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ECORFAN Journal Republic of Nicaragua

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Knowledge Area

The works must be unpublished and refer to topics of agriculture-forest, pathology-sustainable, forest, management, horticulture, engineering and integrated water use and other topics related to Biotechnology and Agricultural Sciences.

Presentation of Content

As the first article we present, *Nixtamal and Tortilla quality on improved maize [Zea mays L.] genotypes for the humid tropic in México*, by Sierra-Macias, Mauro, Vázquez-Carrillo, María Gricelda, Ríos-Isidro, Clara and Gómez-Montiel, Noel Orlando, with adscription in the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, as a second article we present, *Preparation and characterization of Nanocapsules for application as pesticides*, by Aquino-Martínez, Daniel Alejandro, Hernández-Santana, Jhair Alejandro, Nieto-Ruiz, Jessica, Martínez-Pérez, Beatriz, with adscription in the Universidad Politécnica del Valle de México, as third article we present, *Formulation and quality validation of an antiseptic ointment from Jacaranda Flower [Jacaranda mimosifolia]: A biochemical and microbiological approach*, by Gómez-Flores, Nidia Esther, Hernández-Cortés, Elsa, Ramírez-Vaquero, Eduardo Osbaldo and Vásquez-Jiménez, Juan Carlos, with adscription in the TecNM / Instituto Tecnológico de Tehuacán, as fourth article we present, *Effect of using different types of avocado oil in the production of gelatin-based biopolymers Bloom 300*, by Nolasco-Arizmendi, Víctor Alfredo, Rodríguez-Espíndola, Gerardo Daniel, Melo-Máximo, Dulce Viridiana and Melo-Máximo, Lizbeth, with adscription in Universidad Tecnológica de Tula-Tepeji, Instituto Tecnológico de Tlalnepantla and Polytechnic University of the Valley of Mexico, as next article we present, *Determination of chromium as a heavy metal in a surface water body in Frontera, Centla, Tabasco*, by Suarez-García, Sandra Manuela, Zarate, Marco Antonio, Vazquez-Aguilar, Clotilde and Reyes-Hernandez, Guadalupe, with adscription in Instituto Tecnológico Superior de Centla, as next article we present, *Vapor cloud explosion [Vce] model, using the TNT equivalent method, to determine impact zones due to overpressure in a natural gas pipeline*, by Torres-Valle, José Bernardo, Sánchez-Carmona, Fernando, Hernández-Borja, Carlos and García-Trinidad, Enrique, with adscription in Universidad Tecnológica Fidel Velázquez and Universidad Autónoma del Estado de México, as last article we present, *Effect of nitrogen plasma on the mechanical and surface properties of a biopolymer* by Alarcón-Hernández, Fidel Benjamín, Fuentes-Albarrán, María del Carmen, López-Ávila, Jaciel Amisadai and Sandoval-González, Antonia, with adscription in Universidad Autónoma del Estado de Morelos and Center of Research and Technologic Development in Electrochemistry

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Nixtamal and Tortilla quality on improved maize [*Zea mays* L.] genotypes for the humid tropic in México





Calidad de nixtamal y tortilla en genotipos de maíz [*Zea mays* L.] mejorados para el trópico húmedo de México

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Abstract

With the objective of evaluating physical and chemical characteristics and tortilla quality for maize improved genotypes for the humid tropic in Mexico, during fall winter season 2023/24 under irrigation conditions there were evaluated seven maize genotypes from Cotaxtla experiment station, INIFAP; These genotypes were produced in plots of 4 rows 5 m long and 80 cm wide in plant density of 62,500 plants ha⁻¹; The grain humidity varied from 10.5-12.2 %, this humidity is an advantage for storage because reduce fungus proliferation. All seven genotypes registered hectoliter pound between 75 and 78.6 kg hL⁻¹, with hard and intermediate endosperm, both characteristics into the norm specifications NMX-034/1, these genotypes can be processed by the traditional Nixtamalization and floury industries. V-537C registered 1.63 kg of tortilla for each kg of maize grain and presented intermediate hard endosperm and there were produced soft tortillas, Finally, V-537C presented the highest content of Lysine but not for Tryptophan content.

Resumen

Con el objetivo evaluar las características físicas, químicas y calidad de tortillas de maíces mejorados para el trópico mexicano, durante el ciclo otoño invierno 2023/24 bajo condiciones de riego se evaluaron siete genotipos de maíz del Campo Cotaxtla, INIFAP; Estos genotipos fueron producidos en parcelas de 4 surcos de 5 m de largo separados a 80 cm en una densidad de 62,500 plantas ha⁻¹; La humedad de grano varió de 10.5-12.2 %, esta humedad es una ventaja para su almacenamiento porque reduce la presencia de hongos. Los siete genotipos registraron un peso hectolítrico entre 75 and 78.6 kg hL⁻¹, con endospermo duro e intermedio, características dentro de las especificaciones de la norma NMX-034/1, estos genotipos pueden ser procesados por la industria tradicional de Nixtamalización y de la harinización, V-537C registró 1.63 kg de tortilla por cada kg de grano, presentó dureza intermedia y produjo tortillas suaves; Finalmente, V-537C presentó los más altos contenidos de Lisina, pero no de Triptófano.

Nixtamal and Tortilla quality on improved maize (*Zea mays* L.) genotypes for the humid tropic in México

Objectives

a) To evaluate physical and chemical characteristics and tortilla quality for maize improved genotypes for the humid tropic in Mexico

Methodology

There were evaluated in 2024 physical characteristics of maize genotypes humidity, peso hectolítrico weight (PH), índice de flotación index (IF), weight of 100 grains (PCG) and percentage of structures of grain, norm NMX-FF-034/1; Chemical components and quality protein using INFRATEC equipment; se cuantificó protein, lysine and tryptophan, using NIRS

Contribution

The grain humidity varied from 10.5-12.2 %, this humidity is an advantage for storage because reduce the risk of fungus proliferation. All seven genotypes registered hectoliter pound between 75 and 78.6 kg hL⁻¹, with hard and intermediate endosperm, both characteristics into the norm specifications NMX-034/1

Calidad de nixtamal y tortilla en genotipos de maíz (*Zea mays* L.) mejorados para el trópico húmedo de México

Objetivos

Evaluar características físicas, químicas y calidad de tortillas de maíces mejorados desarrollados para el trópico mexicano

Metodología

Se evaluaron en 2024 características físicas de genotipos de maíz: humedad, peso hectolítrico (PH), índice de flotación (IF), peso de cien granos (PCG) y porcentaje de las estructuras del grano (pedicelo [PD], pericarpio [PK], germen [G], endospermo harinoso [EH] y endospermo córneo [EC]) norma NMX-FF-034/1; Componentes químicos y calidad de la proteína en grano entero y usando el equipo INFRATEC, se cuantificó, proteína, aceite y almidón. En harina de grano, se cuantificó proteína, lisina y triptófano, utilizando el equipo NIRS.

