ^{aA}	7.5±0.87 ^{aA}	6.83±0.29 ^{aA}	6.67±0.29 ^{aA}
	12	7.2±1.21 ^{aA}	7.4±0.53 ^{aA}	6.0±0.0 ^{aA}	6.13±1.03 ^{aA}
Tritable Acidity	0	0.038±0.004 ^{cC}	0.058±0.006 ^{aA}	0.077±0.007 ^{bcAB}	0.064±0.007 ^{bB}
	1	0.038±0.004 ^{cC}	0.058±0.006 ^{cB}	0.077±0.007 ^{bcA}	0.064±0.007 ^{bAB}
	3	0.058±0.00 ^{bA}	0.038±0.011 ^{dA}	0.058±0.00 ^{cA}	0.051±0.013 ^{bA}
	5	0.051±0.004 ^{bcB}	0.077±0.00 ^{abA}	0.058±0.004 ^{cB}	0.051±0.010 ^{bB}
	7	0.058±0.004 ^{bBC}	0.077±0.00 ^{abA}	0.064±0.004 ^{bcB}	0.051±0.004 ^{bc}
	9	0.077±0.007 ^{aAB}	0.058±0.004 ^{cAB}	0.096±0.026 ^{abA}	0.045±0.011 ^{bB}
	12	0.083±0.010 ^{aBC}	0.064±0.007 ^{bcC}	0.115±0.020 ^{aAB}	0.154±0.020 ^{aA}

Averages of three repetitions ± standard deviation, followed by the lowercase letter in the column and the row not different by Tukey test ($p > 0.05$). T1: control; T2: 0.1%; T3: 0.2% and T4: 0.3% muña essential oil, respectively.

Regarding soluble solids, all treatments maintained the concentration of soluble solids during twelve days of storage time at 5 ± 1 °C and did not show significant differences. Similar results were presented in other studies like Ozturk et al. (2021), who evaluated the effect of coatings based on cellulose nanofibrils, chitosan, and trans-cinnamaldehyde on freshly cut melons. Their results were stable for all samples until day 7 and the samples showed no significant differences during the evaluation. Ortiz-Duarte, Pérez-Cabrera, Artés-Hernández, & Martínez-Hernández (2019) evaluated the influence of ag-chitosan nanocomposites in edible coatings on the quality of freshly cut melon for 13 days at 5 °C. All treatments showed no significant differences in terms of °Brix and pH. The study that evaluated freshly cut pineapples coated with sodium alginate with citral nanoemulsion showed their total soluble solids maintained around 17 °Brix (Prakash, Baskaran, & Vadivel, 2020). A study evaluated Brix degrees of pre-cut Rocha pears coated with *Codium tomentosum* algae extract. Results showed that there is no significant difference between the treatments evaluated for 15 days at 4 °C (Augusto et al., 2022).

Moreover, all treatments increased in titratable acidity during twelve days storage period. Treatments 3 and 4 with a greater concentration of muña essential oil and black maca flour increased in acidity compared to T2 during the storage period.

The acidity of the fruit is related to its maturity which depends on the type and quantity of organic acids, moreover the conversion of organic acids into sugars, and the microbial growth in the fruit (Yousuf, Qadri, & Srivastava, 2018). The study of cut pineapples coated with sodium alginate with citral nanoemulsion showed values between 0.51 and 0.62 during 12 days of storage (Prakash, Baskaran, & Vadivel, 2020). Ortiz-Duarte, Pérez-Cabrera, Artés-Hernández, & Martínez-Hernández (2019) showed that titratable acidity decreased during storage of freshly cut melon coated with chitosan for 13 days at 5 °C and it is related to citric and malic acids of the fruit. No large differences in titratable acidity were shown in all samples.

Color measurement

Table 2 presents the color values for the different treatments validated in minimally processed melon for 12 days. The luminosity parameter decreased over the days of storage; a darkening was observed on the third day of analysis. On the last day, all samples differed from the first day and each treatment.

Table 2 Color of melon coating based on black maca flour and nanoclay with muña essential oil in different concentrations at 5 ± 1 °C, for 12 days.

