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Valorization of Pitahaya (Selenicereus sp.) Stalk Residues for Bioplastics Production

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Abstract

The increasing accumulation of solid wastes, especially those derived from Polyethylene Ter-ephthalate, a slow degrading polymer, has caused significant ecological damage. This research addresses the possibility of mitigating this impact through the production of bioplastic from pitahaya (Selenicereus sp) stalk, using mucilage extracted from stalks older than 12 months. The methodology included homogenization, filtration, double centrifugation and precipitation with 96% alcohol, achieving a mucilage yield of 51.75%. Ten physicochemical properties were studied, such as pH, moisture, ash content, fat, and more. Using a four-treatment experimental design, bioplastic films were evaluated by enriching them with grenetin, vinegar and glycerin to improve their structure. Treatments T3 and T4 showed excellent physico-mechanical characteristics, standing out in strength, elongation and water vapor permeability. These findings confirm that pitahaya stalk mucilage is a promising candidate for the production of sustainable bioplastics, aligning with established standards and offering an innovative approach to plastic waste management.

Keywords: *Bioplastics; Pitahaya (Selenicereus sp); Mucilage Extraction; Physicochemical Properties; Envi-ronmental Impact; Sustainable Materials.*

1. Introduction

The plastic industry generates a negative impact worldwide by not being degradable and impacting the biosphere. (Ojeda & Mercante, 2021). The industry starts since the 1950s with a total production of 1.7 million tons and by 2012 it reached 288 million tons (Kaza et al., 2018). China is the largest producer, accounting for 30% of the total on the Asian continent, 17% from Europe, 18% from North America, 7% from the Middle East and Africa, and 4% from Latin America. (Helwig et al., 2008). In Ecuador, by the year 2021, each inhabitant in an urban area will produce around 0.86 kg of solid waste per day. (INEC, 2021), with a total collection of 12,613 tons per day, of which 43.8% corresponds

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to inorganic waste, with plastic being the largest waste, representing 11%, divided into rigid plastic with 6.51% and soft plastic with 4.45%.(MPCEIP & GIZ, 2021).

According to established figures, the use of plastic has been increasing due to the high demand in the processes of packaging, packing, transportation and commercialization of everyday products (Jiménez Cardona, 2019) together with a deficient recycling system and the exaggerated degradation time represent an environmental problem that generates the contamination of natural resources due to the synthetic polymers that are elaborated. (Oviedo Sandoval & Ventura Rojas, 2020), for such reason, the search to implement sustainable alternatives with biodegradable characteristics to substitute the common plastic (’Le Corre, 2010), bioplastics made from renewable material from plant sources such as organic waste that do not generate negative effects on the environment when decomposing can be considered as a viable alternative (Riera & Palma, 2018).

Bioplastic is considered a biodegradable plastic made of biopolymers from natural sources, such as starch, cellulose or from microorganisms, which in the future could replace petroleum-derived plastic (Valero-Valdivieso et al., 2013). It is an alternative with multiple benefits such as its capacity for degradation and reintegration of its components in nature, reduction of carbon footprint by using vegetable waste such as banana peel, potato, pitahaya peel, which requires a low energy cost (Cerda Martínez et al., 2019).

The pitahaya is a perennial climbing plant native to tropical America belonging to the family of cacti that are characterized by the storage of mucilage in the stem or stalk as it is commonly known to retain water for the plant in times of drought. (Esquivel & Araya Quesada, 2012). The production of pitahaya in Palora, Morona Santiago, Ecuador during 2019 was 12 thousand tons, of which 80% was destined for international markets, while the stalk is discarded or used as fertilizer for the same (Huachi et al., 2015), these factors have to be considered for the research because the feasibility of the use of pitahaya stalk (Selenicereus sp) to obtain bioplastic can be determined.

2. Materials and Methods.

2.1. Sample design.

The collection of samples of pitahaya stalks was carried out in the farm "Primavera JAM", property of the association "WEST PALORA FRUIT", located in the community of San Vicente de Tarqui, within the Sangay Parish, in the Palora Canton of the province of Morona Santiago.

The pitahaya stalk samples were meticulously selected from crops that exceeded 12 months of age and that had been recently pruned at the end of the last harvest. This selection criterion guarantees the freshness of the samples and, therefore, the obtaining of a higher viscosity mucilage through the wet extraction method. It is crucial to ensure that the stalks are free of pests or impurities that could compromise or contaminate the mucilage extraction process.