Contribución

La humedad de grano varió de 10.5-12.2 %, esta humedad es una ventaja para su almacenamiento porque reduce los riesgos de la presencia de hongos. Los siete genotipos registraron un peso hectolítrico entre 75 and 78.6 kg hL⁻¹, con endospermo duro e intermedio, características dentro de las especificaciones de la norma NMX-034/1

Quality protein, Nixtamal, tortilla, humid tropic

Calidad de proteína, nixtamal, tortilla, trópico húmedo

Area: Development of strategic leading-edge technologies and open innovation for social transformation

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Introduction

In México, Maize is the most important crop because it is part of the diet for human consumption, the sown area, and generates 36% of the agriculture production value. During 2022, there were sown in México, 7.47 million of hectares with maize, with 3.90 t ha⁻¹ in yield and a total production of 26.55 million tons, with an apparent *per cápita* consume of 338.10 kg; From the total production, 19.35 million tons were utilized for the direct consume which of them, 67% through the masa and tortilla industry in the nixtamalization process and 33% is through the flour industry. Besides, during 2022, 17.40 million tons of yellow grain were imported for industry and animal feed [SIAP, 2022].

In the tropical region in México, during 2022, there were sown 2.8 million of hectares with maize, which of them one million are located in agronomic provinces of good and very good productivity, and 91 thousand hectares are sown under irrigated conditions; In this area is feasible the use of improved seed of hybrids, synthetics and varieties with high yield potential under favorable conditions of climate soil and management by farmers [SIAP, 2022; Espinosa *et al.*, 2019; Sierra *et al.*, 2019].

Maize in Mexico have multiple uses as grain, fodder and industrial use; however, the most important use is the direct consumption through the tortillas, tamales, Huchepos, Corundas, Atoles, totopos, tlayudas, Pozole, among others. Maize is an invention of Mexican men, however, the process of nixtamalization is an invention of Mexican women and through this process, they have created multiple dishes and ways for direct consumption [Sierra *et al.*, 2019; Sierra *et al.*, 2024]

In maize breeding through evaluating different environments are identifying better genotypes in yield, adaptation, and agronomic traits, however, is very important that farmers have access to seed with genetic, physiological, physical and sanitary good quality [Andres *et al.*, 2017; Espinosa *et al.*, 2012; Flores *et al.*, 2016; Sierra *et al.*, 2016a; Sierra *et al.*, 2016].

The tortilla is the most common way in human consumption of maize and is part of the diet of all Mexican people, and demand greater white maize production.

Thus, in the maize breeding program at Cotaxtla experiment station, which belongs to INIFAP in México, there have been conducting research for generating hybrids, synthetics and open pollinating maize varieties with very good adaptability to different environmental conditions, greater yield and productivity, tolerant to principal diseases, drought and lodging; adaptation to climate, soil and management by farmers; Besides, these genotypes have been adopted by seed producers and farmers in the southeast in México [Espinosa *et al.*, 2019; Sierra *et al.*, 2019; Reyes 1985; Andrés *et al.*, 2014; Andrés *et al.*, 2016; Sierra *et al.*, 2016]. The Tuxpeño race in the humid tropics has been the basis for genetic improvement for this region; principally white grain focused to human consumption. However, is very important to evaluate the grain and tortilla quality, physical and chemical characteristics according with the industrial in nixtamalization and flouring norms. The objectives of this research were to evaluate the physical and chemical characteristics and tortilla quality for maize improved genotypes developed for the humid tropic in Mexico

Methodology

Localization. The tropical area in Mexico, according with García [2004], the climatic group A, that correspond to humid and subhumid warm conditions [Aw0, Aw1, Aw2, Am y Af] is located in the coast region in the Gulf of Mexico and the pacific ocean. This region corresponds to the influence area on which the maize hybrids and varieties have been generated, evaluated promoted and are located the producers of improved seed; The genotypes evaluated were produced in Cotaxtla Experimental Station INIFAP, in Veracruz, located at the km 34 through the public road from Veracruz-Córdoba in the municipality of Medellín de Bravo, Veracruz, in the 18° 56' North Latitude and 96° 11' West longitude and altitude of 15 masl. García [2004]. The soil in Cotaxtla is Vertisol, with medium texture trough the profile and slightly acid pH [6.6] [INEGI, 2020].

Germplasm used. H-518, H-520, V-537C, V-540, SINT 4B, V-537CxVS-536, SINT 4BxVS-536, commercial and experimental genotypes derived from the Tuxpeño race and developed at Cotaxtla experimental station which belongs to the National Institute of forestry, agricultural and livestock research [INIFAP]. [Sierra *et al.*, 2019]

Sierra-Macias, Mauro, Vázquez-Carrillo, María Gricelda, Ríos-Isidro, Clara and Gómez-Montiel, Noel Orlando. [2025]. Nixtamal and Tortilla quality on improved maize [*Zea mays* L.] genotypes for the humid tropic in México. ECORFAN Journal Republic of Nicaragua. 11[19]1-8: e11119108.

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Description of grain production.