Parameters	Days	Treatments			
		T1	T2	T3	T4
L*	0	61.7±0.1 ^{aB}	67.3±0.63 ^{aA}	67.3±0.63 ^{aA}	67.3±0.63 ^{aA}
	1	61.5±0.13 ^{aB}	67.2±0.63 ^{aA}	67.2±0.63 ^{aA}	67.2±0.63 ^{aA}
	3	60.9±0.13 ^{aC}	66.5±0.62 ^{aA}	62.9±0.42 ^{bB}	63.5±0.66 ^{bB}
	5	59.2±0.19 ^{bC}	65.0±1 ^{aA}	61.9±0.54 ^{bB}	62.1±0.49 ^{bB}
	7	54.7±0.54 ^{cC}	61.6±1.2 ^{bA}	58.7±0.56 ^{cB}	59.8±0.22 ^{cAB}
	9	46.9±0.88 ^{dC}	59.3±1.3 ^{bcA}	54.5±0.57 ^{dB}	55.2±0.48 ^{dB}
	12	46.0±0.82 ^{dC}	58.6±1.2 ^{cA}	52.1±0.52 ^{eB}	53.4±0.8 ^{eB}
a*	0	-2.2±0.1 ^{cA}	-2.2±0.5 ^{aA}	-2.2±0.5 ^{bA}	-2.2±0.5 ^{aA}
	1	-1.8±0.1 ^{bcA}	-2.2±0.5 ^{aA}	-2.2±0.5 ^{bA}	-2.2±0.5 ^{aA}
	3	-1.8±0.1 ^{bcA}	-2.1±0.5 ^{aA}	-1.8±0.3 ^{abA}	-1.9±0.5 ^{aA}
	5	-1.6±0.2 ^{abcA}	-2.0±0.8 ^{aA}	-1.8±0.4 ^{abA}	-1.8±0.4 ^{aA}
	7	-1.1±0.6 ^{abcA}	-1.7±1 ^{aA}	-1.5±0.4 ^{abA}	-1.6±0.2 ^{aA}
	9	-0.3±0.9 ^{abA}	-1.5±1.1 ^{aA}	-1.2±0.4 ^{abA}	-1.2±0.4 ^{aA}
	12	-0.2±0.9 ^{aA}	-1.8±0.5 ^{aA}	-1±0.4 ^{aA}	-1.1±0.6 ^{aA}
b*	0	10±0.03 ^{aB}	16.1±0.27 ^{aB}	16.1±0.27 ^{aA}	16.1±0.27 ^{aA}
	1	9.7±0.04 ^{aB}	16.0±0.27 ^{aA}	16.0±0.27 ^{aA}	16.0±0.27 ^{aA}
	3	9.7±0.04 ^{aC}	15.7±0.27 ^{aA}	13.8±0.25 ^{bB}	13.4±0.07 ^{bcB}
	5	9.2±0.06 ^{bC}	15.1±0.44 ^{aA}	13.7±0.23 ^{bB}	13.8±0.21 ^{bB}
	7	7.7±0.17 ^{cC}	13.6±0.54 ^{bA}	12.3±0.24 ^{cB}	12.8±0.09 ^{cB}
	9	5.7±0.26 ^{dC}	12.6±0.58 ^{bcA}	10.6±0.24 ^{dB}	10.9±0.2 ^{dB}
	12	5.4±0.24 ^{dC}	12.3±0.54 ^{cA}	9.5±0.22 ^{eB}	10.1±0.34 ^{eB}

Averages of three repetitions ± standard deviation, followed by the lowercase letter in the column and the row not different by Tukey test ($p > 0.05$). T1: control; T2: 0.1%; T3: 0.2% and T4: 0.3% muña essential oil,

respectively.

Regarding L*, sample T1 (control) presented 61.7 on day 0 and 46 on day 12. A study used coating chitosan-based and encapsulated trans-cinnamaldehyde, the control treatment showed an L value of 50.07 on the first day and 41.01 on the 15th day of storage (Martíñon, Moreira, Castell-Perez, & Gomes, 2014).

T2 presented the best values in color analyses; it showed 58.6 brightness, the lowest darkening among the samples in 12 days. Basaglia et al. (2021) evaluated chitosan coating-based and cinnamon essential oil on pineapple pieces, and their results were similar of this work, the value L* was 68.49 on day 0 and 57.06 on day 12.

