LWT - Food Science and Technology 232 (2025) 118430

Contents lists available at ScienceDirect

LWT

journal homepage: www.elsevier.com/locate/lwt

Chayote and cucumber peels as raw material for edible leathers (pestils): valorization of vegetable residues

Giovana de Menezes Rodrigues [a], Vitor Augusto dos Santos Garcia [b], Fernanda Maria Vanin [a], Cristiana Maria Pedroso Yoshida [c], Rosemary Aparecida de Carvalho [a,*]

[a] University of São Paulo, Faculty of Animal Science and Food Engineering, Av. Duque de Caxias Norte, 225, Pirassununga, Sao Paulo, Brazil
[b] São Paulo State University, Faculty of Agricultural Sciences, Street José Barbosa de Barros, 1780, Botucatu, Sao Paulo, Brazil
[c] Federal University of São Paulo, Institute of Environmental, Chemical and Pharmaceutical Sciences, Street São Nicolau, 210, Diadema, Sao Paulo, Brazil

ARTICLE INFO

Keywords:
Pestil
Antioxidant activity
Browning index
Stability
Bioactive compounds
Cucumis sativus L.
Sechium edule J

ABSTRACT

Edible leathers (pestils) are dehydrated products obtained from drying vegetable purees, resulting in flexible sheets with a leather-like texture. They represent a practical, nutritious and stable healthy snack option. The objective of the study was to evaluate the properties and stability of leathers (pestils) based on purees. Formulations were prepared with varying concentrations of chayote peel puree (60, 70 and 80 g/100 g) and cucumber (40, 50 and 60 g/100 g), with agar-agar (2 g/100 g). The leathers were produced using the tape-casting technique and dried at 50 °C for 9h. Characterization included microstructural and mechanical properties, and storage stability under accelerated conditions for 40 days. Samples with higher concentrations of chayote peel puree exhibited greater thickness (0,199–0,229 mm), puncture force (13,34-14,33 N), and puncture deformation (1,41-1,47 %) compared to those formulated with cucumber peel puree. Water content increased up to fourfold during storage, promoting the realease of bioactive compounds and antioxidant activity. Cucumber peel leathers showed better color stability and a lower browning index, likely due to natural antioxidants. Higher puree concentrations also led to increased total phenolic content and antioxidant activity. These results highlight the potential of vegetable peels in developing sustainable, nutritious snacks with good storage stability.

1. Introduction

Edible leathers (pestils) are food products obtained by drying a thin layer of fruit or vegetable puree (Gómez-Pérez et al., 2019), resulting in a restructured, flexible sheet with a soft texture and glossy appearance, resembling leather (Demarchi et al., 2013). This characteristic appearance gives the product its name and to distinguish it from conventional snack types (Collins Washam-Hutsell, 1987).

Generally, edible leathers exhibit a final thickness between 0.300 and 3.000 mm and are recognized not only for their practicality and longer shelf life, but also for their nutritional value (Rodrigues et al., 2023). They can be consumed directly or used as edible wraps, enhancing their versatility in food applications (Otoni et al., 2017). Due to their diverse composition, edible leathers contribute to a healthy and balanced diet by providing fiber, vitamins, and mineral, and they align with current consumer demand for nutritious, plant-based foods (El-Said Ali, 2019).

The characteristics of edible leathers depend largely on the formulation. Variables such as the concentration of puree (Abdrabou, 2023; Ezekiel & Olukuewu, 2013; Offia-Olua & Ekwunife, 2015) and the addition of ingredients such as hydrocolloids (Tontul & Topuz, 2018), sugars (Valenzuela & Aguilera, 2015), acids (Demarchi et al., 2013), antioxidants (Torres et al., 2015), and preservatives (Ahmad et al., 2005) affect texture, color, and stability.

Therefore, different formulations have been explored with the aim of optimizing the properties of vegetable leathers, especially with regard to nutritional value. However, despite growing interest, studies specifically addressing the production of edible leathers (pestils) using vegetables residues, such as peels, and evaluating the stability of their bioactive compounds over time remain scarce.

In this context, chayote (*Sechium edule* J.) is considered a nutritious and affordable vegetable, but it has a short shelf life due to its high moisture content (89–95 g/100 g) (Vieira et al., 2019). Its peel stands out as a rich source of bioactive compounds, with concentrations higher than those of the pulp (Loizzo et al., 2016). Studies also report high levels of flavonoids and phenolics in chayote residues (Ordoñez et al.,

* Corresponding author.
E-mail address: rosecarvalho@usp.br (R.A. Carvalho).

https://doi.org/10.1016/j.lwt.2025.118430
Received 10 July 2025; Received in revised form 20 August 2025; Accepted 30 August 2025
Available online 30 August 2025

2006), with 26 distinct phenolic compounds identified in the peel, including phenolic acids, flavones, and flavonols (Díaz-de-Cerio et al., 2019).

Another widely cultivated vegetable with characteristics similar to chayote is cucumber (*Cucumis sativus* L.), whose global production exceeded 178 million tons in 2023 (FAOSTAT, 2023). With a high moisture content (96.4 g/100 g) (Mukherjee et al., 2013), cucumbers show rapid loss of visual and sensory quality during storage (Saha et al., 2016), which limits their shelf life to 14 days (Sarker et al., 2021). Cucumber peel, which is often discarded, is also rich in fiber and minerals such as potassium and magnesium (Sumathi et al., 2008), as well as compounds with antioxidant and antimicrobial properties (Sotiroudis et al., 2010). Anjani et al. (2023) isolated quercetin from cucumber peel and observed significant antioxidant activity and antimicrobial effect in this compound.

The search for strategies that reduce food waste and promote the use of vegetable residues in product development has become increasingly relevant in the context of food security, nutrition, and sustainability. Among the innovative practices in this area, the production of edible leathers (pestils) stands out as a healthy and alternative method of vegetable consumption (Ciurzyńska et al., 2019). Technologies capable of transforming food residues into stable, appealing, and functional products, such as edible leathers, can play a key role in minimizing post-harvest losses and food waste. This approach aligns with global sustainability goals, including SDG 2 (Zero Hunger and Sustainable Agriculture) and SDG 12 (Responsible Consumption and Production).

In this context, the present study aimed to reuse chayote and cucumber peels to develop nutritious, low-ingredient edible leathers (pestils). To achieve this goal, different formulations were evaluated for their microstructural and mechanical properties, as well as their moisture stability, color, bioactive compounds, and antioxidants under accelerated storage conditions.