During 2024 were evaluated seven maize genotypes from Cotaxtla experiment station, INIFAP; These genotypes were produced during the fall winter season 2023/24 under irrigation conditions in plots of 4 rows 5 m long and 80 cm wide in plant density of 62,500 plants ha⁻¹; The weeds were controlled based on Atrazine in preemergent application and were controlled pests in leaves during developing crop [Reyes, 1990]. In fertilization was utilized the formula 161-46-00, applying all the phosphorus and 30% of the nitrogen at planting date, the rest of nitrogen was applied 35 days from planting date using urea as nitrogen source. The agronomic management have influence in the presence of the Lysine and Tryptophan aminoacids [Vera *et al.*, 2012]

Physical characteristics. There were evaluated the physical characteristics as follow: humidity of grain, hectoliter weight [PH], flotation index, [IF], weight of 100 grains [PCG] and percentage of the grain structures [pedicel [PD], pericarpic [PR], germen [G], endosperm farinose [EH] and cornea endosperm [EC]] according with the norm NMX-FF-034/1 [SE, 2020].

Chemical components and proteína quality. In complete grain and using equipment INFRADEC, there were quantifying protein, oil, and starch. In flouring of grain without treatment, there were quantifying protein, Lysine and Tryptophan using equipment NIRS, in both cases were followed the methodologies described by Palacios [2018]. The quality protein index [ICP] was calculated using the relation: percentage of de tryptophane /percentage of protein]*100 [Twumasi *et al.*, 2016]. All these variables were gotten by duplicated.

Tortilla quality. The maize genotypes were nixtamalized following the traditional method described by Vázquez *et al.*, [2023] and Salinas *et al.*, [2017].

Consist in cooking 500 g of maize grain in a solution of 1000 mL of water and 10 g of lime [1.0% according with the maize grain quantity]. Time of cooking is assigned based on flotation index [IF] [SE, 2020].

The nixtamal was keeping repose during 16 hours and then was rinsed with 1000 ml of water.

The next step was to grind the nixtamal in a Stone grind Fumasa® Mod. de 5 HP. MN-80 Universal [Fumasa S.A., Méx.] for getting the dough. The dough was molded forming disks of 20 cm diameter and 1.5 mm of thickness, and there were cooking in a machine for making tortillas Villamex, Model V-14C/R, provided of three comales, heated at 310, 280 and 270 °C respectively, on which each disk of dough kept 45, 30 and 35 minutes

In the liquor of cooking [nejayote] there was evaluated the loss of dry matter [PMS]; in the nixtamal, the pericarp retained [PR] and the humidity [HN] [SE, 2020]; in grain and tortillas recently elaborated [30'], packed and stored during 24 h to 4°C, there was evaluated the humidity, the color, the force of compression and the elongation, these two last variables were measured with a texturometer Brookfield® [Model CT3, Middleboro, Massachusetts, EUA] utilizing a punch finish in a globe of 10 mm of diameter. The results were expressed in grams-force [gf] and mm respectively. The yield was evaluated in tortillas recently elaborated and was expressed in kg of tortilla by kg of processed grain.

The color in grain and tortillas recently elaborated [30'] and stored was qualified using a colorimeter Hunter Lab MiniScanXE Plus® [Reston, VA, EE. UU.]. There was registered the luminosity [L*], a* and b*, with these last variables there was calculated, the angle of tone hue [$hue = \arctan\left[\frac{b}{a}\right]$] and the purity index [$chroma = [a^2 + b^2]^{1/2}$] [Sant'Anna *et al.*, 2013].

Results and discussion

Physical characteristics. The grain humidity varied from 10.5-12.2 %, this humidity is an advantage for storage because reduce the risk of fungus proliferation. The improved maize genotypes, were characterized for small grain weight of 100 gr less than 33 g [NMX-034 [SE, 2020], Is important to mention that GRUMA is buying big grain preferring [PCG > 38 g]. All seven genotypes registered hectoliter pound between 75 and 78.6 kg hL⁻¹, with hard and intermediate endosperm, both characteristics into the norm specifications NMX-034/1 [SE, 2020] and the GRUMA demand [Table 1]. These genotypes can be processed by the traditional Nixtamalization and floury industries.

Box 1**Table 1**

Physical variables and structural components of improved maize grains for the Mexican tropic. Cotaxtla, Ver. Fall Winter season 2023-2024.

Genotypes	Grain Humidity [%]	Hectolitic Weight [Kg hL ⁻¹]	Weight of 100 grains [g]	Flotation Index [%]	Hard Grain \$
H-518	10.5±0	75±0.28	23.7±0.01	53±2.83	I
H-520	11.3±0.35	78.2±0.28	28.3±0.02	28±2.12	D
V-537 C	11.4±0.57	75.4±0.28	24±0.01	41±3.54	I
V-537CxVS-536	11.6±0.78	78.6±0.28	27.2±0.01	35±0.71	D
V-540	11.3±0.42	77.2±0	26±0.01	34±1.41	D
Sintético 4B	12.2±0.92	78.6±0.28	25.8±0.01	29±7.07	D
Sint 4BxVS-536	11.9±0.78	79±0.28	22.6±0.01	23±0	D
NMX-034[1] 2020	> 73			010	
GRUMA [2020]	> 73	> 38	< 48	-45	

Source: Own elaboration

In the structural components, the maize hybrid H-520 and the experimental Synthetic 4B, had percentages of pedicel above established by GRUMA. Except the experimental varietal cross SINT4BxVS-536, which percentage of germen was above 13 % accepted by GRUMA, the rest of genotypes, compliment the cumplen las specifications of this enterprise. In the sum of: pedicel, pericarp and germen, we can see that all genotypes were into specifications of GRUMA [Table 2].

