

**THE MUCILAGE OF FORAGE CACTUS: A SUSTAINABLE ALTERNATIVE FOR
FOOD PRESERVATION AND BIODEGRADABLE PACKAGING**

**A MUCILAGEM DA PALMA FORRAGEIRA: UMA ALTERNATIVA
SUSTENTÁVEL PARA A CONSERVAÇÃO DE ALIMENTOS E EMBALAGENS
BIODEGRADÁVEIS**

**LA MUCILAGO DE LA PALMA FORRAJERA: UNA ALTERNATIVA
SOSTENIBLE PARA LA CONSERVACIÓN DE ALIMENTOS Y ENVASES
BIODEGRADABLES**

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**Lady Daiane Costa de Sousa Martins¹, Wagner Martins dos Santos², Alexandre
Maniçoba da Rosa Ferraz Jardim³, Jheizon Feitoza do Nascimento Souza⁴, Lara Rosa
de Lima e Silva⁵, Pedro Paulo Santos de Souza⁶, Márcia Bruna Marim de Moura⁷,
Klébia Raiane Siqueira de Souza⁸, Elania Freire da Silva⁹, Thieres George Freire da
Silva¹⁰, Luciana Sandra Bastos de Souza¹¹, Adriano Nascimento Simões¹²**

¹ Doctoral student in Agricultural Engineering. Universidade Federal Rural de Pernambuco (UFRPE).
E-mail: ladydaianecsm@gmail.com Orcid: <https://orcid.org/0000-0002-0942-4673>
Lattes: <http://lattes.cnpq.br/0248842512558444>

² Doctoral student in Agricultural Engineering. Universidade Federal Rural de Pernambuco (UFRPE).
E-mail: wagnnerms97@gmail.com Orcid: <https://orcid.org/0000-0002-3584-1323>
Lattes: <http://lattes.cnpq.br/4506292783833761>

³ Doctoral student in Agricultural Engineering. Universidade Federal Rural de Pernambuco (UFRPE).
E-mail: alexandremrfj@gmail.com Orcid: <https://orcid.org/0000-0001-7094-3635>
Lattes: <http://lattes.cnpq.br/9981205244282499>

⁴ Doctoral student in Biotechnology. Universidade Estadual Paulista Júlio de Mesquita Filho (UNESP).
E-mail: jheizon.nascimento@outlook.com Orcid: <https://orcid.org/0000-0003-0657-5545>
Lattes: <http://lattes.cnpq.br/5282052637705053>

⁵ Master's student in Plant Production. Universidade Federal Rural de Pernambuco (UFRPE).
E-mail: lara.rosa@ufrpe.br Orcid: <https://orcid.org/0009-0000-3312-1800>
Lattes: <http://lattes.cnpq.br/2018292846131861>

⁶ Master's student in Plant Production. Universidade Federal Rural de Pernambuco (UFRPE).
E-mail: pedro.paulossouza057@gmail.com Orcid: <https://orcid.org/0009-0001-1403-0169>
Lattes: <http://lattes.cnpq.br/7010919912848920>

⁷ Master's student in Biodiversity and Conservation. Universidade Federal Rural de Pernambuco (UFRPE).
E-mail: marciabruna78@gmail.com Orcid: <https://orcid.org/0000-0002-4255-0735>
Lattes: <http://lattes.cnpq.br/9275493400169999>

⁸ Master's student in Biodiversity and Conservation. Universidade Federal Rural de Pernambuco (UFRPE).
E-mail: klebia.raiane@ufrpe.br Orcid: <https://orcid.org/0009-0000-6263-017X>
Lattes: <http://lattes.cnpq.br/0240299184262533>

⁹ Doctoral student in Plant Science. Universidade Federal Rural do Semi-Árido (UFERSA).
E-mail: elania.freire23@gmail.com Orcid: <https://orcid.org/0000-0002-7176-3609>
Lattes: <http://lattes.cnpq.br/6644267105942189>

¹⁰ Dr. in Agricultural Meteorology. Universidade Federal Rural de Pernambuco (UFRPE).
E-mail: thieres.silva@ufrpe.br Orcid: <https://orcid.org/0000-0002-8355-4935>
Lattes: <http://lattes.cnpq.br/0213450385240546>

¹¹ Dr. in Agricultural Meteorology. Universidade Federal Rural de Pernambuco (UFRPE).
E-mail: luciana.sandra@ufrpe.br Orcid: <https://orcid.org/0000-0001-8870-0295>
Lattes: <http://lattes.cnpq.br/1186468548787818>