Regarding the parameter, a*, T1 and T3 increased in 12 days. Also, the control treatment showed increased chroma a* values.

Chroma b* values presented a reduction in all treatments over the days of storage. The coating treatments showed lower enzyme browning in comparison with the control.

Martíñon, Moreira, Castell-Perez, & Gomes (2014) studied coatings using chitosan, pectin, and encapsulated cinnamaldehyde and they presented decreased values of chroma b* with and without coating. The melon oxidation increased during storage, even under refrigeration.

In addition, Fig. 2 confirms the results in the color analysis, the coating treatments, especially T2 showed less darkening with the passage of days of storage.

Firmness

Table 3 The firmness of melon-coating based on black maca flour and nanoclay with muña essential oil in different concentrations at 5 ± 1 °C, for 12 days.

Parameters	Days	Treatments			
		T1	T2	T3	T4
Texture	0	55.19±0.36 ^{aD}	60.87±0.36 ^{aA}	56.76±0.24 ^{aC}	59.29±0.24 ^{aB}
	1	54.04±0.04 ^{bC}	59.39±0.24 ^{bA}	53.12±0.24 ^{bD}	55.19±0.24 ^{bB}
	3	50.71±0.29 ^{cC}	53.13±0.07 ^{cA}	52.95±0.11 ^{bA}	51.67±0.10 ^{cB}
	5	43.83±0.10 ^{dC}	51.96±0.18 ^{dA}	49.2±0.26 ^{cB}	44.08±0.05 ^{dC}
	7	35.38±0.10 ^{eD}	49.2±0.11 ^{eA}	41.1±0.67 ^{dB}	39.91±0.20 ^{eC}
	9	34.34±0.08 ^{fD}	47.02±0.10 ^{fA}	38.65±0.08 ^{eB}	34.92±0.24 ^{fC}
	12	28.73±0.10 ^{gC}	47.27±0.10 ^{fA}	34.37±0.23 ^{fB}	25.04±0.08 ^{gD}

Averages of three repetitions $\pm$ standard deviation, followed by the lowercase letter in the column and the row not different by Tukey test ($p > 0.05$). T1: control; T2: 0.1%; T3: 0.2% and T4: 0.3% muña essential oil, respectively.

The firmness of all treatments decreased during the storage period at 5 ± 1 °C. The control presented a greater loss of texture compared to the treatments coated with muña essential oil and black maca flour. Treatment 2 showed 22.3% texture loss, less than T3 and T4. Another study in minimally processed papayas coated with white croaker protein isolate and montmorillonite showed a 17.64% loss of firmness, lower than our study (Cortez-Vega, Pizato, & de Souza, 2014). The loss of texture is directly related to the loss of water. One study evaluated the loss of firmness in freshly cut apples coated with a polymeric matrix of cassava flour and turmeric oil. The control treatment obtained the greatest loss of water and therefore the greatest loss of firmness (Sharif et al., 2019).

Also, the loss of firmness is related to tissue deterioration due to enzymatic degradation (Yousuf, Qadri, & Srivastava, 2018). For this reason, essential oils in low concentrations could decrease enzymatic activity, thus avoiding tissue deterioration and improving texture during the shelf-life of freshly cut fruits (Teixeira, Balbinot, & Borges, 2022). Decreased firmness of minimally processed coated fruit can be attributed to the migration of moisture from the fruit to the coating (Glicerina et al., 2019).

Water Activity

Water activity (a_w) is one of the main factors determining feed stability and its estimation is more important than the quantities of the total amount of water present (Rahman, 2015). Water activity in foods is the free water fraction that is not bound to polymeric starch and protein. Free water fraction is available to participate in microbial, chemical, and physical reactions (Rahman & Labuza, 2020; Rahman, 2019). Also, water activity is responsible for the water retention capacity in the cell wall of the tissue of foods.

Table 4 The water activity (a_w) of melon coating based on black maca flour and nanoclay with muña essential oil in different concentrations at 5 ± 1 °C, for 12 days.