2. Materials e methods

2.1. Materials

Chayotes (*Sechium edule* J.) and cucumbers (*Cucumis sativus* L.) purchased from supermarkets in the city of Pirassununga-SP, agar-agar (Quimer Comercial Ltda, São Paulo-SP, Brazil), sodium hypochlorite (Triex, Sertãozinho-SP, Brazil), sodium bromide (Synth, Diadema-SP, Brazil), potassium iodide (Neon, Suzano-SP, Brazil), methanol (Neon, Suzano-SP, Brazil), formic acid (Sigma-Adrich, Sant Louis-MO, USA), Folin-Ciocalteu reagent (Sigma-Aldrich, Buchs, Switzerland), anhydrous sodium carbonate (Synth, Diadema-SP, Brazil), sodium acetate (Êxodo Científica, Hortolândia-SP, Brazil), glacial acetic acid (LSChemicals, Ribeirão Preto-SP, Brazil), ferric chloride (Êxodo Científica, Hortolândia-SP, Brazil), 2,4,6-tri(2-pyridyl)-s-triazine (TPTZ, Sigma-Aldrich, Buchs, Switzerland), 2,2′-azinobis(3-ethylbenzothiazoline-6-sulfonic acid ($ABTS^{\bullet+}$, Roche, Mannhein, Germany), anhydrous monosodium phosphate (Synth, Diadema-SP, Brazil), anhydrous disodium phosphate (Synth, Diadema-SP, Brazil), fluorescein sodium salt (Sigma-Aldrich, Sant Louis-MO, USA) and 2,2′-azobis(2-methylpropionamidine) dihydrochloride (AAPH, Sigma-Aldrich, Shanghai, China).

2.2. Production of vegetable-based leathers (pestils)

The vegetables were sanitized in sodium hypochlorite solution according to the manufacturer's instructions (0.8 %, for 15 min) and then rinsed in running water (Concha-Meyer et al., 2016). The peels were removed from the vegetables using a manual peeler, then cut (2.0 cm), and distributed on perforated trays for steam cooking (98 °C, 100 % steam for 1h) in a combination oven (Prática, C-Mas Gourmet, Piracicaba-SP, Brazil), following the conditions established in preliminary tests. Then, the peels were crushed (3000 rpm for 3 min) in a Cutter food processor (Sammic, CKE-5, Linda-a-Velha, Portugal). The purees were frozen (Brastemp Flex freezer, BVR28MB, Joinville-SC, Brazil) for 48h. To ensure homogeneity, the purees obtained were mixed to obtain a single batch and stored in plastic packaging (Grespan, Zip Bags, 24 × 34 cm) until use. Prior to leather production, the purees were thawed at 5 ± 2 °C (Consul refrigerator, CRM54, Joinville-SC, Brazil) for 12h.

The leathers (pestils) were produced by the tape-casting technique with different concentrations of chayote peel puree (CHPP, 60, 70 and 80 g/100 g) and cucumber peel puree (CCPP, 40, 50 and 60 g/100 g). Agar-agar was used at a fixed concentration of 2 g/100 g. The agar-agar was solubilized in distilled water (100 ± 2 °C; IKA-C-MAG HS7-Germany hot plate) under mechanical stirring (IKA, Digital RW20, Germany) at 1000 rpm for 1 min. Then, the previously heated puree (90 ± 2 °C) in a thermostatic bath (Marconi, MA159, Piracicaba-SP, Brazil) was added to the agar-agar solution under mechanical stirring (1000 rpm for 2 min). The leather-forming mass (LFM) was spread on a Teflon plate using the ZAA 2300 spreader (Zehntner Testing Instruments, Sissach, Switzerland) with the aid of a high-precision adjustable applicator (4 mm, TKB Erichsen, APF 01/20, Mooca-SP, Brazil), operating at a speed of 10 mm/s. The leathers (pestils) were subjected to drying in an oven with air circulation (Marconi, MA 037, Piracicaba-SP, Brazil) at 50 °C for 9h, as defined in preliminary tests. Before analysis, the leathers (pestils) were stored for 48 h in a desiccator containing a saturated saline solution of NaBr (Synth, Diadema-SP, Brazil), at a relative humidity of 58 % at room temperature (25 ± 3 °C) as proposed by Simão et al. (2019).

2.3. Visual appearance and scanning electron microscopy (SEM)

The leathers were visually evaluated for homogeneity, formation of a continuous matrix, ease of removal from the drying support and handling of the final product. For scanning electron microscopy (SEM) analysis, leather samples (surface and internal structure) were analyzed using an electron microscope (Tabletop Hitachi TM-3000, Hitachi Hight-Technology Corporation, Tokyo, Japan) with a 15 kV electron beam. To evaluate the internal structure, the samples were fractured using liquid nitrogen.

2.4. Thickness and mechanical properties

Thickness was determined using a digital dial indicator (Mitutoyo Corp., Absolute, Kawasaki, Kanagawa, Japan) with a USB converter (Mitutoyo Corp., IT-016U, Kawasaki, Kanagawa, Japan) attached. The puncture force (PF) and puncture deformation (PD) properties were determined according to Gontard et al. (1993), using a texturometer (TA.XT2, Stable Micro Systems, England). Leather samples (diameter 70 mm) were stored in a desiccator containing saturated saline NaBr solution (58 % relative humidity) at room temperature (25 ± 3 °C) for 48 h. The samples were fixed in a circular perforated cell (internal diameter 52.6 mm). A cylindrical probe (Cylinder Stainless, P/2 = 2 mm) was used to perform the test and the test speed was set at 1 mm/s. The data obtained were PF (N) and distance (mm) through the Exponent software (version 6.1.7.0, Stable Micro Systems, England) and PD (%) was calculated according to Equation (1).

$$PD = \sqrt{D^2 + l_0^2} \text{ - } l_0/l_0 \tag{1}$$

Where: (PD) = puncture deformation (%); D = distance traveled by the probe (mm); l_0 = is the initial length of the leather, which is the internal radius of the circular cell (26.3 mm).

2.5. Stability

Stability was evaluated according to the methodology described by Tontul and Topuz (2018). The samples were cut and packaged in low-density plastic packaging (10 cm × 15 cm x 0.10 mm; Uniopack

Embalagens Plásticas), sealed (Barbi, TI-400, Itu-SP, Brazil) and stored in a desiccator containing a saturated saline solution of potassium iodide (Neon, Suzano, São Paulo-SP, Brazil) under accelerated conditions of temperature (35 °C; BOD oven Marconi, MA415, Piracicaba-SP, Brazil) and relative humidity (68 %), for a period of 40 days.

Analyses during storage were performed on days 1 and 40, evaluating the following parameters: moisture content, color parameters, and concentration of total phenolic compounds and antioxidant activity (FRAP, $ABTS^{\bullet+}$ and ORAC).

2.5.1. Water content

Leather samples (10 cm × 2.5 cm) were weighed using a previously tared filter weight and dried in a vacuum oven (~600 mmHg, Marconi, MA030, Piracicaba-SP, Brazil) at 70 °C for 6 h (AOAC, 2012). The results were expressed in g/100 g dry sample.

2.5.2. Color parameters

The color of the leathers was determined using a spectrophotometer (HunterLab, Aeros, Virginia, USA). Samples measuring 7 cm in diameter were placed on a white surface for analysis in triplicate. The color parameters determined were L* (luminosity), a* and b*, using illuminant D65 and an observation angle of 10°. The equipment was configured to perform 7 measurements per second over the sample area, with a reading time of 5 s (totaling 35 readings). From the values of L*, a* and b*, the browning index (BI) was calculated according to Maskan (2001) using Equations (2) and (3).

$$BI = 100(x - 0,31)/0,17 \quad (2)$$

$$x = a^* + 1,75L^*/5,645L^* + a^* - 3,012b^* \quad (3)$$

2.5.3. Extraction of total phenolic compounds and antioxidant compounds

The extraction of total phenolic compounds and antioxidants from leathers (pestils) was performed according to the methodology proposed by Kamiloglu and Capanoglu (2014). The leathers (pestils) samples were ground (Philips-Walita blender, RI2001, Amsterdam, Netherlands) and the samples (2 g) were dispersed in 5 mL of aqueous methanol solution (75 % v/v), acidified with formic acid (0.1 % v/v). The mixture was kept in an ice bath coupled to ultrasound (Ultronique, Eco-Sonics, Q3.8/40, Indaiatuba-SP, Brazil) for 15 min and then centrifuged (Eppendorf, 5430 R, Sumarezinho-SP, Brazil) at 27,000 g for 10 min at 4 °C. The supernatant (extract) was then transferred to properly identified amber vials. The extraction process was repeated 3 times with the same sample, totaling 20 mL of solvent used.