¹² Dr. in Plant Physiology. Universidade Federal Rural de Pernambuco (UFRPE).
E-mail: adriano.simoes@ufrpe.br Orcid: <https://orcid.org/0000-0001-8438-2621>
Lattes: <http://lattes.cnpq.br/1895049701533568>

ABSTRACT

The forage cactus (*Opuntia spp.*) stands out as a strategic crop for semiarid regions due to its high water-use efficiency and resistance to water stress and intense solar radiation. In addition to its fundamental role in animal feeding, this species shows great potential for the utilization of bioactive compounds with industrial applications. Among these compounds, the mucilage extracted from the cladodes has attracted increasing scientific and technological interest. It is a natural, biodegradable, and biocompatible polysaccharide, whose physicochemical properties provide it with high water retention capacity, viscosity, and the ability to form films and gels. These characteristics make cactus mucilage a promising alternative for the production of biodegradable packaging and edible coatings, especially in the post-harvest preservation of fruits and vegetables, contributing to loss reduction and extended shelf life. Beyond reducing dependence on synthetic polymers, its use adds value to the cactus crop and promotes the development of the regional bioeconomy, with a positive impact on environmental sustainability and food security. However, the advancement of its large-scale application depends on further studies aimed at standardizing extraction methods, chemically characterizing the compound under different edaphoclimatic conditions, and evaluating its performance in cultivation systems. Thus, the full utilization of forage cactus, especially its mucilage, represents a concrete opportunity for technological innovation and the valorization of natural resources adapted to semiarid environments.

Keywords: Sustainability. Natural Polysaccharides. Post-Harvest Preservation.

RESUMO

A palma forrageira (*Opuntia spp.*) destaca-se como uma cultura estratégica para as regiões semiáridas, em razão de sua elevada eficiência no uso da água e resistência a condições de estresse hídrico e alta radiação solar. Além de seu papel fundamental na alimentação animal, essa espécie apresenta grande potencial para o aproveitamento de compostos bioativos com aplicações industriais. Entre esses compostos, a mucilagem extraída dos cladódios tem despertado crescente interesse científico e tecnológico. Trata-se de um polissacarídeo natural, biodegradável e biocompatível, com propriedades físico-químicas que lhe conferem alta capacidade de retenção de água, viscosidade e formação de filmes e géis. Essas características tornam a mucilagem de palma uma alternativa promissora para a produção de embalagens biodegradáveis e revestimentos comestíveis, especialmente na conservação pós-colheita de frutas e hortaliças, contribuindo para a redução de perdas e o prolongamento da vida útil dos alimentos. Além de reduzir a dependência de polímeros sintéticos, seu uso agrega valor à cultura da palma e promove o desenvolvimento da bioeconomia regional, com impacto positivo na sustentabilidade ambiental e na segurança alimentar. Contudo, o avanço de sua aplicação em escala industrial depende de estudos adicionais voltados à padronização dos métodos de extração, à caracterização química sob diferentes condições edafoclimáticas e à avaliação de desempenho em sistemas cultivos. Assim, o aproveitamento integral da palma forrageira, especialmente da mucilagem, representa uma oportunidade concreta de inovação tecnológica e valorização de recursos naturais adaptados ao semiárido.

Palavras-chave: Sustentabilidade. Polissacarídeos Naturais. Conservação Pós-Colheita.

RESUMEN

La palma forrajera (*Opuntia spp.*) se destaca como un cultivo estratégico para las regiones semiáridas debido a su alta eficiencia en el uso del agua y su resistencia a condiciones de

estrés hídrico y alta radiación solar. Además de su papel fundamental en la alimentación animal, esta especie presenta un gran potencial para el aprovechamiento de compuestos bioactivos con aplicaciones industriales. Entre estos compuestos, la mucilago extraída de los cladodios ha despertado un creciente interés científico y tecnológico. Se trata de un polisacárido natural, biodegradable y biocompatible, cuyas propiedades fisicoquímicas le confieren una alta capacidad de retención de agua, viscosidad y formación de películas y geles. Estas características hacen de la mucilago de palma una alternativa prometedora para la producción de envases biodegradables y recubrimientos comestibles, especialmente en la conservación poscosecha de frutas y hortalizas, contribuyendo a la reducción de pérdidas y a la prolongación de la vida útil de los alimentos. Además de reducir la dependencia de polímeros sintéticos, su uso agrega valor al cultivo de la palma y promueve el desarrollo de la bioeconomía regional, con un impacto positivo en la sostenibilidad ambiental y la seguridad alimentaria. Sin embargo, el avance de su aplicación a escala industrial depende de estudios adicionales orientados a la estandarización de los métodos de extracción, a la caracterización química bajo diferentes condiciones edafoclimáticas y a la evaluación del desempeño en sistemas de cultivo. Así, el aprovechamiento integral de la palma forrajera, especialmente de su mucilago, representa una oportunidad concreta de innovación tecnológica y valorización de los recursos naturales adaptados al semiárido.