Parameters	Days	Treatments			
		T1	T2	T3	T4
Aw	0	0.984 $\pm$ 0.002 ^{aA}	0.991 $\pm$ 0.003 ^{aA}	0.994 $\pm$ 0.002 ^{aA}	0.991 $\pm$ 0.005 ^{aA}
	1	0.985 $\pm$ 0.002 ^{aA}	0.992 $\pm$ 0.003 ^{aA}	0.995 $\pm$ 0.002 ^{aA}	0.992 $\pm$ 0.005 ^{aA}
	3	0.985 $\pm$ 0.011 ^{aA}	0.993 $\pm$ 0.003 ^{aA}	0.996 $\pm$ 0.002 ^{aA}	0.993 $\pm$ 0.003 ^{aA}
	5	0.988 $\pm$ 0.002 ^{aB}	0.993 $\pm$ 0.002 ^{aAB}	0.997 $\pm$ 0.003 ^{aA}	0.996 $\pm$ 0.001 ^{aA}
	7	0.989 $\pm$ 0.003 ^{aB}	0.995 $\pm$ 0.003 ^{aAB}	0.997 $\pm$ 0.003 ^{aA}	0.998 $\pm$ 0.001 ^{aA}
	9	0.989 $\pm$ 0.005 ^{aA}	0.995 $\pm$ 0.001 ^{aA}	0.998 $\pm$ 0.004 ^{aA}	0.998 $\pm$ 0.003 ^{aA}
	12	0.991 $\pm$ 0.005 ^{aA}	0.995 $\pm$ 0.002 ^{aA}	0.998 $\pm$ 0.002 ^{aA}	0.998 $\pm$ 0.002 ^{aA}

Averages of three repetitions $\pm$ standard deviation, followed by the lowercase letter in the column and the row not different by Tukey test ($p > 0.05$). T1: control; T2: 0.1%; T3: 0.2% and T4: 0.3% muña essential oil, respectively.

There were no significant differences in water activity between treatments during the twelve days of storage at 5 ± 1 °C. A study showed similar results to ours, it evaluated grapes with pectin edible coating and lemon essential oil, it maintained water activity during 35 days of storage at 4 °C (Breceda-Hernandez, Martínez-Ruiz, Serna-Guerra, & Hernández-Carrillo, 2020). These results could be attributed to the addition of essential oil with hydrophobic properties that decreases the water vapor permeability of the coating (Nastasi, Kontogiorgos, Daygon, & Fitzgerald, 2022). On the other hand, a study reports different results, chitosan/nano-silica/nisin coating decreases the water activity of fresh-cut melon coated, compared with the control (Sami et al., 2021).

Microbiological quality

Susceptibility to the growth of microorganisms is determined by food-water activity (a_w) (Rahman, 2015). Almost all minimally processed fruits have around 0.98 aw, therefore they are sensitive to the development of pathogenic bacterias, mold, and yeasts (Wiley, 2017).

All treatments showed the absence of *Escherichia coli* and *Salmonella*. However, there was the presence of molds and yeasts in all the treatments. Fig. 3 shows that the control exhibits 5.44 log CFU g⁻¹, treatments 2, 3, and 4 with coating showed lower growth of molds and yeasts 4.06; 4.49, and 4.24 CFU g⁻¹, respectively during the 12 days of storage compared to the control. There was no significant difference between coated treatments.

The study about fresh-cut papaya coated with white croaker protein isolate and montmorillonite showed slightly decreased growth of molds and yeasts 6.21 ± 0.10 CFU g⁻¹ at day 12 of storage, compared to the control 7.03 ± 0.03 CFU g⁻¹ Cortez-Vega et al., (2014). Moreover, Pizato et al. (2022) evaluated the antimicrobial effect of the application of 1 and 1.5% of clove essential oil in a coating that showed the grow 5.14 and 3.85 CFU g⁻¹ of molds and yeast. The present study showed lower quantities of molds and yeasts 4.06 CFU g⁻¹, on day 12 of storage. This difference can be attributed to the addition of muña essential oil in coated treatments. Essential oils present antimicrobial activity against molds, yeasts, and mesophiles in coatings for fresh-cut fruits and vegetables during storage time (Yousuf et al., 2018). The mainly compound of muña essential oil is pulegone between 33.48 and 85% (Benites et al., 2018). A *vitro* study with 11.25 and 22.5 uL/ml of the essential oil of *Mentha pulegium* that contains 76.35% of pulegone inhibited 100% growth of *Aspergillus niger* and 87.91% for *Aspergillus flavus* (Aimad et al., 2021).