Box 2**Table 2**

Physical variables and structural components of improved maize grains for the Mexican tropic. Cotaxtla, Ver. Fall Winter season 2023-2024

Genotypes	Pedicel	Pericarp	Endospermo			SUM
			Germen	Fluory	Flint	ΣP+Per+Ger
[%]						
H-518	1.01±0.12	4.75±0.07	11.83±0.31	23.71±8.75	58.7±9.11	17.6±0.35
H-520	2.67±0.3	4.98±0.10	9.36±0.31	53.19±4.9	29.8±4.81	17.0±0.09
V-537 C	0.9±0.03	5.18±0.46	12.96±0.36	42.17±0.41	38.78±1.21	19.0±0.79
V-537CxVS-536	1.14±0.18	5.16±0.8	12.67±0.12	36.29±2.6	45.23±3.71	18.5±1.1
V-540	1.14±0.01	5.49±0.14	12.46±0.40	29.47±4.64	51.43±3.38	19.1±0.26
Sintético 4B	2.4±0.08	6.0±0.12	10.9±0.40	33.6±0.54	47.2±0.91	19.3±0.37
Sint 4BxVS-536	0.92±0	5.45±0.52	13.43±0.16	27.64±1.94	52.56±2.30	19.8±0.35
GRUMA [2020]	< 1.2	< 5.5	< 13.0	< 32	> 48	< 21.5

Source: Own elaboration

Chemical components and quality protein. The protein was between 7.3-11.4 % with a mean value of 8.9 %.

The average content of oil registered was 5.22 %, corresponding to highest value for V-537C maize variety [Table 3], besides this variety registered among the highest percentage of germen [$x=13.0$ %]. The content of starch was similar in all evaluated genotypes with an average value of 70.91 %.

The protein content in the floury, measured in the equipment NIRS, varied slightly with respect to obtained by Infratech equipment, which can be attributed to lost that can be occur during milling that can permit concentration or dilution in components. Thus, the hybrid H-518 and open pollinating maize variety V-537C, that registered intermediate endosperm and were that registered less protein and more oil. The amino acids Lysine and Tryptophan registered values between 0.404-0.310 and 0.069-0.057% respectively. Except H-518 that registered Lysine values, like normal endosperm, the rest of genotypes the rest presented high percentages of Lysine, like QPM maize [Table 3]. The reduced differences among the genotypes may be due to interchange of pollen, with the quality protein maize V-537C and the varietal cross V-537CxVS-536, where the female parent is V-537C.

According with Vera *et al.*, [2012] the climate conditions and the management of crop by farmers, contribute in the content of the amino acids. In average for Tryptophan was 0.062 %, value below than 0.075 % established for QPM genotypes [Twumasi *et al.*, 2016]. The highest content of protein, Lysine and Tryptophan was for V-540, besides, registered less starch [Table 3]. The high ICP of H-518, is due to reduced content of protein and the percentages of Lysine and Tryptophan were smaller than the QPM maize variety. As a conclusion we can see that none of these genotypes reach a quality index ICP of 0.8 established for QPM maize [Twumasi *et al.*, 2016]. The results of Lysine indicate that we should continue sampling this amino acid.

Box 3**Table 3**

Chemical components and quality protein improved maize for Mexican tropic

Genotype s	Humidity	Protein %	oil %	Starch %	Protein %	Lysine %	Tryptophan %	ICP
H-518	11.5±0.0	7.3±0.07	5.6±0.14	71.4±0.28	7.2±0.32	0.310±0.004	0.057±0.002	0.80
H-520	10.1±0.07	9.6±0.0	5.0±0.0	70.3±0.35	10.5±0.12	0.403±0.023	0.065±0.0008	0.61
V-537C	12.6±0.07	8.0±0.14	5.7±0.07	71.3±0.57	9.3±0.33	0.378±0.005	0.063±0.0008	0.68
V-537CxVS-536	13.9±0.0	8.3±0.0	5.0±0.07	71.2±0.21	9.5±0.24	0.375±0.003	0.060±0.0007	0.63
V-540	10.7±0.0	11.4±0.42	5.1±0.07	69.4±0.28	12.1±0.11	0.404±0.022	0.069±0.0005	0.57
Sintético 4B	14.0±0.07	8.6±0.21	5.3±0.0	71.6±0.21	9.1±0.12	0.404±0.003	0.059±0.003	0.65
Sint 4BxVS-536	13.6±0.07	8.9±0.14	5.0±0.14	71.4±0.07	10.1±0.55	0.382±0.005	0.060±0.001	0.60
Twumasi-Afryic <i>et al.</i> , [2016]				QPM	> 0.35	> 0.075		0.8

‡In fluory grain without process [measured in the NIRS].

Source: Own elaboration

Quality of tortillas. The lost of solids in the liquor of cooking [nejayote] was between 4.8 to 3.3 % with an average value of 4.3 %, similar values were reported by Salinas *et al.*, [2017] for improved genotypes in the tropic. The percentage of pericarp retained for the nixtamal was between 43.8 and 16.0%, particularly V-537C, was the variety that less pericarp retained in nixtamal [Table 4]. Thus, V-537C was among the genotypes with high lost of solids [$x=4.6\%$]. On the contrary genotypes with high retention of pericarp [V537CxVS536, SINT4BxVS536], were those with less detriment of solids registered [Table 4]. The significative correlation between these two variables [$r=0.71$; $P<0.01$] was reported by Vázquez *et al.*, [2018].

The average for nixtamal humidity [HN] was 44.5 %, V-537 C registered the highest value, nevertheless, less time of cooking [40 min] respect to hard grain genotypes, that had 45 minutes. Besides, V-537C registered 1.63 kg of tortilla for each kg of maize grain and presented intermediate hard endosperm and there were produced soft tortillas, Finally, V-537C presented the highest content of Lysine but not for Tryptophane.