Palabras clave: Sostenibilidad. Polisacáridos Naturales. Conservación Poscosecha.

1 INTRODUCTION

The growing demand for sustainable alternatives to synthetic materials has driven interest in natural compounds from plant sources, especially those capable of acting as biopolymers for industrial and food applications. In this context, the forage palm (*Opuntia* spp.), belonging to the *Cactaceae* family, stands out as a species of high biotechnological potential, widely cultivated in arid and semi-arid regions due to its extraordinary ability to adapt to conditions of water and thermal stress (QUEIROZ et al., 2015; PEREIRA et al., 2015). Originally from Mexico and introduced in Brazil at the end of the nineteenth century, the forage palm culture has consolidated itself as one of the main food alternatives for herds during long periods of drought, occupying a strategic position in livestock in the semi-arid northeast (PEREIRA et al., 2015).

Their wide adaptation to adverse edaphoclimatic conditions is associated with morphophysiological characteristics typical of plants with crassulaceous acid metabolism (CAM), which give them efficiency in water use and water storage capacity in the cladodes. Daytime stomatal closure and nocturnal CO₂ fixation significantly reduce transpiration losses, allowing the plant to maintain metabolic activity under severe water limitation (LÜTTGE, 2004, 2010). In addition, the superficial and extensively branched root system allows rapid absorption of moisture from sporadic rains or dew (SNYMAN, 2006). These adaptations make forage palm not only essential to the sustainability of regional livestock, but also an important source of biomass for industrial purposes.

Among the various bioactive components of this species, the mucilage extracted from cladodes has been gaining scientific and technological prominence. It is a high molecular weight heteropolysaccharide, consisting mainly of sugars such as arabinose, galactose and xylose (TRACHTENBERG; MAYER, 1981), with rheological and emulsifying properties that qualify it as a potential natural hydrocolloid (SÁENZ; SEPÚLVEDA; MATSUHIRO, 2004). Its biocompatibility, biodegradability, and ability to form films and gels make it promising for the formulation of coatings and edible films, applicable in food preservation and in the replacement of synthetic polymers derived from petroleum (GHERIBI et al., 2018).

In recent years, research has demonstrated the potential of forage palm mucilage in the postharvest preservation of fruits and vegetables, acting to reduce mass loss, maintain firmness and conservation of bioactive compounds (DEL-VALLE et al., 2005; ALLEGRA et al., 2016; MORAIS et al., 2019). In addition, its application in plasticized formulations

increases its mechanical strength and flexibility, enabling its use in the manufacture of biodegradable packaging with performance comparable to conventional synthetic materials.

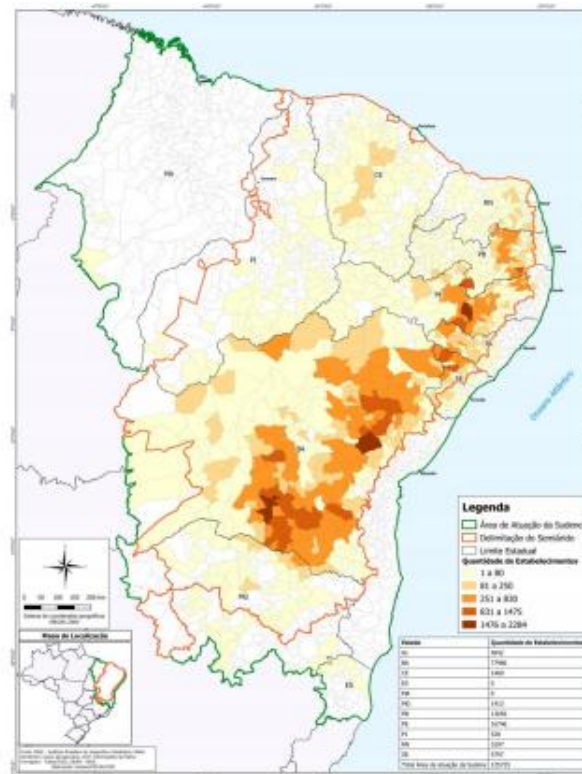
Thus, understanding the agronomic, structural and physicochemical aspects of forage palm and its mucilage is essential for the advancement of sustainable technologies aimed at the food and materials industry. Thus, this review aims to present a comprehensive view of the forage palm culture, emphasizing the properties, composition and applications of mucilage as a raw material for the development of coatings and edible films, contributing to the full use of this species in the context of bioeconomy and environmental sustainability.