A study evaluated an alginate-based coating on fresh-cut covered melon treatments with 0.7% cinnamon and 0.5% clove essential oils showed a lower growth of molds and yeasts during 12 days of storage compared to the control (Raybaudi-Massilia et al., 2008).

Conclusion

Muña essential oil shows antimicrobial properties in the edible coating with black maca flour and montmorillonite on minimally processed melon. Muña essential oil treatments reduced water loss of melon and inhibited the microbial growth of *E. Coli* and *Salmonella sp.*, and delayed the growth of mold and yeast. Treatment 2 (0.1% muña essential oil) presented the best results according to weight loss, firmness, and delayed mold and yeasts. This coating extended melon shelf life up to 12 days in refrigeration at $5 \pm 1^\circ\text{C}$ compared to the control.

Declarations

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Data Availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interest The authors declare that they have no conflict of interest.

Author contributions

Noelia Xiomara Pacheco Torreblanca: Conceptualization; data curation; formal analysis; investigation; methodology; validation; visualization; writing – original draft. **María Cecilia Pacco Huamani:** Conceptualization; data curation; formal analysis; investigation; methodology; validation; visualization;

writing – original draft. **Katerin Victoria Carlos Tapia**: Conceptualization; data curation; formal analysis; investigation; methodology; validation; visualization; writing – original draft. **Sandriane Pizato**: Funding acquisition; project administration; resources; writing – review and editing. **William Renzo Cortez-Vega**: Funding acquisition; project administration; resources; writing – review and editing. **Grethel Teresa Choque Delgado**: Project administration; supervision; writing – review and editing.