2.5.3.1. Concentration of total phenolic compounds. The determination of total phenolic compounds was performed by the Folin-Ciocalteau method, according to the methodology proposed by Singleton et al. (1999). Aliquots (0.5 mL) of the extract were added to test tubes and then 2.5 mL of Folin-Ciocalteau (1:10, v/v, diluted in distilled water) were added and after 6 min, 2 mL of anhydrous sodium carbonate aqueous solution (7.5 %, m/v) were added. The solution was homogenized in a vortex shaker (IKA, Vortex 1, V1, Germany) and kept at rest for 2 h (absence of light, room temperature). Afterwards, the absorbance was determined in a spectrophotometer (PerkinElmer, Lambda 35 UV–Vis, USA) at 760 nm. Gallic acid (0.022–0.064 mg/mL). The results were expressed in mg gallic acid equivalent (GAE)/100 g dry sample.

2.5.3.2. FRAP - ferric reducing antioxidant power. The antioxidant activity by the iron ion reduction method (FRAP) was determined according to the methodology proposed by Benzie and Strain (1999). Aliquots (100 μL) of the extract, 300 μL of distilled water and 3 mL of FRAP reagent were homogenized in a vortex (IKA, Vortex 1, V1, Germany) and stored in a thermostatic bath (Marconi, MA159, Piracicaba-SP, Brazil) at 37 °C for 30 min. After this period, the absorbance was determined using a spectrophotometer (PerkinElmer, Lambda 35 UV–Vis, USA) at 593 nm. Trolox was used as an external standard to construct the calibration curve (concentrations ranging from 5 to 22.5 μM) and the results were expressed in μmol Trolox equivalent (TE)/100 g dry sample.

2.5.3.3. $ABTS^{\bullet+}$. The antioxidant activity was evaluated by the $ABTS^{\bullet}+$ (2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) free radical method according to the methodology described by Re et al. (1999) using 30 μL of extract with $ABTS^{\bullet+}$ solution (3 mL). The solution was then homogenized (IKA vortex shaker, Vortex 1, V1, Germany) and kept in the absence of light for 6 min. The absorbance was determined at 734 nm (PerkinElmer Lambda 35 UV–Vis spectrophotometer, USA). Trolox was used as an external standard (concentrations ranging from 100 to 2000 μM) and the results were expressed in μmol Trolox equivalent (TE)/100 g dry sample.

2.5.3.4. ORAC - Oxygen radical absorbance capacity. The antioxidant activity, by the oxygen radical absorbance capacity (ORAC) method, was determined according to the methodology proposed by Ou et al. (2001) using a spectrofluorimeter (BMG Labtech, FLUOstar OPTIMA, Offenburg, Germany). Fluorescein solution (150 μL, 81 mM) was placed in each well of a microplate (96-well, Greiner Bio-One) and the extract was added afterwards (aliquots of 25 μL of the extract). The microplate was incubated at 37 °C for 10 min and then 25 μL of AAPH solution (152 mM) was added. The fluorescence decay was determined at 1-min intervals for 120 min, using excitation wavelengths of 485 nm and emission wavelengths of 528 nm. Trolox was used as an external standard (concentrations ranging from 12 to 96 μM) and the results were expressed in μmol Trolox equivalent (TE)/100 g dry sample.

2.6. Statistical analysis

For the analysis of mechanical properties, triplicates of the production were performed, with five samples of each formulation analyzed (totaling 15 samples). In the analysis of stability during storage, moisture content and color parameters were evaluated in duplicate formulations, with three samples per duplicate (totaling 6 points per day). The concentration of total phenolic compounds and antioxidant activity were evaluated from two replicates per formulation. From each replicate, two extracts were obtained, and each extract was analyzed in triplicate, totaling 12 points per day. Statistical analyses were performed using SAS software (version 9.4, SAS, Inc.) and the difference between means was determined by Duncan's test at a 95 % confidence interval.

3. Results and discussion

3.1. Visual appearance and scanning electron microscopy (SEM)

All formulations presented a continuous but heterogeneous matrix, characterized by the visible presence of plant fibers (Fig. 1). This characteristic results from the incorporation of insoluble fibrous components from the plant peels into the agar matrix, contributing to the formation of the observed heterogeneous matrix. The edible leathers (pestils) were easily removed from the drying surface and handled without tearing, indicating adequate leather formation and satisfactory mechanical integrity.

Chagas et al. (2024) reported fiber concentrations of approximately 2 g/100 g in chayote puree and 1.5 g/100 g in cucumber puree, values that help explain the fibrous appearance observed in the present study. The visual characteristics of the leathers produced are consistent with those described for other formulations, such as apple pulp and peel leathers (Ciurzyńska et al., 2019) and spinach-based leathers (Kalengkongan, Sihombing, & Wahyu, 2019).