2 THE CULTIVATION OF FORAGE PALM

Forage palm (*Opuntia* spp.) It belongs to the Cactus family (QUEIROZ et al., 2015), and this plant is widely distributed in Mexico and the South American continent. In Brazil, this culture was introduced at the end of the nineteenth century (QUEIROZ et al., 2015). The main cultivated species of forage palm are *Opuntia Indica* Fig and *Nopalea cochenillifera* (L.) Salm- Dyck. In the Brazilian semi-arid region, the number of localities producing this crop is around 125,725 properties (Figure 1) with its production in greater concentration in the states of Alagoas, Pernambuco and Paraíba (PEREIRA et al., 2015). For the Brazilian semi-arid region, this plant has high relevance, since it is one of the main crops used for the food supply of livestock in long periods of drought (PEREIRA et al., 2015).

Figure 1

Map of geographical distribution of forage palm producing properties, in the area of operation of Sudene



Source: Sudene, (2017).

The great adaptability to the semiarid regions of this crop is due to the morphophysiological characteristics that enable its survival in environments with water scarcity, high temperatures and low fertile soils (PEREIRA et al., 2015). Among them, the following stand out; the use of storage mechanisms of water and nutrients in the rainy season, to be used in the season of water scarcity. This mechanism is called crassulaceous acid, which allows the stomata to open at night for CO₂ uptake and daytime stomatal closure, which reduces water loss through transpiration during the acquisition of inorganic carbon (LÜTTGE, 2004, 2010). In addition, the osmotic effect of the accumulation of organic acids allows the nocturnal acquisition of water from the transpiration stream, with the temporary storage of water in the vacuoles (LÜTTGE, 2010). These plants also have a network of fine roots close to the superficial layers of the soil (up to 10-20 cm), specialized for rapid absorption of water from light rains or even dew (SNYMAN, 2006). These characteristics give the forage palm aptitude to deal with low water availability and high solar radiation rate (LÜTTGE, 2004, 2010; PEREIRA et al., 2015), typical conditions of the semi-arid Northeast.

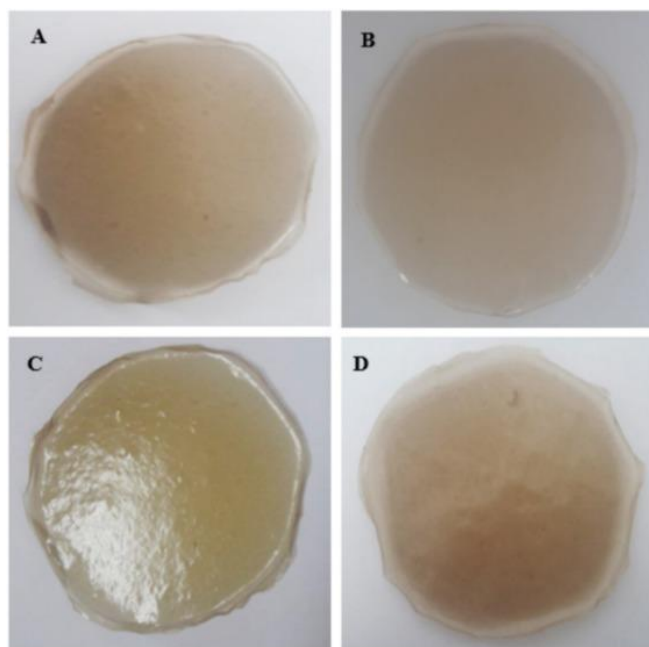
3 FORAGE PALM MUCILAGE

Polysaccharides from biomass derivatives, such as mucilage from different species, have stood out over synthetic polymers, due to the fact that they are derived from renewable, biocompatible and biodegradable sources (VALDÉS; GARRIGÓS, 2016). The mucilage of forage palm is obtained from cladodes, which is a heteropolysaccharide that has a high molecular weight and branched structure (SEPÚLVEDA et al., 2007), composed mainly of sugars such as arabinose, galactose, xylose (TRACHTENBERG; MAYER, 1981), it is considered by the industry to be a potential hydrocolloid because it has characteristics such as: viscosity, elasticity, emulsifying properties, capacity to retain water (MEDINA-TORRES et al., 2000; SÁENZ; SEPÚLVEDA; MATSUHIRO, 2004) and for having a translucent and amorphous appearance.

