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Applying an alginate and mucilage-based edible coating to avocado halves favors some physical attributes and consumer acceptance

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Abstract. The avocado is a highly perishable fruit, leading to significant potential waste and loss in some links of the agri-food chain, with negative environmental and economic impacts. This study explored the influence of an alginate and mucilage-based edible coating on some physical attributes, cold storage, and consumer acceptance of avocado halves coated at the ready-to-eat stage. Two lots of avocado halves were formed. One was treated with an edible coating formulated from alginate and mucilage; the other was uncoated. Uncoated and coated avocado halves were cold-stored at 4 ± 1 °C and 95% relative humidity for 12 d. The fruit mass loss (FML), fresh firmness (FF), and some color parameters were measured every other day. The experiment was conducted in a completely random design with three replicates at each sampling date. On the sixth day, a sensory study was performed with 30 untrained panelists who were frequent avocado eaters. The coated avocado halves were brighter, redder, and yellower during the experimental period than uncoated avocado halves. A significant color differences (*ΔE**) were found between coated and uncoated avocado halves. At the end of the experiment, the coated samples had the lowest FML and FF and the greatest consumer acceptance. Therefore, the edible coating presented here is a feasible technology for minimally-processed avocado halves and for high-latitude markets, where this fruit is scarce.

Keywords: *Opuntia albicarpa* Scheinvar*; mucilage; alginate; shelf life; Persea americana* var. 'Hass'*; sensory analysis.*

Introduction

The avocado (*Persea americana*) is appreciated worldwide for its nutritional and functional properties (San José *et al*., 2023). In 2020, 8 M t were produced worldwide, with Mexico as the principal producer with 2.4 M t (FAOSTAT, 2020). Although avocado consumption is mainly fresh, consumption of minimally processed or processed avocados (*e.g*., guacamole, frozen slices, sauces, puree, preserves, and dehydrated) has increased. The processed avocado market is projected to go from $1,700 M USD in 2018 to $2,700 M USD in 2024 (Ramos-Aguilar *et al*., 2021).

Minimally processed or processed avocado is prone to enzymatic browning, softening, and attack by microorganisms (Ramos-Villarroel *et al*., 2011; Velderrain-Rodríguez *et al*., 2021). The intense light pulses have been used to minimize this process (Mandal *et al*., 2020) and to increase the shelf life of minimally processed avocado (Aguiló-Aguayo *et al*., 2014; Ramos-Aguilar *et al*., 2021; Velderrain-Rodríguez *et al*., 2021). Alternatively, edible coatings (ECs) have been developed to increase shelf life and temporally maintain the commercial quality of minimally processed fresh products (Bierhals *et al*., 2011). The ECs are a thin layer used to coat food to improve shelf life, minimize moisture removal and gas exchange and, therefore, temporarily minimize enzymatic browning (González-Aguilar *et al*., 2010; Chavan *et al*., 2023). The ECs are prepared from polysaccharides e.g., chitosan, starch, cellulose, pectin, sodium alginate or mucilage (Kong *et al*., 2022), because these compounds are non-toxic, biocompatible, biodegradable and easy to process (Voss *et al*., 2018). Additionally, to increase their functionality, the ECs can be enriched with antimicrobial, probiotic or antioxidant agents (Khodaei *et al*., 2020; Marangoni-Júnior *et al*., 2022).

The sodium alginate is an unbranched polysaccharide extracted mainly from brown algae (Mrudulakumari-Vasudevan *et al*., 2021). It is composed of β-D-mannuronate and α-L-guluronate fractions linked by (1−4) glycosidic bonds (Zhou *et al*., 2022). Transparent, uniform, water-soluble films with low permeability to fat, oil, and oxygen are formulated from sodium alginate (Mahcene *et al*., 2020; Nair *et al*., 2020) and applied to minimally-processed fresh products such as melon (Sarengaowa *et al*., 2019), apple (Chen *et al*., 2021), guava (Luna-Zapién *et al*., 2023) and rose apple (Duong *et al*., 2023).