In this research, sample selection was based on the specific characteristics of the stems collected. The selected stems ranged in size from 60 cm in length, 4 cm in thickness and 5 cm in width, with a weight ranging from 200 grams to over 300 grams.

2.2. Extraction of mucilage from pitahaya stalk

For this study, raw material free of microbiological and physical damage was selected. The selected samples were washed with distilled water and subjected to a disinfection process using sodium hypochlorite. Once disinfected, they were cut into 3x3 cm pieces. These pieces were placed in a blender, where they were homogenized for three minutes. The resulting mixture was filtered to eliminate coarse particles. Subsequently, a centrifugation process was carried out to separate the phases and discard the remaining residues. Finally, the substance was left to stand in 96% alcohol for a period of 24 hours in order to purify it and eliminate any remaining impurities (León-Martínez et al., 2011).

2.3. Technique for the elaboration of the bioplastic from the mucilage of the pitahaya stalk.

The technique for producing bioplastics from pitahaya stalk mucilage transforms agricultural waste into new products in a sustainable manner. The process begins with the extraction of the mucilage, followed by its purification. It is then combined with selected biopolymers and natural plasticizers, which improves its flexibility and handling. The precise formulations used in the production of the bioplastic are detailed in the table below.

Table 1. Formulations for bioplastic processing

Components	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Pitahaya stem mucilage	0 g	20 g	40 g	60 g
Grenetina	6,67 g	6,67 g	6,67 g	6,67 g
Vinegar	4,18 g	4,18 g	4,18 g	4,18 g
Glicerina	4,17 g	4,17 g	4,17 g	4,17 g

2.4. Techniques for the physicochemical characterization of pitahaya stalk mucilage.

For an accurate characterization of dried mucilage, a detailed analysis process was performed that included weighing and measuring the sample after cooling it in a desiccator, fat extraction using Soxhlet with diethyl ether, evaporation of the ether and weighing of the defatted sample (Arab et al., 2021). The sample was boiled for 30 minutes with H2SO4 and NaOH, neutralized, dried and calcined at 550°C in a muffle (Montoya-Arroyo et al., 2014). In addition, it was hydrated and weighed in DE 4.5 and 10 buffer solutions, analyzed in the refractometer after boiling with water, and its bulk density was determined. Protein and nitrogen content was calculated by Kjeldahl digestion, distillation and titration (García-Cruz et al., 2013). Finally, a dilution was prepared for HPLC-IR chromatographic analysis, thus guaranteeing the reliability of the data.

2.5. Physico-mechanical characterization technique for pitahaya (Selenicereus sp) stalk bioplastic.

We sectioned 70 mm long by 20 mm wide sheets of four different bioplastics for each formulation tested. Using a spring dynamometer with a capacity of 20 N, mounted on a universal support, we clamped the sheets between two clamps, one attached to the nylon and the other to the scissor lift, to proceed with the resistance measurements (Bowden & Young, 1974).

In parallel, we prepared test tubes containing silica gel and introduced 20x20 mm bioplastic fragments in them, sealing them hermetically. We weighed the sheets together with the tube to then place them in a desiccator, under controlled conditions of 65% relative humidity and a temperature of 29°C for six hours (Bertuzzi et al., 2007); (Huang & Qian, 2008) recording the weight every hour to calculate the Water Vapor Permeability (WVP) with the equation:

$$\mathrm{WVP} = \frac{(\mathrm{P}_2 - \mathrm{P}_1) * \mathrm{e}}{\mathrm{t} * \mathrm{S}" * (\mathrm{HR}_2 - \mathrm{HR}_1)} \qquad (1)$$

where \(S'\) is the water vapor pressure, \ (HR_1 \) and \(HR_2\) are the internal and external relative humidities, respectively, \(e\) is the sample thickness, and \(t\) is the time.