In the surface micrographs (Fig. 1), characteristic fiber filaments

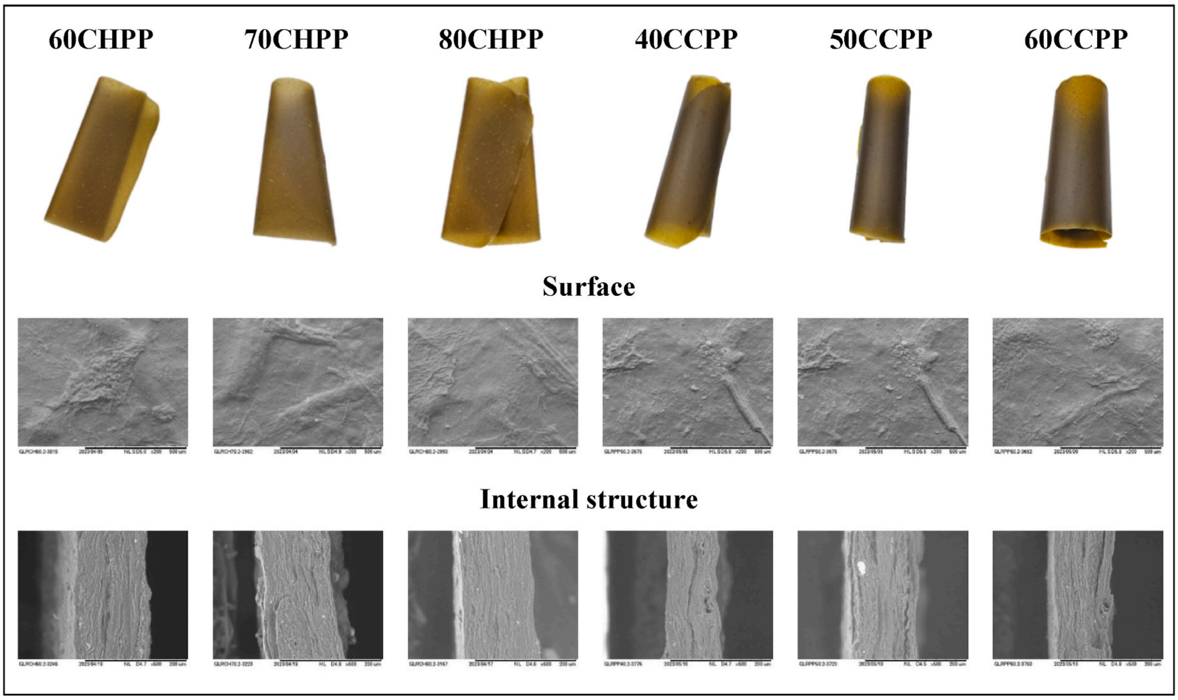

Fig. 1. Edible leathers (pestils) based on chayote peel puree (CHPP) and cucumber (CCPP) in visual appearance and scanning electron microscopy (SEM), where: 60CHPP: 60 g CHPP/100 g; 70CHPP: 70 g CHPP/100 g; 80CHPP: 80 g CHPP/100 g; 40CCPP: 40 g CCPP/100 g; 50CCPP: 50 g CCPP/100 g; 60CCPP: 60 g CCPP/100 g.

were observed in both the chayote peel puree leathers (CHPP) and the cucumber peel puree leathers (CCPP), suggesting the presence of vegetable fibers throughout the polymeric matrix. In the micrographs of the internal structure, a compact and cohesive matrix was observed, which can be attributed to the interaction between the agar-agar and the non-starch polymers present in the vegetable peels. However, small insoluble agar-agar particles were also observed.

Iahnke et al. (2015) reported a heterogeneous surface of gelatin-based films due to the incorporation of carrot residue (8.5 %) and attributed this fact to the high content of insoluble fibers in the residue, due to the higher concentration of fibers on the surface during the drying process, causing the formation of a less smooth surface. While Wongphan and Harnkarnsujarit (2020) observed in the internal structure of starch, agar-agar and maltodextrin films, the formation of layers as the agar-agar content increased (0–30 % w/w) and that low amounts of agar-agar can result in more homogeneous matrices.

Table 1
Effect of chayote peel puree (CHPP) and cucumber peel puree (CCPP) in thickness (TH) and puncture force (PF) and puncture deformation (PD).

Leather (pestil)	TH (mm)	PF (N)	PD (%)
60CHPP	0.199 ± 0.014^{Ba}	13.34 ± 1.05^{Aa}	1.41 ± 0.32^{Aa}
70CHPP	0.200 ± 0.018^{Ba}	13.43 ± 1.23^{Aa}	1.45 ± 0.20^{Aa}
80CHPP	0.229 ± 0.009^{Aa}	14.33 ± 1.63^{Aa}	1.47 ± 0.10^{Aa}
40CCPP	0.109 ± 0.018^{Cb}	10.08 ± 1.49^{Bb}	0.72 ± 0.16^{Ab}
50CCPP	0.140 ± 0.010^{Bb}	11.83 ± 2.09^{ABb}	0.75 ± 0.16^{Ab}
60CCPP	0.152 ± 0.018^{Ab}	13.36 ± 1.62^{Aa}	0.89 ± 0.13^{Ab}

Note = 60CHPP: 60 g CHPP/100 g; 70CHPP: 70 g CHPP/100 g; 80CHPP: 80 g CHPP/100 g; 40CCPP: 40 g CCPP/100 g; 50CCPP: 50 g CCPP/100 g; 60CCPP: 60 g CCPP/100 g. Means followed by the same capital letter (comparison between vegetable peel purees) and lowercase letter (comparison between stability days) do not differ statistically ($p > 0.05$).

3.2. Thickness and mechanical properties

The edible leathers thickness increased significantly ($p < 0.05$) with incorporation of puree, regardless of the vegetable. However, the thickness of leathers based on chayote peel puree (CHPP) was greater than that observed in leathers made from cucumber peel puree (CCPP), as shown in Table 1.

A tendency for puncture force (PF) and puncture deformation (PD) values to increase with increasing puree concentration was observed, although this variation was not statistically significant for the range studied. However, this increase may be related to the formation of a more rigid polymer network with the incorporation of puree in the presence of agar-agar, reducing the flexibility of the matrix (Wongphan & Harnkarnsujarit, 2020).

Regarding the different vegetables, it was found that CHPP leathers presented significantly higher values ($p < 0.05$) of deformation at rupture compared to CCPP leathers. This difference can be attributed to the composition of chayote, which is naturally rich in complex carbohydrates, such as fiber and starch (Vieira et al., 2019), in addition to containing non-starch polysaccharides, such as galacturonic and glucuronic acids, and sugars such as galactose (Ke et al., 2023). These compounds may have interacted with agar-agar, promoting the formation of a denser and more cohesive polymer network (Fig. 1).

According to Amoroso et al. (2022), these results reinforce the influence of the structural composition of the plant matrix, in plants with a higher content of solids and fibers, which tend to form firmer and more resistant structures, while the addition of hydrocolloids such as agar-agar acts on structuring, intensifying cohesion. Diamante et al. (2013) reported that, in apple, currant and pectin leathers, increasing the concentration of concentrated apple juice reduced the force, with values between 9.28 and 29.66 N, results close to those found in this study.

3.3. Stability

3.3.1. Water content

The water content of CHPP and CCPP leathers increased under the storage conditions evaluated (Fig. 2), reaching up to four times higher in CHPP leathers and approximately three times higher in CCPP leathers, compared to the initial values.

Similarly, Ezekiel and Olukuewu (2013) reported a significant increase in the moisture content of carrot and mango leathers after 60 days of storage (28 ± 1 °C). Sarkar et al. (2019) also observed an approximate 20 % increase in the water content of mango leathers packaged in biodegradable paper pouches and stored at room temperature (30 ± 5 °C) for six months, indicating that the type of packaging material influences moisture gain.

3.3.2. Color parameters

The increase in the puree concentration significantly influenced ($p < 0.05$) the L* (luminosity) values of the leathers, regardless of the type of vegetable used (Table 2). A reduction in the L* parameter was also observed over the storage time, being significant ($p > 0.05$) for some formulations (Table 2). This reduction in luminosity may be associated with the greater thickness of the leathers with a higher puree concentration (Table 1), which reduces light reflection, as well as due to the higher content of solids and pigments naturally present in these vegetables, which intensify the color.

In general, all formulations presented reduced a* values, indicating a predominance of greenish tones, as can be visually observed in Fig. 1. The characteristic coloration of the leathers may be associated mainly with the presence of chlorophyll (Omoba & Onyekwere, 2016). These values remained stable, especially for the cucumber peel puree leathers (CCPP), regardless of the puree concentration used or the storage time.