Forage cactus mucilage has the ability to swell when dissolved in water, forming colloidal and viscous suspensions (SEPÚLVEDA et al., 2007). Due to its polymeric matrix, it contains filmogenic and elastic properties (CONTRERAS-PADILLA et al., 2015), who can act as a barrier to water transfer, showing potential for use in the food industry, in the elaboration of coatings; In addition, mucilage is a raw material with biodegradability and toxicity (PRAJAPATI et al., 2013). When added to plasticizers, mucilage has greater potential for the elaboration of edible films (Figure 2), thus being considered a sustainable alternative also for the production of food packaging, replacing petroleum-derived plastic packaging (GHERIBI et al., 2018).

Figure 2

Cactus mucilage films plasticized with glycerol (A), sorbitol (B), PEG 200 (C) and PEG 400 (D)



Source: Gheribi et al., (2018).

4 PHYSICOCHEMICAL COMPOSITION OF MUCILAGE

The physicochemical composition of mucilage varies according to the species, the age of the cladodes and the edaphoclimatic conditions in which the cladodes are obtained (GEBRESAMUEL; TSIGE GEBRE-MARIAM, 2012). Monrroy et al., (2017) when extracting and characterizing the mucilage *Opuntia cochenillifera* (L.) Miller found that it contained an average of 40% carbohydrates, 7.4% crude protein, 1.6% nitrogen, 0.4% phosphorus, 1.2% potassium, 1.85% calcium and 0.35% magnesium. In addition, this study found that at concentrations of 1.4 and 6% the density values were 1.03, 1.03 and 1.05 g. mL⁻¹, electrical conductivity was 2.3, 4.9 and 5.4 mS cm⁻¹ and pH ranging between 4.8 and 5.0.

Sepúlveda et al., (2007) characterized the mucilage of *Opuntia* spp and found that it contained on average 5.6% moisture; 7.3% protein; 37.3% ash; 1.14% nitrogen; 9.86% calcium and 1.55% potassium. Jouki et al., (2013) found that when studying the mucilage obtained from quince seeds, it had 78.43% total sugar, 3.39% protein, 8.86% moisture, 6.71% ash and 1.98% fat content. Contreras-Padilla et al., (2016) studied the physicochemical and rheological properties (flow and deformation of the fluid) of mucilage and found that it is slightly acidic with a pH between 5.6 and 6, in addition to mucilage has non-Newtonian fluid behavior, high elastic properties, this behavior happens primarily at 100 days of maturity.

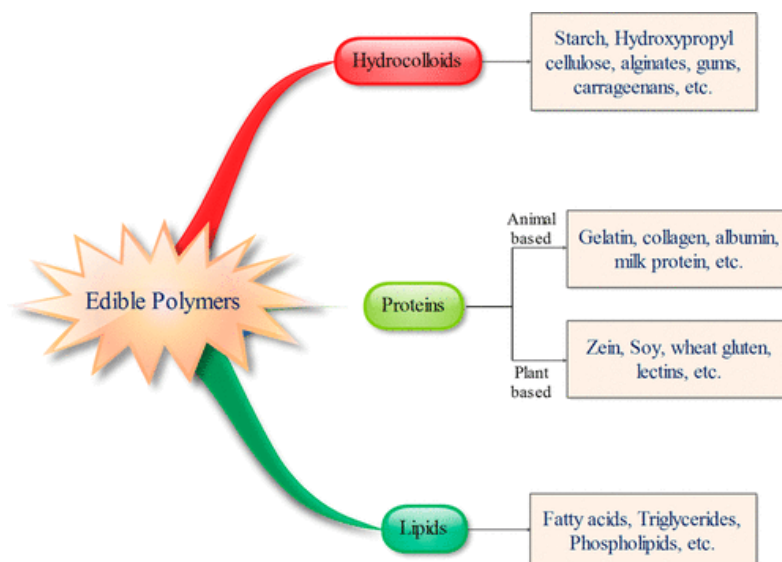
Mucilage is a compound that has a molecular weight ranging from 2.3×10^4 to 4.3×10^6 g.mol⁻¹. (CONTRERAS-PADILLA et al., 2015). Mucilage is composed of the sugars galactose, arabinose, galacturonic acid and glucose (ESPINO-DÍAZ et al., 2010). Medina-Torres et al., (2000) when studying the rheological properties of the mucilage of *Opuntia ficus indica*, observed a marked dependence of viscosity as a function of temperature, ionic strength and pH, in which as there is an increase in pH from acid to alkaline, there is an increase in viscosity, while with the increase in ionic strength there is a decrease in viscosity.