The cactus pear mucilage (*Opuntia* spp.) is a linear heteropolysaccharide composed of arabinose, xylose, galactose, galacturonic acid and rhamnose (Stintzing and Carle, 2005). This compound, in addition to having therapeutic properties (Galati *et al*., 2007; Galati *et al*., 2001; Jaramillo-Flores *et al*., 2003; Trombetta *et al*., 2006), has gained importance as a functional additive (Contreras-Padilla *et al*., 2016) and is used by the food industry as a food thickener and emulsifier (León-Martínez *et al*., 2010), bioactive compound encapsulant (Soto-Castro *et al*., 2019) or as a material for coating fresh fruits and vegetables (Del-Valle *et al*., 2005; Zambrano-Zaragoza *et al*., 2014).The *Opuntia* mucilage-based ECs retard deterioration of commercial quality and sensory properties of minimally-processed fruits such as fig (Allegra *et al*., 2017), strawberry (Del-Valle *et al*., 2005) and kiwi (Allegra *et al*., 2016). However, to our best knowledge, there are no studies on the formulation and application of alginate mucilage-based ECs for conservation of minimally processed avocados. This study explored the influence of an alginate mucilage-based edible coating on some physical attributes, cold storage, and consumer acceptability of avocado halves coated at the ready-to-eat stage. It was hypothesized that the coating would delay enzymatic browning, extend shelf life and increase consumers' acceptance of minimally processed avocado halves.

Material and Methods

Plant material

The cactus pear plants of *Opuntia albicarpa* Scheinvar var. Cristalina were established at the Campo Experimental Zacatecas (latitude 22°54'N, longitud 102°39'W, elevation 2,197 m) of the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP) of Mexico. On May 29, 2019, one-year-old cladodes were collected for mucilage extraction around and from the outer edges of three non-irrigated experimental plants. The mucilage of these plants has higher phenolic compounds and antioxidant capacity than irrigated plants. The cladode samples were stored at -18 °C until

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processing. The avocados (*Persea americana* var. 'Hass') were purchased in a local market in Gómez Palacio, Durango, Mexico. The fruit had no cosmetic or free-pathogen damage at ripeness Grade 3 (50% color break from green to black).

Mucilage extraction

The cladodes of non-irrigated 'Cristalina' plants were selected based on their high polyphenol content and antioxidant capacity (unpublished data). They were de-spined manually and sanitized with 200 ppm chlorinated water. The chlorenchyma was removed. Approximately 100 g of the hydrenchyma was cubed (≈ 1 cm^3) and blended with distilled water (1:10) for 45 s. The pH was adjusted to 7.00 ± 0.1 with 5 N NaOH and the mixture was heated at 50 °C with constant stirring for 16 h, then filtered through a sieve. The filtrate was mixed with 96% (v/v) ethanol (1:2). The mixture was stirred for 2 h at room temperature and maintained at 4 °C for 24 h until separation. The supernatant was decanted and the precipitate was concentrated in a rotary evaporator (BUCHI R-210, Flawil, Switzerland), lyophilized, and vacuum-packed. The mucilage extraction was carried out between March and April 2019 in the Facultad of Ciencias Químicas of the Universidad Juárez del Estado de Durango (24° 02' N and 104° 67' W).

Coating preparation

Approximately 1 g mucilage and 1.25 g sodium alginate, as stabilizer (Perea-Flores *et al*., 2023), were dissolved in 100 mL distilled water at 55 to 60 °C. Afterward, 600 mg sorbitol, 5 mL glycerol, 1.0 mL tween 80, 0.75 mL soy lecithin and 12 mL olive oil were added. This mixture was homogenized at 22,000 rpm for 13 min with an Ultraturrax T18 (IKA Works, Inc., Wilmington, USA; (Reyes-Avalos *et al*., 2016).

Avocado samples preparation/coating application

The avocados were washed with 0.02% sodium hypochlorite and later, they were manually cut into longitudinal halves. Two lots of 60 avocado halves each were formed. The first lot was immersed in distilled water for 30 s to prepare the uncoated control. The second lot was first treated with 0.1% (w/w) citric acid:ascorbic acid (70:30). Then, the avocado samples were dipped into the coating emulsion for 30 s, the excess solution was removed manually and the coated pieces were immersed in 2% $CaCl_2$ for 1 min to gel. To dry the coating, the avocado halves were exposed to dry air flow (9 to 10 m s^{-1} and 20 °C) for 40 to 50 min. The experimental samples were placed in plastic containers and stored at 4 °C and 95% relative humidity for 12 d (Kader and Arpaia, 2002).