Box 4

Table 4

Quality nixtamalero-tortillera of improved genotypes for mexican tropic

Varieties	% lost	% Pericarp	Humidity [%]					Yield Tortill [kg/Kg maize]
	Dry matter	Retained	H Nixtamal	H dough	HT [30']	HT [24 h]	HT [48 h]	
H-518	3.9±0.7	39.3±1.2 7	45.0±0.25	0.2±0.11	45.8±0.8 5	40.6±0.45	44.1±0.1 8	1.58±0.007
H-520	4.8±1.0	26.01±2.0	44.3±0.23	0.6±0.19	45.0±1.0 3	44.3± 0.35	43.9±1.0 2	1.55±0.014
V-537C	4.6±1.4	16.0±0.9 8	45.8±0.32	2.2±0.27	45.2±0.9 1	43.9±0.51	44.0±0.2 9	1.63±0.042
V537CxVS536	3.3±0.8	42.3±1.7 1	42.9±1.7	7.5±0.23	42.2±0.3 5	42.5±0.11	43.3±0.6	1.5±0.007
V-540	4.7± 0.5	30.0±1.3	44.6±1.45	8.9±0.31	45.1±0.5 3	44.4±0.41	44.1±0.3 5	1.5±0.015
SINT 4B	4.3±0.9	41.2±1.9 0	45.1±0.83	9.8±0.18	43.2±1.0 1	43.8±0.43	41.2±0.1 2	1.47± 0.028
SINT4BxVS56	3.6±0.0	43.8±1.2 1	44.5±1.21	8.2±0.28	43.1±0.8 2	43.9±0.48	41.1±0.4 1	1.44±0.0

Source: Own elaboration

The softer tortillas, recently elaborated, 24 and 28 h after of stored were made with V-537C [Table 5]. The varietal crosses V537CxVS536 and SINT4BxVS536 were those which retained the highest pericarp retention [$x=43.1\%$], produced tortillas with less humidity [$x=42.6\%$], besides these crosses were that required more force for breaking [$x=3.0\text{ N}$], especially after 24 h of stored [Table 5].

Box 5

Table 5

Force of breaking and elongation of tortillas recently elaborated [30'] and stored [24 and 48 h] to 4°C, of improved genotypes for the humid tropic in México

Genotypes	Force of breaking [N]			Elongation [mm]		
	30 min	24 h	24 h	30 min	24 h	24 h
H-518	2.1±0	1.9±0.1	1.8±0	6.7±1.2	4.2±0.1	6.5±1.1
H-520	1.9±0.1	3±0.2	2±0	5.4±1.1	7.7±0.4	5.1±0.4
V-537 C	1.7±0	1.6±0	1.5±0.1	5.6±0.4	5.5±0.6	5.8±0.2
V537CxVS536	1.8±0.1	3.2±0.1	2.7±0	7.7±0.1	9.7±3.1	8.5±1
V-540	2.2±0.1	1.8±0	2.8±0	7.1±0.6	8±0	8.6±0
SINT 4B	2±0	2.6±0	2.7±0.3	6.9±0.5	7.8±0.9	7.3±1.3
SINT4BxVS536	1.9±0.1	2.8±0	1.8±0.1	6.5±0	7.4±0.5	6.7±1

Source: Own elaboration

Color in grain and tortillas. The average luminosity in grain was 69.7%, value increased in tortillas [$x=73.9\%$], this is because of the dilution of pericarp by effect of the nixtamalization and the predominance of the white starch in endosperm. The grains of V-540 and V-537C were those that presented the clearest tone and highest color purity [chroma], while H-520 had grains with creamier tones and lower color purity [Table 6].

In freshly made tortillas [30'] the lightest tone was for SINT4BxVS-536, conversely the lowest purity was in the cream color [$x=19.97$]. The lower purity of color in tortillas is attributed to the color changes caused by lime [Ca [OH]2] and the cooking of the dough, where the Maillard reaction occurs, which is a color change towards brownish tones, which is produced by the caramelization of sugars or proteins when subjected to heat. As well as the color change due to the cooking of the dough itself. The tortillas stored for 48 hours in refrigeration, from SINT4BxVS36, were the lightest in color [Table 6].

Box 6

Table 6

Parámetros of color in grain and tortillas from improved maize genotypes for mexican tropic.

Variedades	Color en Grano		Tortillas [30']		Tortillas [24 h]		Tortillas [48 h]	
	Hue [°]	Crom a	Hue [°]	Crom a	Hue [°]	Crom a	Hue [°]	Crom a
H-518	83.43±0.2	28.57±1.4	85.87±0	21.46±0.1	85.69±0.2	20.5±0.2	90.55±0.1	19.35±0.3
H-520	81.78±0.3	25.96±0.3	86.93±0.2	20.07±0	85.76±0.6	21.09±1	91.33±0.1	19.67±0.2
V-537 C	84.28±0.6	29.69±0	86.53±0.3	21.38±0.2	86.8±0.2	21.76±0	89.95±0	20.82±0.3
V537CxVS-536	82.35±0.2	28.72±0.1	85.93±0.4	21.76±0.2	89.79±0.1	20.36±0.2	89.39±0	20.33±0.2
V-540	84.36±0.9	27.02±0	87.73±0.1	20.85±0.1	91.34±0.4	20.1±1	91.4±0.1	19.51±0.6
SINT 4B	83.07±0.5	31.52±0.7	86.46±0.1	20.6±0.2	89.44±0.1	19.83±0.4	89.74±1.1	20.35±0.4
SINT4BxVS536	83.03±0.5	28.7±0.1	87.97±0.2	19.97±0.9	90.76±1	20.56±0.2	91.2±0	20.25±0

Source: Own elaboration

Conclusions

The seven improved varieties showed similarities in their physical characteristics; all had small grains and a predominance of hard endosperm. All met the specifications of the NMX-034/1 standard [SE, 2020].

The V-537C, which had intermediate-firmness grains, produced the softest, freshest and most stored tortillas and the highest tortilla yield.

Its lysine content was high, typical of a high-protein corn, but its tryptophan content was not. Neither of these varieties had the tryptophan levels expected of QPM corn.

The varieties evaluated can be processed by the fresh dough and nixtamalized flour industries.

Conflict of interest

Authors declare no interest conflict.

Authors' contribution statement

Sierra-Macias, Mauro: Corresponsable in Project: “Mejoramiento genético y registro de variedades de maíz para el trópico bajo de México y sus nichos ecológicos”. Participating in generating maize genotypes y producing the grain for the samples utilized in these Physical, chemical and nixtamalization analysis

Vázquez-Carrillo, María Gricelda: Physical, chemical and nixtamalization analysis for maize hybrids and varieties for the humid tropic.

Ríos-Isidro, Clara: Asistant in the maize program Campo experimental Cotaxtla, colaborated in generating maize genotypes and producing the grain for the samples utilized in these Physical, chemical and nixtamalization analysis, organization of the data and elaborating the information.