5 EDIBLE COATINGS AND FILMS

It is known that the food industry is increasingly interested in new technologies that act to increase the post-harvest life of food, such as the use of edible coatings, biocoatings and biofilms (ASSIS; BRITTO, 2014). Edible films are defined as a thin layer of edible material formed on a surface of a food. The main materials used for the formation of edible films are polysaccharides, proteins, and lipids (ESPINO-DÍAZ et al., 2010), thus the films are classified as: hydrocolloids, proteins, and lipids (Figure 3) (ALI; AHMED, 2018).

Figure 3

Different Categories of Edible Polymers and Examples



Source: Ali & Ahmed, (2018).

The use of this technology aims to extend the shelf life of food, providing a reduction in moisture loss, control of gas permeability and microbial activity, in addition to preserving the structural integrity of the tissues (ARVANITOYANNIS; PSIADOU; NAKAYAMA, 1996;

GHERIBI; HABIBI; KHWALDIA, 2019). Edible films with good mechanical properties have great potential to replace synthetic films, resulting in the reduction of environmental pollution because the films obtained are biodegradable (DEL-VALLE et al., 2005). Palm mucilage has the ability to form films, however, the film formed is brittle, brittle and not very flexible. Due to this, it is necessary to add plasticizers as they provide elasticity, resistance and maintain the physical integrity of the film formed. Glycerol, sorbitol, and polyethylene glycol are among the major plasticizers used in addition to mucilage to improve their mechanical and elastic properties (GHERIBI et al., 2018).