In addition, we cut bioplastic samples to a thickness of 0.25 mm with an accuracy of 0.01 mm, measuring four samples of each formulation with a micrometer to obtain an average. We weighed the samples on an analytical balance and transferred them to an oven at 105°C for 24 hours. After heat treatment, the samples were cooled in a desiccator for final weighing and the moisture content of the bioplastic was calculated using the equation:

$$\mathrm{H} = \frac{\text{Initial film weight} - \text{Final film weight}}{\text{Initial film weight}} * 100 \qquad (2)$$

In another experiment to determine the solubility, we immersed the bioplastic films in 80 mL of distilled water and stirred at 100 rpm for one hour. Subsequently, we filtered and took the samples to the oven at 105°C for 24 hours. Again, we cooled and weighed the samples, applying the solubility equation:

$$\mathrm{S} = \frac{\text{Peso inicial seco película} - \text{Peso final seco película}}{\text{Peso inicial seco película}} * 100 \qquad (3)$$

3. Results and discussion

3.1. Extraction of mucilage

Four pitahaya stalks with different masses were analyzed, specifically 388.69 g, 242.46 g, 221.77 g and 360.11 g, from which a total of 627.75 g of mucilage was extracted. The average mucilage extraction yield from pitahaya stalk, based on three experimental replicates, was 51.75%. This value is comparable to the extraction yield of Nopal (Opuntia tomentosa) mucilage, which is approximately 48.18% according to (Hinojosa-Gijón et al., 2019). In addition, dry yields of pitahaya stalk mucilage ranged from 55.27 % to 78.36 %, according to reports by (García Cruz Elena, 2011).

With a mucilage volume of 365.30 ml, an average percentage of total sugars of less than 0.8% was recorded. This low sugar content is similar to that found in pitahaya (Hylocereus undatus) stem mucilage, especially in terms of glucose and galactose. (Erik Alpizar Reyes, 2019)). In contrast, cactus mucilage shows significant differences, mainly due to the high presence of L-arabinose, D-galactose, L-xylose, galacturonic acid and L-rhamnose, substances that considerably influence the molecular weight of bioplastics. (Luna-Zapién et al., 2023).

3.2. Analysis of the physicochemical characterization of mucilage (Selenicereus sp).

Table 2. Physicochemical characterization of the mucilage (Selenicereus sp).

Number of repetitions	% humidity	% ash	% fat	% fiber	% water retention	% soluble solids	% bulk density	% Protein
1	96,62	2,1	7,3	3,85	1,89	2,31	2,1	11,8
2	96,49	1,7	5,3	2,45	4,02	2,51	1,7	11,7
3	95,67	1,9	6,05	2,25	4,03	2,73	1,9	11,9
Total average	96,22	1,93	6,23	2,85	3,31	2,52	1,92	11,8

The high moisture percentages observed in our three replicates show a remarkable similarity with the values reported for yellow cactus, which presents 94.33 % moisture in cladodes older than one year, according to (Guzmán Loayza & Chávez, 2007). As for the ash content, an average value of 1.93% was recorded for the three replicates, a figure that is in line with the findings of (Pascoe-Ortiz et al., 2019) who reported 1,558% ash in the mucilage of Opuntia ficus-indica cactus and a range of 1 to 2% in the mucilage extracted from carob seed, according to (Nereida Villa-Uvidia et al., 2020). On the other hand, the fat content in the mucilage of pitahaya stalk proved to be higher than the 0.0235% found in the mucilage of Opuntia ficus-indica by (Arcan & Yemenicioğlu, 2011) This increase is relevant, considering that research on thermoplastic biocomposites based on vegetable oils highlights the usefulness of fatty acids for the synthesis of polymers as plasticizers. Therefore, Pitahaya residues could have promising applications in the synthesis of thermoplastic biocomposites.

The fiber content in the mucilage of pitahaya stalk shows similarities with the values found by (ABAD, 2021) for prickly pear cactus (Opuntia ficus-indica). However, Opuntia tomentosa mucilage contains a greater amount of fiber, reaching 9.20%, according to (Restrepo, Jorge; Aristizabal, 2010). In terms of water holding capacity, pitahaya mucilage is less efficient than chia mucilage flour, which retains 7.23 g/g of water according to (Maurtua et al., 2020) and powdered pitaya peels, with a 43.88% retention rate, as reported by (Hinojosa-Gijón et al., 2019) Regarding the soluble solids content, measured in Brix degrees, the average of 0.1 in our study is similar to the results obtained by (García Cruz Elena, 2011) by maceration of pitahaya stem mucilage. In comparison, the soluble solids in the nopal mucilage are significantly higher, reaching 15º Brix, as reported by (Rodríguez Henao, 2017).