The b* values were also positive in all formulations, suggesting a yellowish coloration. The chayote peel puree leathers (CHPP) presented higher b* values than the CCPP leathers, indicating a greater predominance of yellow.

Regarding the browning index (BI), the CHPP leathers presented an increase of up to 25 % after 40 days of storage under accelerated conditions, differing significantly ($p < 0.05$) from the first day (Table 2). Possibly, under these storage conditions, pigment degradation and darkening reactions occurred, such as the Maillard reaction, due to the

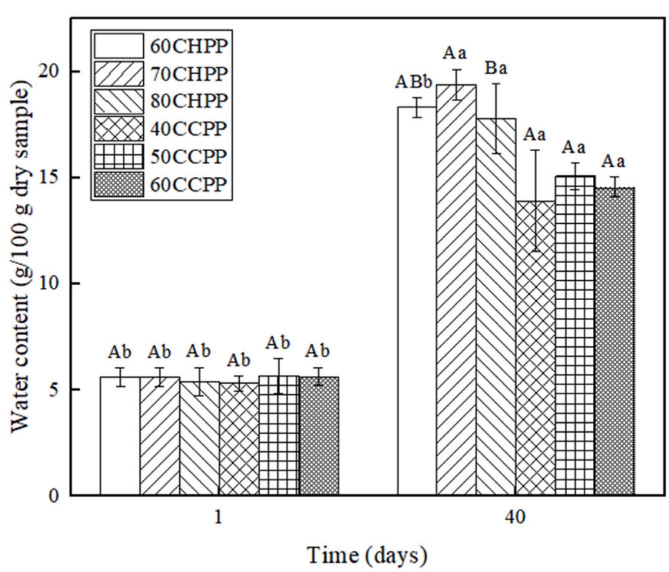

Fig. 2. Effect of chayote peel puree (CHPP) and cucumber peel puree (CCPP) concentration on the water content of edible leathers (pestils) stored under accelerated conditions (35 °C - 68 % relative humidity). Note = 60CHPP: 60 g CHPP/100 g; 70CHPP: 70 g CHPP/100 g; 80CHPP: 80 g CHPP/100 g; 40CCPP: 40 g CCPP/100 g; 50CCPP: 50 g CCPP/100 g; 60CCPP: 60 g CCPP/100 g. Means followed by the same capital letter (comparison between the concentration of vegetable peel puree) and lowercase letter (comparison between stability days) do not differ statistically ($p > 0.05$).

presence of sugars and other compounds present in the chayote (Maskan, 2001).

A contrary effect was observed for the cucumber leathers, which presented a 21 % reduction in BI after 40 days of storage. This decrease was significant ($p < 0.05$) mainly in the formulation with a higher concentration of puree, possibly due to the greater protection of the pigments responsible for the green coloration, such as chlorophyll. The lower BI may be associated with the presence of antioxidant compounds naturally found in cucumber peel, which contributed to inhibiting browning reactions (Torres et al., 2015).

3.3.3. Total phenolic compounds and antioxidant activity

Overall, the increase in the puree concentration, regardless of the vegetable used, resulted in a significant increase in the content of total phenolic compounds (Table 3). This trend was mirrored in all antioxidant activity assays (FRAP, $ABTS^{\bullet +}$ and ORAC). As expected, the higher concentration of puree provides a greater amount of active compounds to the leathers, offering greater availability of phenolic compounds and antioxidant activity.Acording to Loizzo et al. (2016) greater initial availability of phenolic compounds in formulations with a higher pure peel content, since phenolic compounds are concentrated mainly in vegetable peels. This behavior corroborates previous studies that reported that chayote and cucumber peels are rich in phenolic compounds and have high antioxidant potential (Anjani et al., 2023; Loizzo et al., 2016; Nagarajaiah & Prakash, 2015; Yunusa et al., 2018).

During accelerated storage (35 °C, 68 % RH, 40 days), the total phenolic content increased further, possibly due to the polymerization of compounds, leading to the formation of derivatives with higher antioxidant activity than the original components. A similar behavior was reported by Torres et al. (2015). Manzocco et al. (2001) also observed that non-enzymatic browning reactions, such as the Maillard reaction, can produce potent antioxidant compounds. The observed increase in the browning index (Table 2) suggests the occurrence of the Maillard reaction during storage, resulting in the interaction between reducing sugars and amino acids and consequently an increase in antioxidant activity. Both chayote and cucumber peels contain bioactive phenolics and non-starch polysaccharides, including pectin (Ke et al., 2023; Loizzo et al., 2016; Sotiroudis et al., 2010), which can undergo structural transformations during storage, increasing their antioxidant potential.

In addition, according to Phan The et al. (2009), agar-agar is capable of forming a semi-rigid three-dimensional matrix, which captures and immobilizes the solvent and molecules present in the medium. In newly produced leather, this network may have initially trapped phenolics, limiting their extraction. During storage, the observed increase in humidity (Fig. 2) likely weakened intermolecular interactions, disrupted cellular structures, and facilitated the release of bound bioactives. Agar-agar gels can alternate between single- and double-helical conformations (Song et al., 2012), and prolonged exposure to warm, humid conditions can promote partial restructuring of the matrix, further enhancing compound release.

Similar results were reported in apple leathers, where antioxidant activity (ORAC) increased by 28 % after 35 days at 30 ± 2 °C (Torres et al., 2015), although changes in total phenolic compounds and other antioxidant assays varied. Similar increases in the concentration of total phenolic compounds and antioxidant activity after storage were reported in fruit leathers by Concha-Meyer et al. (2016), Giacalone et al. (2019) and Sharma et al. (2016), suggesting that structural and chemical transformations occurring during storage may improve their nutritional properties. Concha-Meyer et al. (2016) reported an increase in total phenolic content from approximately 160 to 260 mg chlorogenic acid equivalents/100 g in strawberry leathers stored under accelerated conditions (30 ± 2 °C for 25 days).

Table 2
Effect of chayote peel puree (CHPP) and cucumber peel puree (CCPP) concentration on the color parameters L* (luminosity), a*, b* and BI (browning index) of edible leathers (pestils) stored under accelerated conditions (35 °C - 68 % relative humidity).

Leathers (pestils)	L*		a*		b*		BI	
	Time (days)							
	1	40	1	40	1	40	1	40
60PCCH	70.94 ± 1.44^{Aa}	66.69 ± 1.21^{Ab}	1.46 ± 0.30^{Bb}	5.01 ± 0.65^{Ba}	38.52 ± 1.48^{Ab}	42.43 ± 0.38^{Aa}	75.37 ± 5.36^{Cb}	98.79 ± 2.98^{Ba}
70PCCH	69.20 ± 0.97^{Ba}	66.48 ± 3.38^{Aa}	1.50 ± 0.42^{Bb}	5.56 ± 1.37^{ABa}	39.58 ± 0.67^{Ab}	42.50 ± 1.34^{Aa}	80.98 ± 2.90^{Bb}	100.35 ± 5.91^{Ba}
80PCCH	65.41 ± 0.56^{Ca}	62.89 ± 3.13^{Aa}	2.70 ± 0.49^{Ab}	6.87 ± 1.09^{Aa}	39.56 ± 0.97^{Ab}	42.81 ± 1.31^{Aa}	89.30 ± 4.20^{Ab}	112.19 ± 10.57^{Aa}
40PCPP	50.65 ± 0.93^{Aa}	46.63 ± 1.53^{Ab}	8.80 ± 0.17^{Ab}	9.39 ± 0.50^{Aa}	25.36 ± 1.50^{Aa}	22.69 ± 1.19^{Ab}	79.20 ± 3.80^{Aa}	78.83 ± 5.29^{Aa}
50PCPP	46.72 ± 0.56^{Ba}	44.94 ± 2.49^{Aa}	9.03 ± 0.28^{Aa}	9.47 ± 0.75^{Aa}	21.96 ± 2.10^{Ba}	20.53 ± 4.68^{Aa}	75.30 ± 7.30^{Aa}	74.22 ± 13.95^{Aa}
60PCPP	46.38 ± 3.18^{Ba}	40.58 ± 1.05^{Bb}	8.96 ± 0.26^{Aa}	8.61 ± 0.41^{Ba}	21.28 ± 1.23^{Ba}	14.71 ± 0.81^{Bb}	73.29 ± 3.71^{Aa}	59.21 ± 4.08^{Bb}