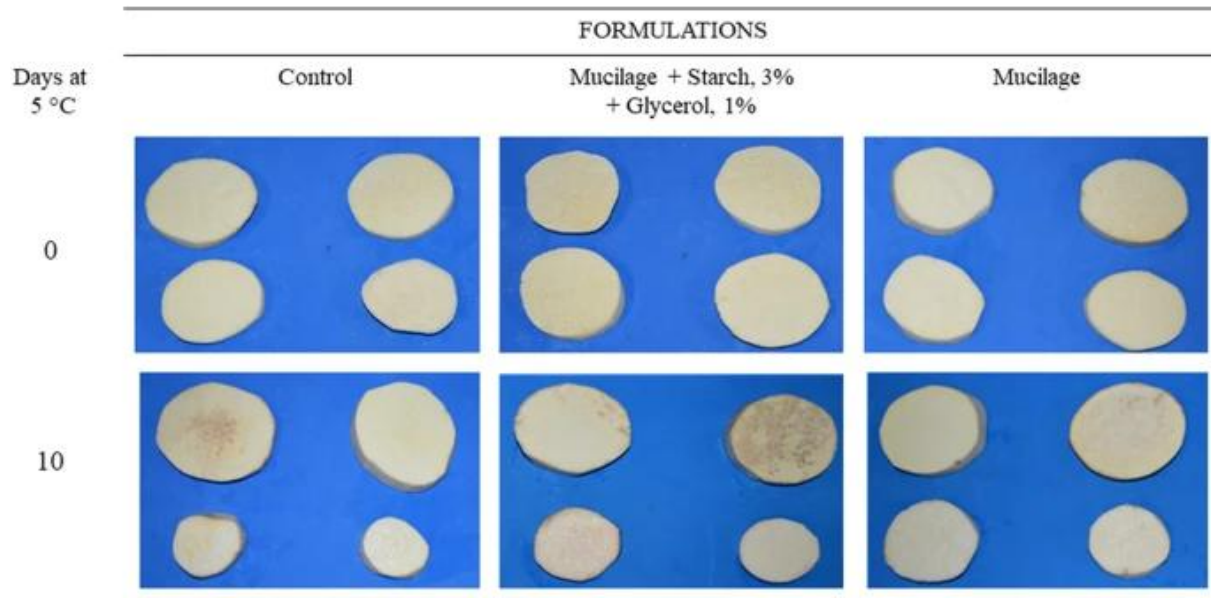
6 APPLICATIONS OF MUCILAGE IN FOOD PRESERVATION

Forage palm mucilage has become the raw material of studies in several areas. From 1982 to 2020, a total of 275 academic papers were published on this raw material, 70 of which were related to food technology and 31 to polymer studies (SCIENCE, 2020). Several studies have been developed on the use of forage palm mucilage as a raw material for the formulation of edible coatings. Del-Valle et al., (2005) used mucilage of *Opuntia ficus indica* as an edible coating to be used in the preservation of strawberries, and found that it proved to be efficient in maintaining physical integrity and sensory properties, extending the shelf life of the fruits, being a technology that can potentially reduce post-harvest losses.

Aquino et al., (2009) observed a protective function of mucilage combined with high concentrations of citric acid and sodium disulfide, since during drying there was a reduction in browning of bananas. Allegra et al., (2016) applied a palm mucilage-based coating to minimally processed kiwis and observed that it showed a tendency to maintain the bioactive compounds, firmness and reduce weight loss of the fruits, in addition to maintaining their visual quality. Damas et al., (2017) carried out a study in which they manufactured films using the mucilage of fruits of *Cereus hildmannianus* Plasticizers in different concentrations and verified that it has a promising potential for use as edible coatings to be applied in the food industry. In his study Gheribi et al., (2018) concluded that the addition of polyol plasticizers show significant effects on the mucilage films of *Opuntia ficus-indica*, being a sustainable alternative for the production of biodegradable food packaging to replace conventional plastic packaging. Morais et al., (2019) studied the mucilage of *Nopalea cochenillifera* (L.) Salm-Dyck as minimally processed yam edible coatings (Figure 4), and observed a reduction in fresh mass loss and a maintenance in visual and sensory quality, showing that the formulated edible coating is very promising for application in minimally processed roots.

Figure 4

Appearance of minimally processed yam coated with the following formulations: control; mucilage + starch, 3% + glycerol, 1% and mucilage. The slides were kept at 5 ± 2 °C for 10 days



Source: Morais et al., (2019).

7 FINAL CONSIDERATIONS

Forage palm stands out as a crop of extreme importance for semi-arid regions, due to its remarkable adaptation to conditions of water stress and high solar radiation, combined with its socioeconomic relevance in supporting livestock during periods of drought. Its physiological and structural characteristics, associated with the acid metabolism of crassulaceae (CAM), give it high efficiency in the use of water and storage capacity of essential compounds, making it a strategic species both from an agronomic and industrial point of view.

Among the compounds with the highest added value, the mucilage extracted from cladodes has aroused growing scientific interest for its physicochemical and functional properties. It is a natural, biodegradable, non-toxic and biocompatible polysaccharide, with an outstanding ability to form films and coatings, characteristics that make it promising for applications in the food industry and in the development of sustainable packaging. The use of this biomolecule in coatings and edible films has shown positive results in the postharvest conservation of fruits and vegetables, extending the shelf life and maintaining sensory and nutritional attributes of the products.

In view of this, forage palm mucilage represents a viable and environmentally sustainable alternative to synthetic polymers used in the food industry, contributing to the reduction of environmental impact and the strengthening of the regional bioeconomy. However, for its use to be expanded on an industrial scale, complementary studies are still needed to address the standardization of extraction methods, the influence of edaphoclimatic conditions on its composition, and the performance of different formulations in real food systems.

Thus, the valorization of forage palm and the full use of its compounds, such as mucilage, represent not only a strategy for the sustainable use of natural resources in the semi-arid region, but also an opportunity for technological innovation aimed at sustainability, food security, and adding value to a crop traditionally associated with resilience in the face of water scarcity.