The mucilage analyzed had an average density of 1.92 g/mL, higher than the bulk density of 0.64 g/mL of pitahaya shell mucilage, reported by (Aranda & Suarez, 2013) and to that of 1.03 g/cm³ of cocoa mucilage, according to (Vera Shigcha & Zambrano Mora, 2018). In terms of protein content, high levels were observed in comparison with the 8% protein in chia mucilage, described by (Muñoz & Zúñiga, 2017), but lower than the 14.78% found in the tamarind seed mucilage, according to (Erik Alpizar Reyes, 2019). Plant proteins, due to their primary structure and the presence of amino acids such as lysine, serine, cysteine, proline, and structures such as β-folded sheet, are suitable for the creation of bioplastics, according to. (Espada Ruiz, 2016). However, its sensitivity to water requires the addition of other ingredients, such as vinegar, glycerin and grenetin, to optimize the properties of the resulting bioplastic.

Table 3. Physical-mechanical characterization of the bioplastic (Selenicereus sp)

Treatments	Average breaking strength	Average elongation (mm)	Water vapor permeability	Average thickness (mm)	Average humidity (%)	Solubility (%)
T1	29	84,2	6,34E-06	0,029	81,63	36,82
T2	30	87,2	1,40E-07	0,033	80,89	24,30
T3	34,75	84,3	3,02E-07	0,030	77,69	12,12
T4	34,5	83,3	2,31E-07	0,034	81,40	5,83

The bioplastic films developed with pitahaya stalk mucilage showed excellent properties, especially in resistance to rupture. Treatment 3, with 40 g of mucilage, 6.67 g of grenetin to provide protein, 4.18 g of vinegar to improve the polymer structure, and 4.17 g of glycerin as a humectant and to increase elasticity, reached a maximum strength of 34.75 N, according to (Barahona Alvear et al., 2019). However, in terms of elongation, these films presented lower values than those made with nopal (Opuntia spp), as reported by (Pascoe Ortiz et al., 2014) possibly due to a higher concentration of protein and glycerin in nopal, which contribute to higher elasticity.

The water vapor permeability of bioplastics made with pitahaya mucilage was analyzed for 6 hours at a relative humidity of 65%. Treatments T3 and T4 showed the highest permeability, with values of 3.02E-07 and 2.31E-07 gh-1m-1*MPa-1, respectively. This higher permeability is attributed to the high concentration of pitahaya mucilage in its formulation. According to studies by (Navarro, 2010) (Bangyekan et al., 2006) y Uriarte , (Torres et al., 2008) a higher amount of plasticizer in the composition of the bioplastic increases its permeability, which is due to the reduction of intermolecular forces between the polymeric chains. This phenomenon is also observed in bioplastics made with soy protein and cassava starch, as indicated by(Rocha et al., 2014).

The bioplastics elaborated in the four treatments presented a lower thickness compared to the ranges of 0.04-0.05 mm reported by (Restrepo, Jorge; Aristizabal, 2010), but superior to the arracacia xanthorrhiza starch-based plastic sheets, whose thicknesses vary between 0.16 and 0.24 mm according to (Brito Moína et al., 2020) In addition, the moisture in these bioplastics was higher than 26.73 % which negatively impacts their stability and shelf life. Regarding solubility, treatments T3 and T4 showed lower values compared to cactus mucilage (Opuntia joconostle), whose solubility ranges between 44 and 52 % according to (STUCHEL, 2016), highlighting that the specific application of the bioplastic determines the required solubility, varying from totally insoluble films for food wrapping to degrees of solubility that influence the degradability for other uses.

In terms of degradability, the bioplastics started to degrade from day 2, reaching a total degradation in 15 days, similar to bioplastics from cactus (Opuntia tomentosa) mucilage that degraded completely in 18 days, according to(Rabell Contreras et al., 2013). This rapid degradation could be related to the amount of mucilage and protein in the formulation, particularly in treatments 3 and 4, which contained higher amounts of mucilage from the pitahaya stalk and, therefore, showed a more accelerated total degradation.(Erik Alpizar Reyes, 2019)