Gómez-Montiel, Noel Orlando: Responsable in Project: “Mejoramiento genético y registro de variedades de maíz para el trópico bajo de México y sus nichos ecológicos”. Participating in generating maize genotypes organization of the data and elaborating the information

Availability of data and materials

The data and the information that we present in this contribution are data of experiments conducted by INIFAP

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Abbreviations

SECHITI	National Council of Humanity Science and Technology
CP	Postgraduate College
INAPESCA	Fishing National Institute
INIFAP	National Institute of Forestry, Agriculture and Livestock Research
SADER	Agricultural livestock and rural development ministry
SIAP	Service of agrifood and fishing information
TECNM	National Technological of México
UACH	Chapingo Autonomous University
UV	Veracruz University

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Preparation and characterization of Nanocapsules for application as pesticides

Preparación y caracterización de Nanocápsulas para su aplicación como plaguicida

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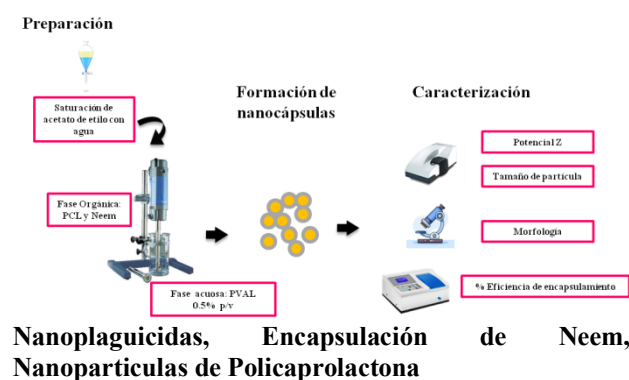
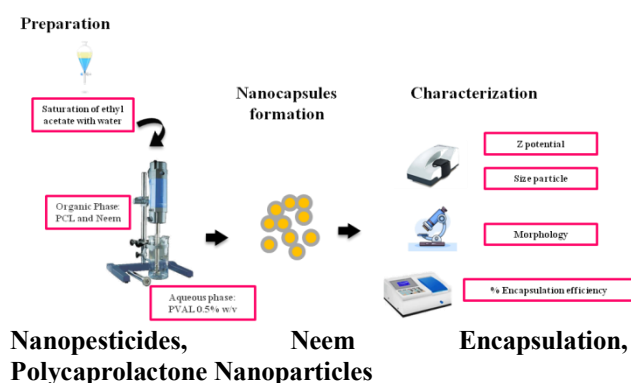


Abstract

In the present work, polymeric nanocapsules of polycaprolactone loaded with neem extract were prepared. The nanocapsules were prepared by the emulsification-diffusion method. The nanocapsules ranged in size from 254 to 369 nm. An encapsulation efficiency of up to 84.5% was achieved.

Resumen

En el presente trabajo, se prepararon nanocápsulas poliméricas de policaprolactona cargadas con extracto de Neem. Las nanocápsulas se prepararon por el método de emulsificación-difusión. Las nanocápsulas obtuvieron un tamaño de 254-369 nm. Se obtuvo una eficiencia de encapsulación de hasta el 84.5%.



Area: Promotion of frontier research and basic science in all fields of knowledge

Citation: Aquino-Martínez, Daniel Alejandro, Hernández-Santana, Jhair Alejandro, Nieto-Ruiz, Jessica, Martínez-Pérez, Beatriz. [2025]. Preparation and characterization of Nanocapsules for application as pesticides. ECORFAN Journal Republic of Nicaragua. 11[19]1-6: e21119106.



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1. Introduction

The excessive use of chemicals in crop protection has led to serious problems for human health and the environment. Moreover, their use has failed to eliminate or reduce crop pests. The constant application of chemicals has caused insects and other organisms to become resistant to these substances, leading to the use of higher doses and eventually to a saturation and/or accumulation of chemical pesticides in agriculture, causing great environmental impact.

The WHO has classified pesticides according to their acute toxicity, in order to warn farmers of the degree of danger [Table 1]. Pesticides can reach the final consumer in two ways, the first via residues on vegetables or via the food chain, concentrating and causing irreparable and permanent damage to human health. [Brechelt A., 2004].

Box 1

Table 1

Toxicological categories of pesticides

Category toxicological		LD50 for the rat [mg/kg of body weight]			
		Oral		Dermal	
		Solids	Liquids	Solids	Liquids
Ia	Extremely dangerous	5 or less	20 or less	10 or less	40 or less
Ib	Highly dangerous	>5-50	>20-200	>10-100	>40-400
II	Moderately dangerous	>50-500	>200-2000	>100-1000	>400-4000
III	Slightly dangerous	> 500	> 2000	> 1000	> 4000

Taken from Brechelt, 2004.

On the other hand, the UN General Assembly established the 2030 Agenda for Sustainable Development, with the aim of favouring the planet, as well as strengthening universal peace. Within this framework, Mexico established a set of actions aimed at achieving at least 10 of the 17 goals of the 2030 Agenda. One of the actions established is to promote agroecology with the support of the Food and Agriculture Organisation of the United Nations [FAO, 2015].

Synthetic pesticides represent one of the main and most effective weapons for the management of agricultural pests, however, they generate high economic costs, environmental pollution, reduction of beneficial organisms and wild species, intoxications, negative effects on applicators and people related to their management and the development of pest resistance [Gutiérrez-Ramírez et al., 2013].

Agriculture requires, among other things, the increased use of chemicals for pest control. In this part, scientific advances have shown that nanomaterials have innovative properties that can be used in the development of a new generation of substances that have been called nano-pesticides. The consideration of nano-pesticides in pest management and control is considered as a first example, the use of colloidal silver which has nanometric particle sizes and has had an increase in its antimicrobial properties due to its large surface area. Nanotechnology applied to pesticides allows the formulation of products that are more specific and less toxic to non-target organisms. The encapsulation of active ingredients in nanoparticles improves the efficacy of pesticides, allowing a lower application dose and reducing pest resistance [Martez L., 2022]. In addition, the use of pesticides at the nanoscale can minimise the risks associated with human and environmental exposure by facilitating a controlled and targeted release of the active ingredient [Vázquez-Núñez, 2022].