Note = 60CHPP: 60 g CHPP/100 g; 70CHPP: 70 g CHPP/100 g; 80CHPP: 80 g CHPP/100 g; 40CCPP: 40 g CCPP/100 g; 50CCPP: 50 g CCPP/100 g; 60CCPP: 60 g CCPP/100 g. Means followed by the same capital letter in the same column (comparison between vegetable peel puree concentration) and lowercase in the same row (comparison between stability days) do not differ statistically ($p > 0.05$).

Table 3
Effect of chayote peel puree (CHPP) and cucumber peel puree (CCPP) concentration on the total phenolic compounds (TPC) and antioxidant activity by FRAP, $ABTS^{\bullet +}$ and ORAC methods of leathers (pestils) stored under accelerated conditions (35 °C - 68 % relative humidity).

Leathers (pestils)	TPC (mg GAE/100 g ds)		FRAP (μmol TE/100 g ds)		$ABTS^{\bullet +}$ (μmol TE/100 g ds)		ORAC (μmol TE/100 g ds)	
	Time (days)							
	1	40	1	40	1	40	1	40
60PCCH	126.76 ± 4.34^{Bb}	212.92 ± 9.65^{Ba}	11.80 ± 0.52^{Bb}	20.62 ± 0.43^{Ca}	553.23 ± 36.08^{Bb}	1058.04 ± 98.08^{Aa}	2443.68 ± 87.46^{Bb}	4593.02 ± 101.18^{Aa}
70PCCH	125.79 ± 6.15^{Bb}	224.56 ± 11.04^{Aa}	12.40 ± 0.28^{Bb}	23.65 ± 0.26^{Ba}	569.18 ± 29.07^{Bb}	1088.96 ± 98.91^{Aa}	2557.49 ± 325.43^{ABb}	4769.01 ± 275.57^{Aa}
80PCCH	146.00 ± 10.22^{Ab}	226.98 ± 4.72^{Aa}	15.46 ± 1.22^{Ab}	24.48 ± 0.74^{Aa}	731.61 ± 59.55^{Ab}	1102.98 ± 56.52^{Aa}	2786.38 ± 318.81^{Ab}	4770.31 ± 107.99^{Aa}
40PCPP	116.58 ± 5.57^{Cb}	157.51 ± 12.05^{Ca}	11.35 ± 0.55^{Cb}	12.05 ± 0.68^{Ca}	459.78 ± 35.48^{Cb}	765.28 ± 53.89^{Ca}	2541.16 ± 192.83^{Cb}	3483.35 ± 275.04^{Ba}
50PCPP	134.82 ± 4.06^{Bb}	192.96 ± 8.65^{Ba}	12.39 ± 0.77^{Bb}	14.01 ± 2.05^{Ba}	558.65 ± 53.08^{Bb}	854.93 ± 54.32^{Ba}	2890.72 ± 159.53^{Bb}	3786.08 ± 348.00^{Aa}
60PCPP	162.12 ± 3.74^{Ab}	213.18 ± 17.39^{Aa}	13.87 ± 1.27^{Ab}	15.16 ± 0.67^{Aa}	665.79 ± 53.85^{Ab}	1052.04 ± 141.77^{Aa}	3284.53 ± 129.12^{Ab}	3879.64 ± 328.25^{Aa}

Note = 60CHPP: 60 g CHPP/100 g; 70CHPP: 70 g CHPP/100 g; 80CHPP: 80 g CHPP/100 g; 40CCPP: 40 g CCPP/100 g; 50CCPP: 50 g CCPP/100 g; 60CCPP: 60 g CCPP/100 g; GAE: Gallic acid equivalent; TE: Trolox equivalent; ds: dry sample. Means followed by the same capital letter in the same column (comparison between vegetable peel puree concentration) and lowercase in the same row (comparison between stability days) do not differ statistically ($p > 0.05$).

4. Conclusion

The edible leathers (pestils) obtained presented a compact and cohesive matrix, although heterogeneous due to the presence of insoluble fibers, as confirmed by micrographs. A higher puree concentration increased the thickness of chayote peel puree leathers compared to cucumber peel puree. Formulations with chayote peel puree also exhibited greater puncture force and deformation, indicating superior mechanical strength and flexibility, likely related to the composition of chayote peel puree. During storage, water content increased significantly. In the chayote peel puree leathers, the increased browning index, associated with higher concentrations of bioactive compounds, suggests that oxidation and Maillard reactions contributed to the formation of compounds with high antioxidant potential. Conversely, the reduced browning index in cucumber peel puree leathers indicates greater color stability, possibly due to natural antioxidants delaying browning. Total phenolic content and antioxidant activity increased over storage, likely resulting from greater release of bound compounds through water absorption and the formation of new compounds during chemical reactions. These results confirm the feasibility of using chayote and cucumber peels in the production of nutritious, value-added pestils, contributing to waste reduction. Considering the observed changes in water content, future research should explore optimized packaging and controlled storage conditions to preserve the characteristics of these products.

CRediT authorship contribution statement

Giovana de Menezes Rodrigues: Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Data curation. **Vitor Augusto dos Santos Garcia:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis. **Fernanda Maria Vanin:** Writing – review & editing, Writing – original draft, Validation, Methodology. **Cristiana Maria Pedroso Yoshida:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology. **Rosemary Aparecida de Carvalho:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior-Brasil (CAPES)-Finance Code 001 (G.M.R.). The authors would like to thank the National Council for

Scientific and Technological Development (CNPq) for productivity grants, Process number: 305262/2019-0 (R.A.C.) and 306117/2025-8 (V.A.S.G.). The authors would like to thank the São Paulo Research Foundation (FAPESP, Process number: 2019/13944-3) for financial support.

Data availability

No data was used for the research described in the article.