4. Conclusions

The research results indicate that pitahaya (Selenicereus sp) stalk mucilage is a promising material for the manufacture of bioplastics due to its favorable physicochemical and mechanical characteristics. This mucilage, with high percentage of moisture and extraction yield similar to Nopal (Opuntia tomentosa) mucilage, stands out for its low sugar content and a fatty acid profile that suggests its usefulness in the production of thermoplastic biocomposites. Its composition, including moisture, ash, fat, fiber, water retention, soluble solids, density and protein, is comparable or even superior to other cactus mucilages, positively influencing the elasticity, solubility and strength of bioplastics. Although pitahaya bioplastics showed lower water retention and remarkable water vapor permeability, their resistance to rupture and elongation, together with efficient degradability, underline their potential as a sustainable material. Despite its viability as a material for bioplastics, it is recognized that further research is needed to optimize its formulation and processing, thus maximizing its properties and commercial viability for various industrial and environmental applications.

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References

’Le Corre, D. B. ’Julien D. A. (2010). Starch Nanoparticles: A Review. Biomacromolecules, 11(5), 1139–1153.

ABAD, K. G. P. (2021). OBTENCIÓN DE BIOPLÁSTICO A PARTIR DEL MUCÍLAGO DE CACTUS (Opuntia ficus-indica) PARA USO COMO ENVOLTURAS ALIMENTICIAS.

Arab, K., Ghanbarzadeh, B., Ayaseh, A., & Jahanbin, K. (2021). Extraction, purification, physicochemical properties and antioxidant activity of a new polysaccharide from Ocimum album L. seed. International Journal of Biological Macromolecules, 180, 643–653. https://doi.org/10.1016/J.IJBIOMAC.2021.03.088

Aranda, Y., & Suarez, E. (2013). Efecto de la impermeabilidad del mucílago de nopal en bloques de tierra comprimidos. Nova Scientia, 6(11), 311–323.

Arcan, I., & Yemenicioğlu, A. (2011). Incorporating phenolic compounds opens a new perspective to use zein films as flexible bioactive packaging materials. Food Research International, 44(2), 550–556. https://doi.org/10.1016/j.foodres.2010.11.034

Bangyekan, C., Aht-Ong, D., & Srikulkit, K. (2006). Preparation and properties evaluation of chitosan-coated cassava starch films. Carbohydrate Polymers, 63(1), 61–71. https://doi.org/10.1016/j.carbpol.2005.07.032

Barahona Alvear, N. S., Tixi Toapanta, H. P., Hugo Calderón, S., & Barahona Alvear, L. (2019). Biopolímeros capaces de reemplazar a los plásticos tradicionales. Ciencia Digital, 3(4), 138–155. https://doi.org/10.33262/cienciadigital.v3i4.954

Bertuzzi, M. A., Castro Vidaurre, E. F., Armada, M., & Gottifredi, J. C. (2007). Water vapor permeability of edible starch based films. Journal of Food Engineering, 80(3), 972–978. https://doi.org/10.1016/J.JFOODENG.2006.07.016

Bowden, P., & Young, R. (1974). Review Deformation mechanisms in crystalline polymers. Materials Science, 9, 2034–2051. https://doi.org/https://doi.org/10.1007/BF00540553

Brito Moína, H. L., Chiuza Rojas, M. R., & Rodríguez Basantes, A. I. (2020). Producción de láminas de plástico biodegradables a partir del almidón de arracacia xanthorrhiza. Dominio de Las Ciencias, 6, 981–994.

Cerda Martínez, J., Moya Romero, O., & Vitoria García, J. E. (2019). Bioplástico Obtención de plásticos biodegradables a partir de glicerina.

Erik Alpizar Reyes. (2019). EXTRACCIÓN, CARACTERIZACIÓN Y EVALUACIÓN DEL MUCÍLAGO DE LA SEMILLA DE TAMARINDO COMOAGENTE ENCAPSULANTE DEL ACEITE DE AJONJOLÍ (Sesamum indicum L.)”. 1–172.

Espada Ruiz, L. F. (2016). DESARROLLO DE MATERIALES BIOPLÁSTICOS PROTEICOS CON ELEVADA CAPACIDAD DE ABSORCIÓN DE AGUA.

Esquivel, P., & Araya Quesada, Y. (2012). Características del fruto de la pitahaya (Hylocereus sp.) y su potencial de uso en la industria alimentaria Pitahaya (Hylocereus sp.): fruit characteristics and its potential use in the food industry. Revista Venezolana de Ciencia y Tecnología de Alimentos, 3(1), 113–129.