In the present research work, polymeric nanopcapsules containing Neem extract were developed for application as a nano-pesticide. Neem extract [*Azadirachta indica* A. Juss] is considered a bioinsecticide with a broad spectrum. Its most important active ingredient is azadirachtin, which has been tested against 220 species of insect pests of the orders *Blattodea*, *Caelifera*, *Coleoptera*, *Dermaptera*, *Diptera*, *Ensifera*, *Heteroptera*, *Isoptera*, *Lepidoptera*, *Phasmida*, *Phthiraptera*, *Siphonaptera* and *Thysanoptera* [López-Díaz y Estrada-Ortiz, 2005].

2. Methodology

2.1. Preparation of Neem Nanocapsules [NCs-PCL-Neem]

The organic phase was prepared with Polycaprolactone [PCL] and Neem Extract in ethyl acetate previously saturated with water.

Aquino-Martínez, Daniel Alejandro, Hernández-Santana, Jhair Alejandro, Nieto-Ruiz, Jessica, Martínez-Pérez, Beatriz. [2025]. Preparation and characterization of Nanocapsules for application as pesticides. ECORFAN Journal Republic of Nicaragua. 11[19]1-6: e21119106.

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The aqueous phase consisted of 0.5% Polyvinyl alcohol [PVAL]. The organic phase was added to the aqueous phase with magnetic stirring at 10,000 rpm using a high speed homogeniser. Stirring was maintained for 10 minutes. Subsequently, deionised water was added to the system and the same stirring conditions were continued for a further 5 minutes. The solvent and as much water as possible were evaporated under reduced pressure in a rotary evaporator. The nanocapsules were recovered by centrifugation at 14600 rpm. Finally, the nanocapsules were dried under vacuum. The prepared systems are presented in table 2.

Box 2

Table 2

Nanoparticulate systems for the preparation of NCs-PCL-Neem nanocapsules

LOT	PCL	Extract Neem
1	200	
2	200	200
3	400	
4	400	200

2.2. Physico-chemical characterisation of NCs-PCL-Neem nanocapsules

2.2.1. Particle size and polydispersion index

Particle size and polydispersity index were determined by the dynamic light scattering technique using a Malvern Zetasizer Nano ZS90 [Malvern Instruments Ltd, UK] with a detection angle of 90° and a wavelength of 633 nm. One millilitre of each colloidal dispersion was diluted to 10 ml with distilled water to obtain a dilute dispersion.

2.2.2 Z-potential of NCs-PCL-Neem nanocapsules

The zeta potential was determined using a ZS90 Nano Zetasizer, based on the electrophoretic movement of the particles in dispersion using polycaprolactone dispersions as a reference. This parameter indicates the degree of repulsion between adjacent particles. The measurements were performed in triplicate.

2.2.3. Morphology of NCs-PCL-Neem nanocapsules

The FertyNeem nanocapsules were visualised under an optical microscope using 2500 x magnification to obtain their morphology.

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2.2.4. Quantification of Neem extract from FertyNeem nanocapsules [NCs-PCL-Neem]

Encapsulation efficiency [E.E.] was determined using the indirect method based on quantifying the unencapsulated active compound [Sotelo-Boyás et al., 2017]. Briefly, 2 ml of each colloidal dispersion was centrifuged at 14 600 rpm for 60 min, to separate the nanocapsules and the stabiliser by removing the supernatant. To the sediment obtained, 1 ml of cyclohexane was added to dissolve the unencapsulated ethyl acetate, but not to dissolve the polymeric barrier in the nanocapsules. The concentration of unencapsulated β-carotene was determined using a UV vis spectrophotometer at a wavelength of 275 nm. The measurements were performed in triplicate and the encapsulation efficiency was determined using the following relationship:

$$E.E. = \frac{[\text{mg Neem added} - \text{mg Neem not encapsulated}]}{\text{mg Neem added}} \times 100 \dots \dots \dots [1]$$

3. Results and Discussion

3.1. Development of the analytical method for the quantification of Neem extract

3.1.2. Determination of the UV vis absorption spectrum of Neem extract

The absorption spectrum of the Neem extract [Figure 1] shows that the wavelength of maximum absorption is 275 nm, a value that coincides with those reported by Macías-Alvarado and Pérez-Alvarado [2021].

Box 3

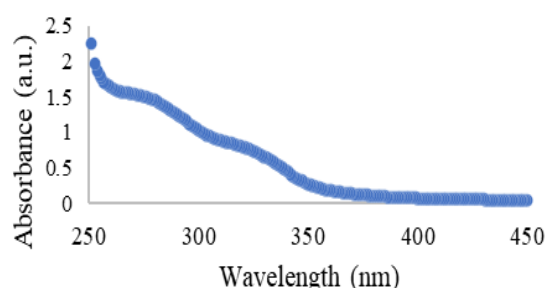


Figure 1

UV vis absorption spectrum of Neem extract in 1% Tween 20. □=275 nm.

Source: [Own elaboration]

3.1.3. Calibration curves for the quantification of Neem extract.

Figure 2 shows a linear relationship between the concentration of Neem extract and its absorbance in the concentration range of 1 to 10 mg/ml of Neem extract [$r^2 = 0.9994$], the equation of the linear relationship is: $y = 0.1419x - 0.0028$.

Box 4

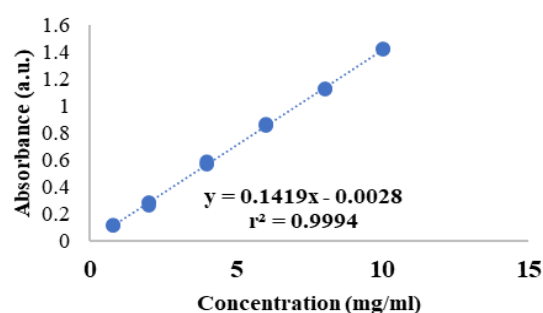


Figure 2

Calibration curve for Neem extract in 1% Tween 20 [$\lambda = 275 \text{ nm}$]

[Own elaboration]

3.1.3. Preparation of NCs-PCL-Neem Nanocapsules

Neem extract, PCL nanocapsules were prepared by the emulsification-diffusion technique. This technique is based on the formation of nanocapsules prepared by emulsification-diffusion, based on the diffusion of the polymer molecules towards the aqueous phase, originating local regions of supersaturation, from which new polymer globules or aggregates are formed that are not completely desolvable.