Response variables

Color

Avocado color (L*, a* and b*) was measured on the pulp surface of six halves with a chroma meter colorimeter (Minolta CR-300, Tokyo, Japan). The difference in total color (ΔE*) was estimated using the follow equation:

$$\Delta E^* = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad (1)$$

Flesh firmness (FF)

Four FF determinations were made on the pulp of each sample (six halves for each sampling date) using a texturometer (Texture Analyser TA.XT Plus model, London, United Kingdom) equipped with

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a two mm diameter puncher, head speed of 1.55 mm s^{-1}, and a sweep distance of eight mm. This response variable was reported in Newtons (N).

Fruit mass loss (FML)

The FML was evaluated every other day by weighing the halves individually on a digital scale (Ohaus, Ciudad de México, México). The FML was reported as the percentage change from the initial weight.

Sensory analysis

The sensory analysis was conducted between March and April, 2021, in the Facultad of Ciencias Químicas of the Universidad Juárez del Estado de Durango. This test used human senses to evaluate sight, smell, taste, touch and acceptability. Three lots of three avocado halves each were used for this purpose. The first lot had fresh avocado halves and the other two lots had uncoated and coated samples after undergoing cold storage at 4 °C and 95% relative humidity for six d. The samples were labeled with three-digit number codes that were provided randomly to 30 untrained panelists, whose age ranges were between 18 and 63 years old, where 28% and 79% were male and female, respectively. All of them were habitual avocado consumers. Between samples, there was a forced one min rest, during which panelists rinsed their mouths thoroughly with drinking water to eliminate residual taste. Each attribute was scored using a hedonic scale labeled from "dislike extremely" to "like extremely."

Statistical analysis

The data were analyzed in a completely random model. The treatment means were separated by Fisher's least significant difference test at $p \leq 0.05$. The sensory analysis information was evaluated by Friedman's test and for the difference among mean treatments Nemenyi test was used. All analysis were performed in Statistica 7.0 system (StatSoft, Inc., Tulsa, United States of America).

Results and Discussion

Color

At the end of the experiment, the brightness (L*) of avocado halves was maintained higher in the coated samples than in uncoated avocado samples (Table 1). This occurred because the latter samples developed enzymatic browning on the surface due to the combination of oxygen exposure and polyphenol oxidase (Al-Amrani *et al*., 2020). The a* and b* color values indicated that the coated avocado halves were greener and yellower than uncoated samples (Table 1). The ΔE values confirmed clear differences between uncoated and coated avocado halves (Table 1; Figure 1). Thus, the color of the coated avocado surfaces suggests that the alginate-mucilage coating preserved the color of minimally processed avocado, similar to the effect of a carboxymethylcellulose coating (Maftoonazad and Ramaswamy, 2005).

Table 1. Mean (± standard deviation; *n* = 3) values of changes of lightness (L*), a*, b*, and color difference (ΔE*) on uncoated or alginate-mucilage-coated avocado halves stored at 4 °C and 95% relative humidity for 12 d.

Time in storage (days)	Avocado halves	Color parameters			
		L*	a*	b*	ΔE
0[†]	Uncoated	70.9 ±1.5 a	-13.0 ± 0.8 a	33.8 ± 0.9 a	0.0 ± 0.0 a
	Coated	69.0 ± 1.6 a	-8.3 ± 0.6 b	34.1 ± 0.9 a	0.0 ± 0.0 a
3	Uncoated	47.3 ± 5.3 b	1.4 ± 1.8 a	24.8 ± 0.4 b	25.7 ± 0.1 a
	Coated	67.1 ± 0.9 a	-6.2 ± 0.7 b	31.2 ± 1.2 a	4.2 ± 0.4 b
6	Uncoated	44.0 ± 4.5 b	4.4 ± 0.7 a	22.7 ± 0.9 b	31.4 ± 1.2 a
	Coated	65.7 ± 0.8 a	-4.4 ± 0.4 b	31.2 ± 0.7 a	6.0 ± 0.6 b
9	Uncoated	40.0 ± 5.2 b	5.3 ± 1.3 a	21.5 ± 2.0 b	34.8 ± 2.5 a
	Coated	63.1 ± 2.6 a	-3.8 ± 0.2 b	31.0 ± 1.6 a	8.1 ± 0.4 b
12	Uncoated	37.6 ± 4.1 b	6.3 ± 0.9 a	18.4 ± 0.3 b	42.9 ± 1.9 a
	Coated	62.1 ± 1.8 a	-3.5 ± 0.2 b	29.7 ± 1.1 a	9.5 ± 0.3 b