García-Cruz, E. E., Rodríguez-Ramírez, J., Lagunas, L. L. M., & Medina-Torres, L. (2013). Rheological and physical properties of spray-dried mucilage obtained from Hylocereus undatus cladodes. Carbohydrate Polymers, 91(1), 394–402. https://doi.org/10.1016/J.CARBPOL.2012.08.048

García Cruz Elena. (2011). “ Optimización del secado por aspersión de mucílago de pitahaya (Hylocereus undatus) en función de sus propiedades reológicas .”

Guzmán Loayza, D., & Chávez, J. (2007). Estudio Bromatológico del Cladodio del Nopal (Opuntia ficus-indica) para el Consumo Humano - Enseñanza de la Química. Revista Sociedad Quimica Del Perú, 73(1), 41–45.

Helwig, N. E., Hong, S., & Hsiao-wecksler, E. T. (2008). Las relaciones económicas y comerciales entre América Latina y Asia-Pacífico. Comisión Económica Para América Latina y El Caribe.

Hinojosa-Gijón, M., Vivar-Vera, M. A., Vivar-Vera, G., Paz-Gamboa, E., & Del Ángel-Zumaya, J. A. (2019). Procesamiento de cáscaras de pitaya como polvos con alto contenido de fibra dietaria: Evaluación tecnofuncional. Coloquio de Investigación Multidisciplinaria, 07, 1692–1698.

Huachi, L., Yugsi, E., Paredes, M., Coronel, D., Verdugo, K., & Coba, P. (2015). Desarrollo de la Pitahaya (Cereus sp.) en Ecuador. La Granja: Revista de Ciencias de La Vida, 22(2), 50–58. https://doi.org/10.17163/lgr.n22.2015.05

Huang, J., & Qian, X. (2008). Comparison of Test Methods for Measuring Water Vapor Permeability of Fabrics. Textile Research Journal, 78(4), 342–352. https://doi.org/10.1177/0040517508090494

INEC. (2021). Boletin Técnico No. 44-2020-GAD Municipales Gestión de Residuos Sólidos. 04(2021), 22.

Jiménez Cardona, J. J. (2019). Análisis del bioplástico de banano desde la perspectiva del diseño industrial para posible aplicación en diseño de producto. Duke Law Journal, 1(1).

Kaza, S., Yao, L. C., Bhada-Tata, P., & Van Woerden, F. (2018). What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050.

León-Martínez, F. M., Rodríguez-Ramírez, J., Medina-Torres, L. L., Lagunas, L. L. M., & Bernad-Bernad, M. J. (2011). Effects of drying conditions on the rheological properties of reconstituted mucilage solutions (Opuntia ficus-indica). Carbohydrate Polymers, 84(1), 439–445. https://doi.org/10.1016/J.CARBPOL.2010.12.004

Luna-Zapién, E. A., Zegbe, J. A., Meza-Velázquez, J. A., & Minjares-Fuentes, R. (2023). CACTUS PEAR (Opuntia spp.) MUCILAGE AND ITS APPLICATION AS FOOD ADDITIVE: AN OVERVIEW. Revista Fitotecnia Mexicana, 46(1), 51–61. https://doi.org/10.35196/rfm.2023.1.51

Maurtua, A. J. P., Luis, H. H. A., Carlos, P. R. J., Mavila, J. E. H., Quispe, W. H. D. L. C., Espinoza, A. T., & Escalante, F. R. P. (2020). Determinación de la tecnología de extracción del mucílago de la semilla de chía (Salvia hispánica L.) y evaluación de sus propiedades funcionales. Brazilian Journal of Development, 6(2), 8148–8166. https://doi.org/10.34117/bjdv6n2-210

Montoya-Arroyo, A., Schweiggert, R. M., Pineda-Castro, M. L., Sramek, M., Kohlus, R., Carle, R., & Esquivel, P. (2014). Characterization of cell wall polysaccharides of purple pitaya (Hylocereus sp.) pericarp. Food Hydrocolloids, 35, 557–564. https://doi.org/10.1016/J.FOODHYD.2013.07.010

MPCEIP & GIZ. (2021). Libro Blanco de Economia Circular de Ecuador. Ministerio de Producción, Comercio Exterior, Inversiones y Pesca, 1(9), 1–211.