References

Abdrabou, E. (2023). Quality attributes of carrot-tamarind leathers. *Journal of Food and Dairy Sciences, 0*(0), 195–205. https://doi.org/10.21608/jfds.2023.225785.1122

Ahmad, S., Vashney, A. K., & Srivasta, P. K. (2005). Quality attributes of fruit bar made from papaya and tomato by incorporating hydrocolloids. *International Journal of Food Properties, 8*(1), 89–99. https://doi.org/10.1081/JFP-200048043

Amoroso, L., De France, K. J., Milz, C. I., Siqueira, G., Zimmermann, T., & Nyström, G. (2022). Sustainable cellulose nanofiber films from carrot pomace as sprayable coatings for food packaging applications. *ACS Sustainable Chemistry & Engineering, 10*(1), 342–352. https://doi.org/10.1021/acssuschemeng.1c06345

Anjani, Srivastava, N., & Mathur, J. (2023). Isolation, purification and characterization of quercetin from Cucumis sativus peels; its antimicrobial, antioxidant and cytotoxicity evaluations. *3 Biotech, 13*(2). https://doi.org/10.1007/s13205-023-03464-8

Benzie, I. F. F., & Strain, J. J. (1999). Ferric reducing/antioxidant power assay: Direct measure of total antioxidant activity of biological fluids and modified version for simultaneous measurement of total antioxidant power and ascorbic acid concentration [2] *Methods in Enzymology, 299*, 15–27. https://doi.org/10.1016/S0076-6879(99)99005-5.

Ciurzyńska, A., Cieśluk, P., Barwińska, M., Marczak, W., Ordyniak, A., Lenart, A., & Janowicz, M. (2019). Eating habits and sustainable food production in the development of innovative "healthy" snacks (running title: Innovative and "healthy" snacks). *Sustainability (Switzerland), 11*(10). https://doi.org/10.3390/su11102800

Collins, J. L., & Washam-Hutsell, L. (1987). Physical, chemical, sensory and microbiological attributes of sweet potato leather. *Journal of Food Science, 52*(3), 646–648. https://doi.org/10.1111/j.1365-2621.1987.tb06693.x

Concha-Meyer, A. A., D'Ignoti, V., Saez, B., Diaz, R. I., & Torres, C. A. (2016). Effect of storage on the physico-chemical and antioxidant properties of strawberry and kiwi leathers. *Journal of Food Science, 81*(3), C569–C577. https://doi.org/10.1111/1750-3841.13214

Demarchi, S. M., Quintero Ruiz, N. A., Concellón, A., & Giner, S. A. (2013). Effect of temperature on hot-air drying rate and on retention of antioxidant capacity in apple leathers. *Food and Bioproducts Processing, 91*(4), 310–318. https://doi.org/10.1016/j.fbp.2012.11.008

Diamante, L., Li, S., Xu, Q., & Busch, J. (2013). Effects of apple juice concentrate, blackcurrant concentrate and pectin levels on selected qualities of apple-blackcurrant fruit leather. *Foods, 2*(3), 430–443. https://doi.org/10.3390/foods2030430

Díaz-de-Cerio, E., Verardo, V., Fernández-Gutiérrez, A., & Gómez-Caravaca, A. M. (2019). New insight into phenolic composition of chayote (Sechium edule (Jacq.) Sw.). *Food Chemistry, 295*, 514–519. https://doi.org/10.1016/j.foodchem.2019.05.146

El-Said Ali, N. M. (2019). Utilization of some fruits and vegetables pulp in processing (Sheets' sweets pieces) products. *Food Technology Research Institute, 79*(54). https://doi.org/10.21608/bnni.2020.132662

Ezekiel, O. O., & Olukuewu, M. T. (2013). Chemical, microbiological and sensory characteristics of leather blends produced from mango (*Mangifera indica* 'Ogbomoso') and carrot (Daucus carota). *Acta Horticulturae, 1007*, 471–478. https://doi.org/10.17660/actahortic.2013.1007.54

FAOSTAT, F. A. O. (2023). *Crops and livestock products*. Roma: FAO. Available at: https://www.fao.org/faostat/en/#data/QCL. (Accessed 8 June 2025).

Giacalone, G., da Silva, T. M., Peano, C., & Giuggioli, N. R. (2019). Development of fruit leather from Actinidia arguta by-product: Quality assessment and shelf life studies. *Italian Journal of Food Science, 31*(3), 470–486. https://doi.org/10.14674/IJFS-1376

Gómez-Pérez, L. S., Navarrete, C., Moraga, N., Rodríguez, A., & Vega-Gálvez, A. (2019). Evaluation of different hydrocolloids and drying temperatures in the drying kinetics, modeling, color, and texture profile of murta (Ugni molinae Turcz) berry leather. *Journal of Food Process Engineering, 43*(2), 1–10. https://doi.org/10.1111/jfpe.13316

Gontard, N., Guilbert, S., & Cuq, J. (1993). Water and glycerol as plasticizers affect mechanical and water vapor barrier properties of an edible wheat gluten film. *Journal of Food Science, 58*(1), 206–211. https://doi.org/10.1111/j.1365-2621.1993.tb03246.x

Iahnke, A. O. e S., Costa, T. M. H., Rios, A. de O., & Flôres, S. H. (2015). Residues of minimally processed carrot and gelatin capsules: Potential materials for packaging films. *Industrial Crops and Products, 76*, 1071–1078. https://doi.org/10.1016/j.indcrop.2015.08.025

Kalengkongan, A. W. P., Sihombing, M., & Wahyu, F. D. (2019). Green spinach leather as a Fe source to increase nutritional intake. *International Conference on Food and Bio-Industry, 443*, 2020. https://doi.org/10.1088/1755-1315/443/1/012043

Kamiloglu, S., & Capanoglu, E. (2014). In vitro gastrointestinal digestion of polyphenols from different molasses (pekmez) and leather (pestil) varieties. *International Journal of Food Science and Technology, 49*(4), 1027–1039. https://doi.org/10.1111/ijfs.12396

Ke, J., Zhang, Y., Wang, X., Sun, J., Wang, S., Ma, Y., Guo, Q., & Zhang, Z. (2023). Structural characterization of cell-wall polysaccharides purified from chayote (*Sechium edule*) fruit. *Food Chemistry X, 19*. https://doi.org/10.1016/j.fochx.2023.100797

Loizzo, M. R., Bonesi, M., Menichini, F., Tenuta, M. C., Leporini, M., & Tundis, R. (2016). Antioxidant and carbohydrate-hydrolysing enzymes potential of *Sechium edule* (Jacq.) Swartz (Cucurbitaceae) peel, leaves and pulp fresh and processed. *Plant Foods for Human Nutrition, 71*(4), 381–387. https://doi.org/10.1007/s11130-016-0571-4

Manzocco, L., Calligaris, S., Mastrocola, D., Nicoli, M. C., & Lerici, C. R. (2001). Review of non-enzymatic browning and antioxidant capacity in processed foods. *Trends in Food Science & Technology, 11*, 340–346. https://doi.org/10.1016/S0924-2244(01)00014-0

Maskan, M. (2001). Kinetics of colour change of kiwifruits during hot air and microwave drying. *Journal of Food Engineering, 48*(2), 169–175. https://doi.org/10.1016/S0260-8774(00)00154-0

Mukherjee, P. K., Nema, N. K., Maity, N., & Sarkar, B. K. (2013). Phytochemical and therapeutic potential of cucumber. *Fitoterapia, 84*, 227–236. https://doi.org/10.1016/j.fitote.2012.10.003