[†]At each storing date, between coatings treatments, within columns, different lowercase letters mean differences by Fisher's least significant difference test ($p \leq 0.05$).

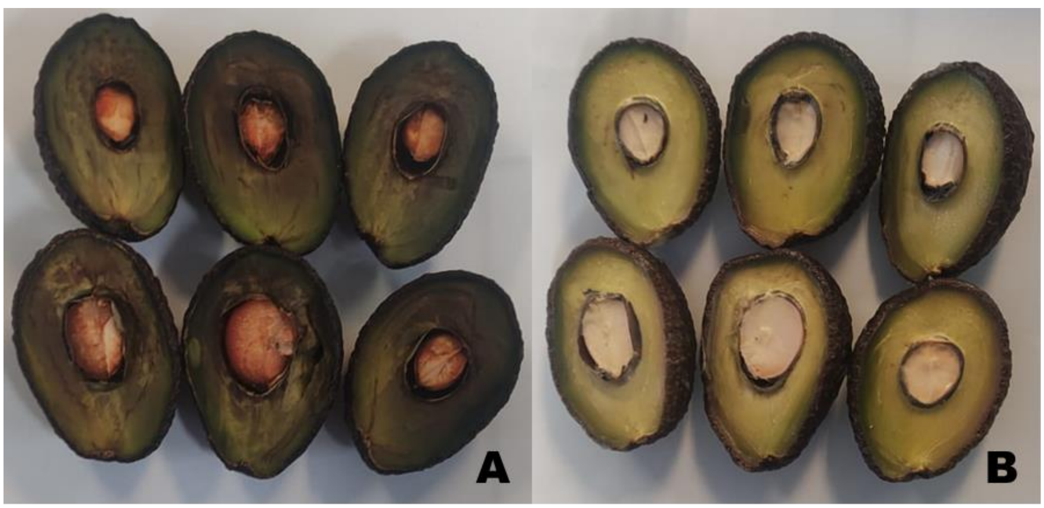

Figure 1. The avocado halves uncoated (A) or coated with an alginate-mucilage film (B) and stored at 4 °C and 95 % relative humidity for nine d.

Flesh firmness (FF) and FML

During storage, FF remained lower in coated (~3.0 N) than in uncoated avocado halves (~7.8 N) (Figure 2). Therefore, the coated avocado halves also had the smallest FML (Figure 3). The main functions of edible coatings are to regulate oxidation processes, moisture transfer, and gas exchange (Rojas-Graü *et al*., 2009), which occurred here (Figures 1, 2, and 3). The edible coat creates a protective barrier and modifies the atmosphere within the avocado halves (Maftoonazad and Ramaswamy, 2005). This minimizes enzymatic browning (polyphenol oxidase activity), because the coat used here contained citric and ascorbic acids (Moon *et al*., 2020). The coating favored a fresher appearance (color, FF, and FML); (Gomes *et al*., 2023) and extended shelf-life (Zhao and McDaniel,

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2005) compared with uncoated avocado samples during cold storage (Duan *et al*., 2011; Souza *et al*., 2005). Regardless of edible coatings are an alternative to extend the shelf life of various food products by acting as barriers to water vapor, O_2, and CO_2, they contain substances to inhibit microorganisms' growth (Perea-Flores *et al*., 2023). Even some polysaccharides such as chitosan can reduce water activity and therefore restrict microbial growth (Apriliyani *et al*., 2020). Nevertheless, here, no microbial contamination was observed in the avocado samples (coated and uncoated) during the experimental period.