Muñoz, L., & Zúñiga, ; M C. (2017). Propiedades físico-químicas y funcionales del mucílago de semilla de chía Resumen /Oral. 2017.

Navarro, C. P. (2010). Recubrimientos comestibles a base de hidroxipropil metilcelulosa: caracterización y aplicación. 219.

Nereida Villa-Uvidia, D., Ángel Osorio-Rivera, M., & Yolanda Villacis-Venegas, N. (2020). Extracción, propiedades y beneficios de los mucílagos. Revista Científica Dominio de La Ciencias, 6, 503–524.

Ojeda, J. P., & Mercante, I. T. (2021). Reciclaje De Residuos Plásticos Para La Producción De Agregados Livianos. Revista Internacional de Contaminación Ambiental, 489–499. https://doi.org/10.20937/rica.54081

Oviedo Sandoval, A. E., & Ventura Rojas, G. P. (2020). Estudio de prefactibilidad para determinar la viabilidad de inversión en la producción y comercialización de bioplástico a base de almidón de papa – Trujillo. 1–60.

Pascoe-Ortiz, S., Rodríguez-Macías, R., Robledo-Ortiz, J. R., Salcedo-Pérez, E., Zamora-Natera, J. F., Rabelero-Velasco, M., & Vargas-Radillo, J. J. (2019). Identificación de propiedades presentes en jugo de Opuntia megacantha Salm-Dyck importantes para la producción de biopolímeros. TIP Revista Especializada En Ciencias Químico-Biológicas, 22, 1–10. https://doi.org/10.22201/fesz.23958723e.2019.0.197

Pascoe Ortiz, S., Martínez Martínez, C., & Varela Echavarría, J. M. (2014). Formulación de una película plástica natural utilizando nopal verdura spp. Anuario de investigación. 53–67.

Rabell Contreras, M. F., Vázquez Morillas, A., Espinosa Valdemar, R. M., Beltrán Villavicencio, M., Osada Velázquez, M. H., & González Filio, J. U. (2013). Propuesta metodológica para la evaluación de la degradabilidad de plásticos mediante composteo. Revista Internacional de Contaminacion Ambiental, 29(SUPPL. 3), 127–133.

Restrepo, Jorge; Aristizabal, I. (2010). CONSERVACIÓN DE FRESA (Fragaria x ananassa Duch cv . Camarosa) MEDIANTE LA APLICACIÓN DE RECUBRIMIENTOS COMESTIBLES DE GEL MUCILAGINOSO DE PENCA SÁBILA (Aloe barbadensis Miller) Y CERA DE CARNAÚBA. Vitae, 17, 252–263.

Riera, M. A., & Palma, R. (2018). Obtención de bioplásticos a partir de desechos agrícolas. Una revisión de las potencialidades en Ecuador. Avances En Química, 13, 69–78.

Rocha, G. O., Farias, M. G., De Carvalho, C. W. P., Ascheri, J. L. R., & Galdeano, M. C. (2014). Biodegradable composite films based on cassava starch and soy protein. Polimeros, 24(5), 587–595. https://doi.org/10.1590/0104-1428.1355

Rodríguez Henao, Y. C. (2017). Evaluación del mucílago de nopal (opuntia ficus-indica) como agente estabilizante en néctar de maracuyá (passiflora edulis). Ciencia La Salle, 1–84.

STUCHEL, K. (2016). Caracterización de una película biopolimérica formulada con mucílago de nopal (Opuntia joconostle). Revista Internacional de Investigación e Innovación Tecnológica, 4(20), 1–14.

Torres, A. W., Pacheco aguilar, R., Rouzaud sandez, O., & Ezquerra brauer, J. (2008). Caracterizacion Parcial Del Colageno Extraido a Partir Del Manto, Aleta Y Tentaculos De Calamar Gigante. Ciencia y Tecnología Alimentaria, 6(2),101-108.[Fecha de Consulta, 108.

Valero-Valdivieso, M. F., Ortegón, Y., & Uscategui, Y. (2013). Biopolímeros: Avances y perspectivas. DYNA (Colombia), 80(181), 171–180.

Vera Shigcha, C., & Zambrano Mora, I. (2018). “EVALUACIÓN DE LAS CARACTERÍSTICAS DEL MUCÍLAGO DE CACAO (Theobroma cacao L.) EN LA OBTENCIÓN DE ALCOHOL ETÍLICO”. 1–96.