REFERENCES

- Ali, A., & Ahmed, S. (2018). Recent advances in edible polymer based hydrogels as a sustainable alternative to conventional polymers.
- Allegra, A., & et al. (2016). The influence of *Opuntia ficus-indica* mucilage edible coating on the quality of “Hayward” kiwifruit slices. *Postharvest Biology and Technology*.
- Aquino, L. V., & et al. (2009). Inhibición del oscurecimiento con mucílago de nopal (*Opuntia ficus indica*) en el secado de plátano Roatán. *Información Tecnológica*, 20(4), 15–20.
- Arvanitoyannis, I., Psomiadou, E., & Nakayama, A. (1996). Edible films made from sodium caseinate, starches, sugars or glycerol. Part 1. *Carbohydrate Polymers*, 31(4), 179–192.
- Assis, O. B. G., & Britto, D. de. (2014). Revisão: Coberturas comestíveis protetoras em frutas: Fundamentos e aplicações. *Brazilian Journal of Food Technology*, 17(2), 87–97.
- Contreras-Padilla, M., & et al. (2015). Characterization of crystalline structures in *Opuntia ficus-indica* (pp. 99–112).
- Contreras-Padilla, M., & et al. (2016). Physicochemical and rheological characterization of *Opuntia ficus* mucilage at three different maturity stages of cladode. *European Polymer Journal*, 78, 226–234.
- Damas, M. S. P., & et al. (2017). Edible films from mucilage of *Cereus hildmannianus* fruits: Development and characterization. *Journal of Applied Polymer Science*, 134(35), 1–9.
- Del-Valle, V., & et al. (2005). Development of a cactus-mucilage edible coating (*Opuntia ficus indica*) and its application to extend strawberry (*Fragaria ananassa*) shelf-life. *Food Chemistry*, 91(4), 751–756.
- Espino-Díaz, M., & et al. (2010). Development and characterization of edible films based on mucilage of *Opuntia ficus-indica* (L.). *Journal of Food Science*, 75(6).

- Gebresamuel, N., & Tsige Gebre-Mariam. (2012). Comparative physico-chemical characterization of the mucilages of two cactus pears (*Opuntia* spp.) obtained. *Journal of Biomaterials and Nanobiotechnology*, 3(January), 79–86.
- Gheribi, R., & et al. (2018). Development of plasticized edible films from *Opuntia ficus-indica* mucilage: A comparative study of various polyol plasticizers. *Carbohydrate Polymers*.
- Gheribi, R., Habibi, Y., & Khwaldia, K. (2019). Prickly pear peels as a valuable resource of added-value polysaccharide: Study of structural, functional and film forming properties. *International Journal of Biological Macromolecules*, 126, 238–245.
- Jouki, M., & et al. (2013). Physical, barrier and antioxidant properties of a novel plasticized edible film from quince seed mucilage. *International Journal of Biological Macromolecules*, 62, 500–507.
- Lüttge, U. (2004). Ecophysiology of crassulacean acid metabolism (CAM). *Annals of Botany*, 93(6), 629–652.
- Lüttge, U. (2010). Ability of crassulacean acid metabolism plants to overcome interacting stresses in tropical environments. *AoB PLANTS*, 1–15.
- Medina-Torres, L., & et al. (2000). Rheological properties of the mucilage gum (*Opuntia ficus indica*). *Food Hydrocolloids*, 14(5), 417–424.
- Monrroy, M., & et al. (2017). Extraction and physicochemical characterization of mucilage from *Opuntia cochenillifera* (L.) Miller. *Journal of Chemistry*, 2017.
- Morais, M. A. dos S., & et al. (2019). Mucilage of spineless cactus in the composition of an edible coating for minimally processed yam (*Dioscorea* spp.). *Journal of Food Measurement and Characterization*, 13(3), 2000–2008.
- Pereira, P. D. C., & et al. (2015). Growth evolution of cactus forage drip irrigated. *Revista Caatinga*, 28(3), 184–195.
- Prajapati, V. D., & et al. (2013). Pharmaceutical applications of various natural gums, mucilages and their modified forms. *Carbohydrate Polymers*.
- Queiroz, M. G. de, & et al. (2015). Características morfofisiológicas e produtividade da palma forrageira em diferentes lâminas de irrigação. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 19(10), 931–938.
- Sáenz, C., Sepúlveda, E., & Matsuihiro, B. (2004). *Opuntia* spp. mucilage's: A functional component with industrial perspectives. *Journal of Arid Environments*, 57(3), 275–290.
- Science, W. of. (2020). Web of Science Core Collection. Web of Science.
- Sepúlveda, E., & et al. (2007). Extraction and characterization of mucilage in *Opuntia* spp. *Journal of Arid Environments*, 68(4), 534–545.
- Snyman, H. A. Ñ. (2006). A greenhouse study on root dynamics of cactus pears, *Opuntia ficus-indica* and *O. robusta*, 65, 529–542.
- Trachtenberg, S., & Mayer, A. M. (1981). Composition and properties of *Opuntia ficus-indica* mucilage. *Phytochemistry*, 20(12), 2665–2668.
- Valdés, A., & Garrigós, M. C. (2016). Carbohydrate-based advanced biomaterials for food sustainability: A review. *Materials Science Forum*, 842, 182–195.