Nagarajaiah, S. B., & Prakash, J. (2015). Chemical composition and bioactive potential of dehydrated peels of benincasa hispida, luffa acutangula, and sechium edule. *Journal of Herbs, Spices, & Medicinal Plants, 21*(2), 193–202. https://doi.org/10.1080/10496475.2014.940437

Offia-Olua, B. I., & Ekwunife, O. A. (2015). Production and evaluation of the physico-chemical and sensory qualities of mixed fruit leather and cakes produced from apple (Musa Pumila), banana (Musa Sapientum), pineapple (Ananas Comosus). *Nigerian Food Journal, 33*(1), 22–28. https://doi.org/10.1016/j.nifoj.2015.04.004

Omoba, S. O., & Onyekwere, U. (2016). Postharvest physicochemical properties of cucumber fruits (Cucumber sativus L) treated with chitosan-lemon grass extracts under different storage durations. *African Journal of Biotechnology, 15*(50), 2758–2766. https://doi.org/10.5897/ajb2016.15561

Ordoñez, A. A. L., Gomez, J. D., Vattuone, M. A., & Isla, M. I. (2006). Antioxidant activities of Sechium edule (Jacq.) Swartz extracts. *Food Chemistry, 97*(3), 452–458. https://doi.org/10.1016/j.foodchem.2005.05.024

Otoni, C. G., Avena-Bustillos, R. J., Azeredo, H. M. C., Lorevice, M. V., Moura, M. R., Mattoso, L. H. C., & McHugh, T. H. (2017). Recent advances on edible films based on fruits and vegetables—A review. *Comprehensive Reviews in Food Science and Food Safety, 16*(5), 1151–1169. https://doi.org/10.1111/1541-4337.12281

Ou, B., Hampsch-Woodill, M., & Prior, R. L. (2001). Development and validation of an improved oxygen radical absorbance capacity assay using fluorescein as the fluorescent probe. *Journal of Agricultural and Food Chemistry, 49*(10), 4619–4626. https://doi.org/10.1021/jf010586o

Phan The, D., Debeaufort, F., Voilley, A., & Luu, D. (2009). Biopolymer interactions affect the functional properties of edible films based on agar, cassava starch and arabinoxylan blends. *Journal of Food Engineering, 90*(4), 548–558. https://doi.org/10.1016/j.jfoodeng.2008.07.023

Re, R., Pellegrini, N., Proteggente, A., Pannala, A., Yang, M., & Rice-Evans, C. (1999). Antioxidant activity applying an improved ABTS radical cation decolorization assay. *Free Radical Biology and Medicine, 26*(9–10), 1231–1237. https://doi.org/10.1016/S0891-5849(98)00315-3

Rodrigues, G. de M., Garcia, V. A., dos, S., Yoshida, C. M. P., Vanin, F. M., & Carvalho, R. A. de (2023). Fruit-based leathers: A comprehensive review of terminologies, composition, and quality attributes. *Food Science and Engineering*, 216–236. https://doi.org/10.37256/fse.4220232791

Saha, A., Tyagi, S., Gupta, R. K., & Tyagi, Y. K. (2016). Guar gum based edible coating on cucumber (*Cucumis sativus* L.). *European Journal of Pharmaceutical and Medical Research, 3*(9), 558–570. https://www.researchgate.net/publication/307863612.

Sarkar, T., Nayak, P., & Chakraborty, R. (2019). Storage study of mango leather in sustainable packaging condition. *Materials Today: Proceedings, 22*, 2001–2007. https://doi.org/10.1016/j.matpr.2020.03.177

Sarker, A., Deltsidis, A., & Grift, T. E. (2021). Effect of Aloe vera Gel-Carboxymethyl cellulose composite coating on the degradation kinetics of cucumber. *Journal of Biosystems Engineering, 46*, 112–128. https://doi.org/10.1007/s42853-021-00092-z/Published

Sharma, P., Ramchiary, M., Samyor, D., & Das, A. B. (2016). Study on the phytochemical properties of pineapple fruit leather processed by extrusion cooking. *LWT - Food Science and Technology, 72*, 534–543. https://doi.org/10.1016/j.lwt.2016.05.001

Simão, R. S., Moraes, J. O., Souza, P. G., Carciofi, B. A. M., & Laurindo, J. B. (2019). Production of mango leathers by cast-tape drying: Product characteristics and sensory evaluation. *LWT - Food Science and Technology, 99*, 445–452. https://doi.org/10.1016/j.lwt.2018.10.013

Singleton, V. L., Orthofer, R., & Lamuela-Raventós, R. M. (1999). *[14] Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu reagent*, 152–178. https://doi.org/10.1016/S0076-6879(99)99017-1

Song, E. H., Shang, J., & Ratner, D. M. (2012). Polysaccharides. *Polymer Science: A Comprehensive Reference, 10*(9), 137–155. https://doi.org/10.1016/B978-0-444-53349-4.00246-6

Sotiroudis, G., Melliou, E., Sotiroudis, T. G., & Chinou, I. (2010). Chemical analysis, antioxidant and antimicrobial activity of three greek cucumber (Cucumis sativus) cultivars. *Journal of Food Biochemistry, 34*, 61–78. https://doi.org/10.1111/j.1745-4514.2009.00296.x

Sumathi, T., Ponnuswami, V., & Senthamizh, B. S. (2008). Anatomical changes of cucumber (Cucumis sativus L.) leaves and roots as influenced by shade and fertigation. *Advances in Natural and Applied Sciences, 2*, 185–192.

Tontul, I., & Topuz, A. (2018). Storage stability of bioactive compounds of pomegranate leather (pestil) produced by refractance window drying. *Journal of Food Process Engineering, 42*(2), 1–11. https://doi.org/10.1111/jfpe.12973

Torres, C. A., Romero, L. A., & Diaz, R. I. (2015). Quality and sensory attributes of apple and quince leathers made without preservatives and with enhanced antioxidant activity. *LWT - Food Science and Technology, 62*(2), 996–1003. https://doi.org/10.1016/j.lwt.2015.01.056

Valenzuela, C., & Aguilera, J. M. (2015). Effects of different factors on stickiness of apple leathers. *Journal of Food Engineering, 149*, 51–60. https://doi.org/10.1016/j.jfoodeng.2014.09.029

Vieira, E. F., Pinho, O., Ferreira, I. M., & Delerue-Matos, C. (2019). Chayote (*Sechium edule*): A review of nutritional composition, bioactivities and potential applications. *Food Chemistry, 275*(March 2018), 557–568. https://doi.org/10.1016/j.foodchem.2018.09.146

Wongphan, P., & Harnkarnsujarit, N. (2020). Characterization of starch, agar and maltodextrin blends for controlled dissolution of edible films. *International Journal of Biological Macromolecules, 156*, 80–93. https://doi.org/10.1016/j.ijbiomac.2020.04.056

Yunusa, A. K., Dandago, M. A., Ibrahim, S. M., Abdullahi, N., Rilwan, A., & Barde, A. (2018). Total phenolic content and antioxidant capacity of different parts of cucumber (*Cucumis Sativus* L.). *Acta Universitatis Cibiniensis. Series E: Food Technology, 22*(2), 13–20. https://doi.org/10.2478/aucft-2018-0008