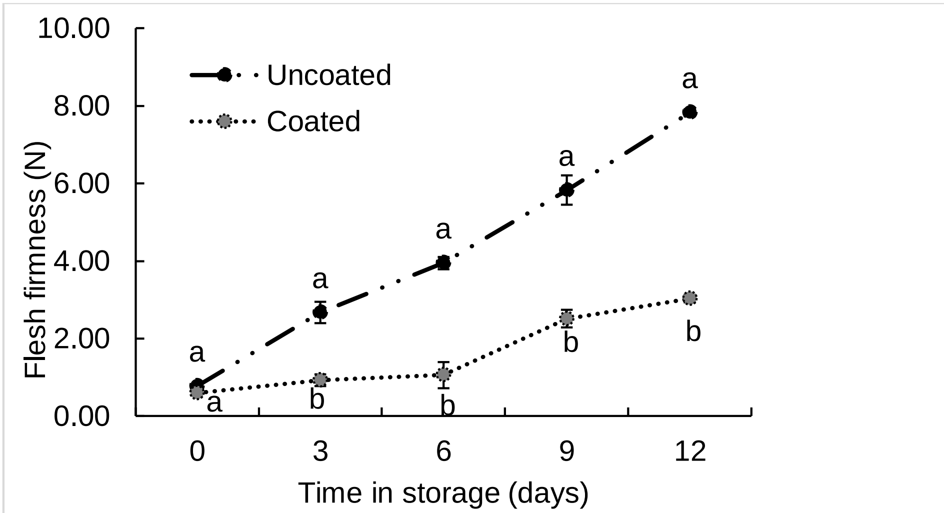

Figure 2. Mean changes in flesh firmness of avocado halves uncoated or coated with an alginate-mucilage film and stored at 4 °C and 95% relative humidity for 12 d. At each sampling date (n = 3), vertical bars represent the standard deviation. The different lowercase letters mean significant differences by Fisher's least significant difference test ($p \leq 0.05$).

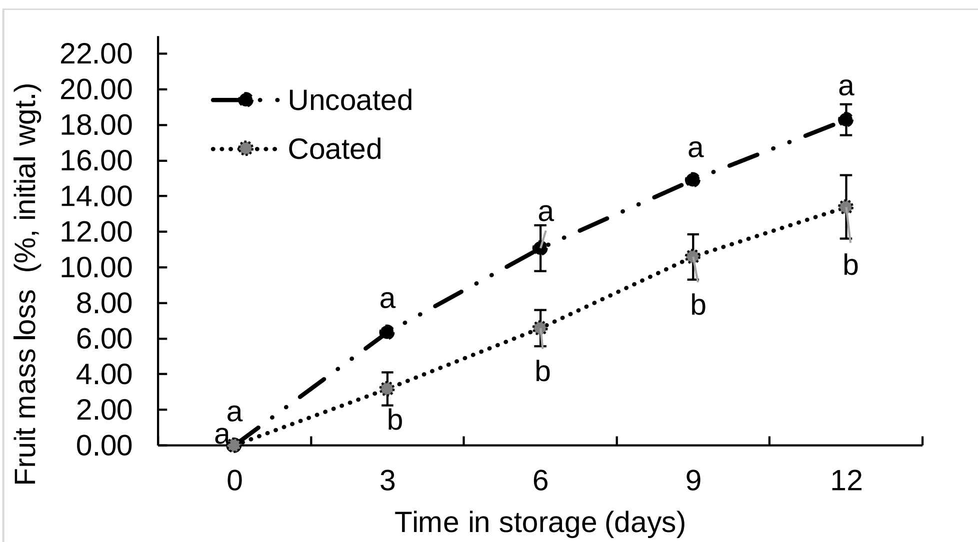

Figure 3. Mean changes in mass loss of avocado halves uncoated or coated with an alginate-mucilage film and stored at 4 °C and 95% relative humidity for 12 d. At each sampling date (n = 3), vertical bars represent the standard deviation. The different lowercase letters mean differences by Fisher's least significant difference test ($p \leq 0.05$).