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Figures

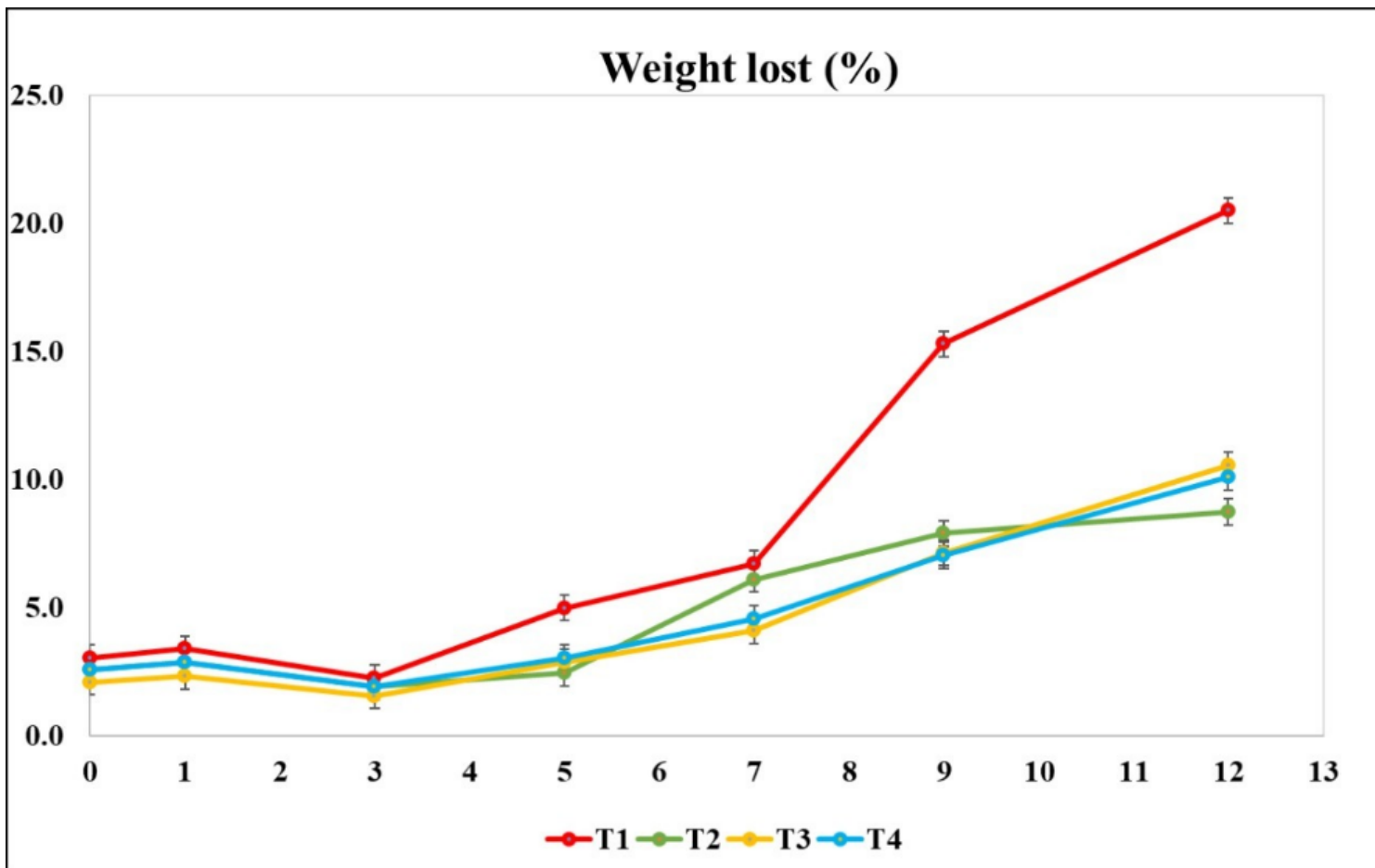


Figure 1

Weight lost in minimally processed melon samples coated with different concentrations of muña essential oil stored at 5 ± 1 °C, for 12 days. T1: control; T2: 0.1%; T3: 0.2% and T4: 0.3% muña essential oil, respectively

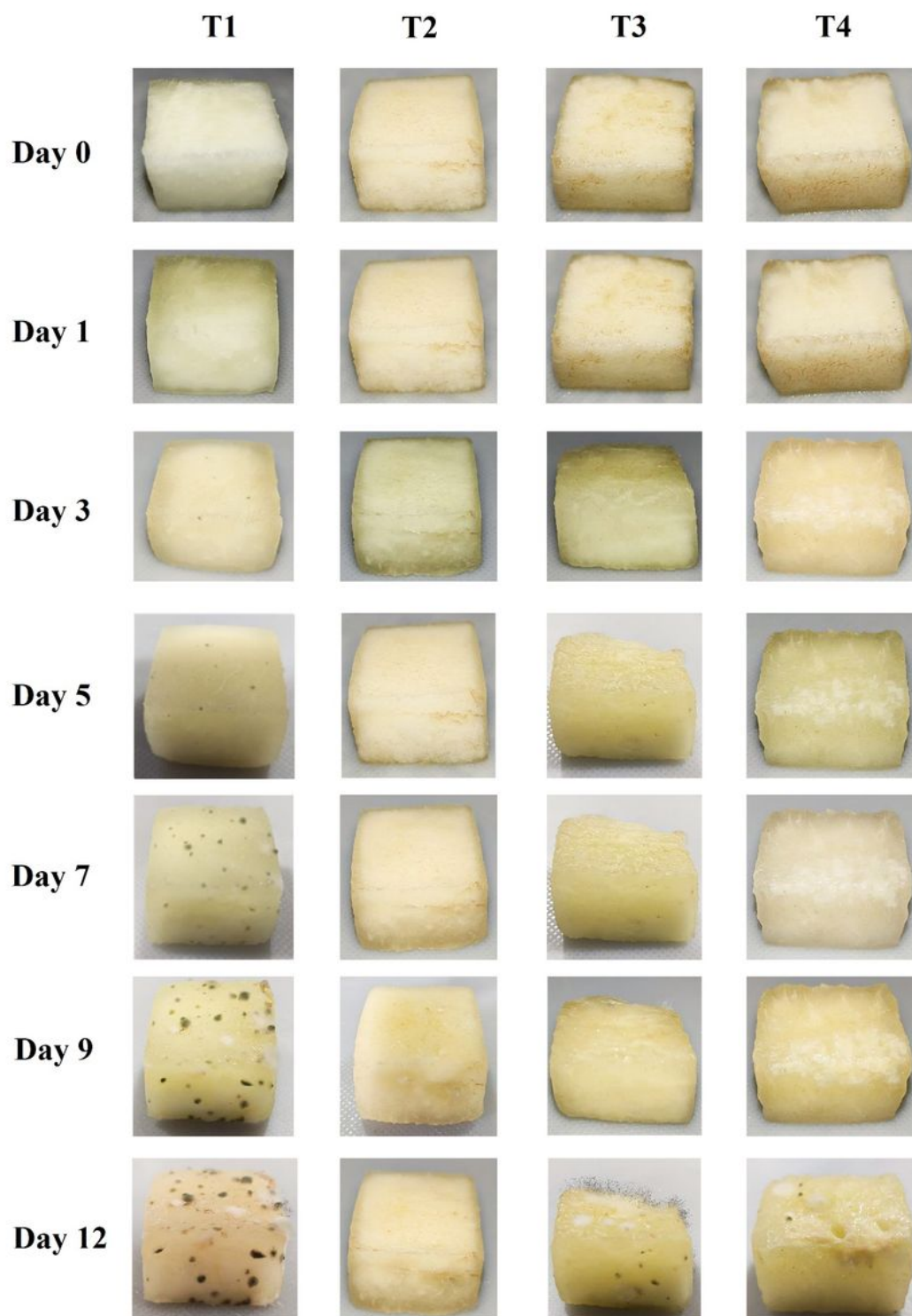


Figure 2

The appearance of melons with or without coatings containing different concentrations of muña essential oil over the days of storage

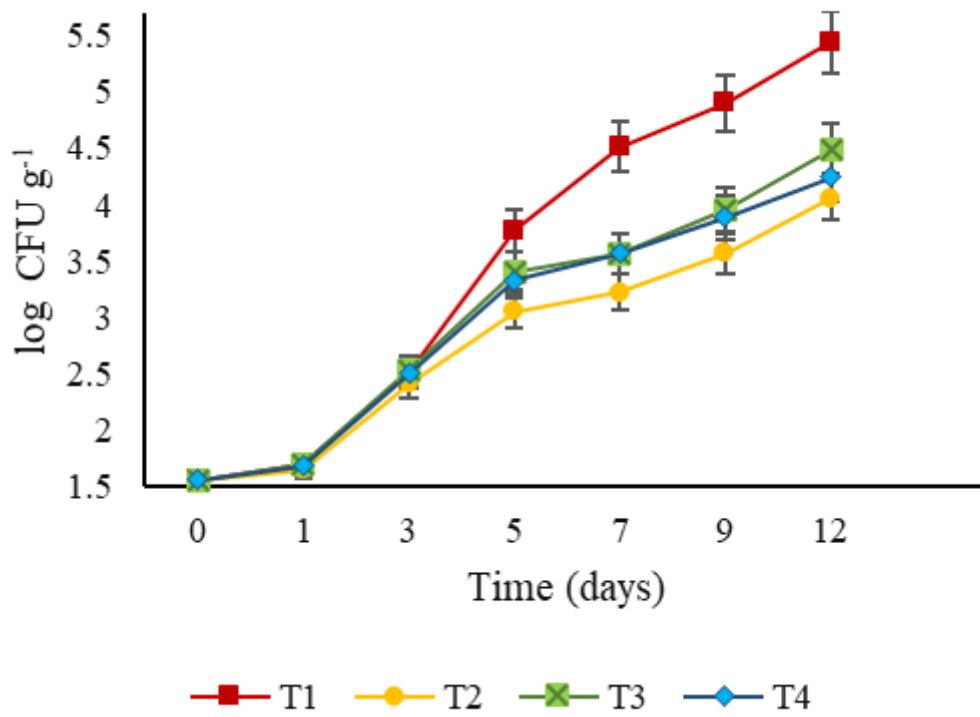


Figure 3

Growth of molds and yeasts found in minimally processed melon samples coated with different concentrations of muña essential oil stored at 5±1 °C, for 12 days