Sensory analysis

The sensory analysis is imperative to measure consumer acceptance or preferences for a new product or technology developed such as edible films and coatings (Zhao and McDaniel, 2005). The fresh avocado halves had the best consumer acceptance in all sensory attributes evaluated, followed by coated and uncoated avocado halves (Figure 4). The coated avocado halves had better appearance (~5.4), color (~5.8), and FF (~6.1) than uncoated avocado halves (~1.8, ~1.7 and ~3.6, respectively), but there was no significant similar trend in acceptability (~5.8) and flavor (~5.9) (Figure 4). The color and FF scored by the panelists were consistent with those obtained using mechanical measures (Table 1 and Figure 2). These results suggest that the panelists' greater acceptance of the coated avocado halves can be attributed to their maintaining better color, while the panelists did not experience bad odors or flavors (Montone *et al*., 2022; Prakash *et al*., 2020).

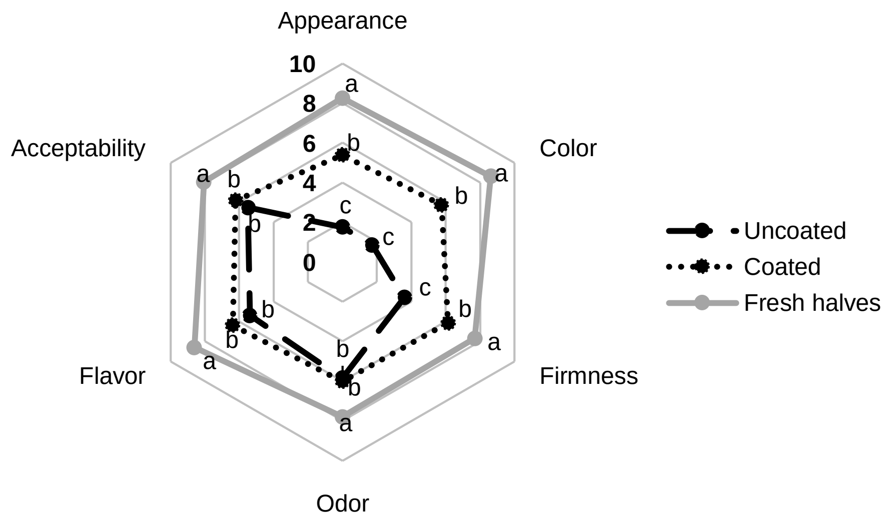

Figure 4. Sensory attribute ratings of uncoated, coated, and fresh avocado halves stored at 4 °C and 95% relative humidity for six days (n = 30). The different lowercase letters mean differences by Nemenyi test ($p \leq 0.05$).

Conclusions

The alginate-mucilage-based coating, when applied to avocado halves undergoing cold room storage, maintained low fresh firmness and delayed fruit mass loss. They were brighter, redder, and yellower than the uncoated avocado halves. The last was confirmed with ΔE^* values. In addition, the sensory analysis revealed that the coated avocado halves won greater consumer acceptance, due to their better appearance, color, and flesh firmness than uncoated avocado halves. Therefore, the edible coating alginate-mucilage-based coating is a viable potential alternative for preserving the commercial quality of avocado halves. Likewise, the alginate-mucilage coating is a potentially viable option to extend the shelf life of minimally processed fruit and vegetables. This could be important for those countries where fresh avocado availability is limited. However, this deserves further research to minimize food waste.

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ETHICS STATEMENT

Not applicable

CONSENT FOR PUBLICATION

Not applicable

AVAILABILITY OF SUPPORTING DATA

All data generated or analyzed during this study are included in this published scientific paper, but are available from the first author on reasonable request.

COMPETING INTERESTS

The authors declare that they have no competing interests in this section.

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AUTHOR CONTRIBUTIONS

Conceptualization, J.A.Z and J.A.M.V; methodology, E.A.L.Z and J.A.M.V; software, E.A.L.Z; validation J.A.Z and J.A.M.V; formal analysis, E.A.L.Z; investigation, E.A.L.Z; resources, J.A.Z and J.A.M.V; data curation, E.A.L.Z; J.A.Z and J.A.M.V; writing—original draft preparation, E.A.L.Z; writing—review and editing, J.A.Z; visualization, E.A.L.Z; supervision, J.A.Z and J.A.M.V; project administration, J.A.Z and J.A.M.V; funding acquisition, J.A.Z and J.A.M.V. All authors have read and agreed to the published version of the manuscript.

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