The stability of these aggregates by the stabiliser is important to avoid their coalescence. This stability allows the formation of nano-sized particles after complete diffusion of the organic solvent [Quintanar-Guerrero, et al., 1997].

The diffusion emulsification technique allowed us to prepare FertyNeem nanocapsules with spherical morphology and an average size of 250-450 nm [Figures 3 and 4].

Box 5

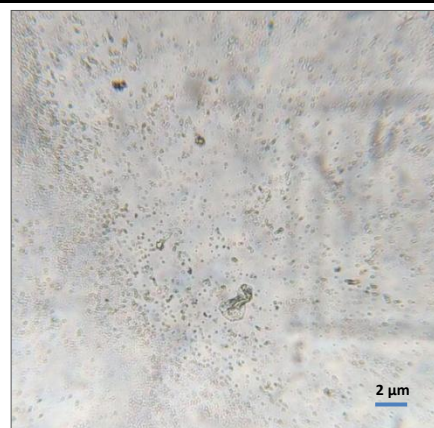


Figure 4

Optical micrograph of NCs-PCL polymeric nanocapsules. Images taken with optical microscopy equipment at 2500x

Source: [Own elaboration]

Box 6

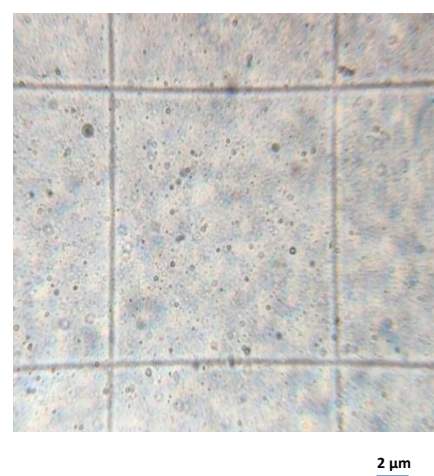


Figure 5

Optical micrograph of NCs-PCL-Neem polymeric nanocapsules. Images taken with an optical microscope at 2500x.

Source: [Own elaboration]

The values for particle size, Z-potential and encapsulation efficiency are shown in table

Box 7

Table 3

Nanoparticulate systems for the preparation of NCs-PCL-Neem nanocapsules.

LOT	PCL [mg]	Neem Extract [mg]	Proportion PCL:Neem	Average size [nm]	PDI	Potential Z [mV]	Encapsulation efficiency of Neem [%]
1	200			254.8	0.197	-6.56	
2	200	200	1:1	305.4	0.214	-3.56	78.43
3	400			287.6	0.145	-4.65	
4	400	200	2:1	369.8	0.187	-2.78	84.5

The results shown in table 3 indicate that with the 2:1 polymer-Neem ratio, there is greater encapsulation efficiency, due to the fact that there is a greater amount of polymer in the formulation, which gives the nanocapsules greater stability. With respect to the charge, a decrease in the Z potential is observed in those formulations that have Neem, which may be due to the presence of an amount of Neem close to the surface of the nanocapsules. This decrease in charge is presented by Pasquoto-Stigliani et al. [2017], who encapsulated Neem extract in nanoparticulate formulations of PCL.

4. Conclusions

Polymeric PCL nanocapsules were prepared from Neem extract by the emulsification-diffusion technique with an encapsulation efficiency of up to 84.5%. Physicochemical characterisation tests showed the formation of spherical nanocapsules, with an average size of 250-369 nm.

Declarations

Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that might have appeared to influence the article reported in this paper.

Authors' contribution

Aquino-Martínez, Alejandro: Contributed the project idea, performed the preparation and characterisation of the polymeric nanocapsules and drafted the manuscript.

Hernández-Santana, Jhair Alejandro: Contributed to the physicochemical characterisation studies.

Nieto-Ruiz, Jessica: Contributed to the physicochemical characterisation studies.

Martínez-Pérez, Beatriz: Contributed to the supervision of the preparation and characterisation studies, as well as assisting in the drafting of the manuscript.

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Abbreviations

FAO: Food and Agriculture Organization of the United Nations

NCs: Nanocapsules

PCL: Polycaprolactone

WHO: World Health Organization

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Formulation and quality validation of an antiseptic ointment from Jacaranda Flower [Jacaranda mimosifolia]: A biochemical and microbiological approach

Formulación y validación de calidad de una pomada antiséptica a base de flor de Jacaranda [Jacaranda mimosifolia]: Un enfoque bioquímico y microbiológico

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Abstract

This study evaluated the implementation of quality parameters for the development of an antiseptic ointment made with Jacaranda flower [J. mimosifolia] extract. Mexican Official Standards [NOM-248-SSA1-2011, NOM-259-SSA1-2022, and NOM-073-SSA1-2015] were applied to ensure good manufacturing practices, microbiological control, and stability. The optimal formulation included petroleum jelly, coconut oil, and menthol, resulting in a stable and safe composition with proven antimicrobial effectiveness. Organoleptic, pH, and microbiological viability studies were conducted for 21 days under three different environmental conditions. Results showed absence of pathogens such as Staphylococcus aureus, E. coli, and fungi, while maintaining physicochemical properties. It is concluded that the developed formulation is safe, effective, and suitable for topical application, with potential use in minor injuries and dermatological diseases.

Resumen

El presente estudio evaluó la implementación de parámetros de calidad para el desarrollo de una pomada antiséptica elaborada con extracto de flor de Jacaranda [J. mimosifolia]. Se aplicaron diversas normas oficiales mexicanas [NOM-248-SSA1-2011, NOM-259-SSA1-2022 y NOM-073-SSA1-2015] con el propósito de establecer criterios de buenas prácticas de manufactura, control microbiológico y estabilidad. La formulación óptima incluyó jalea de petrolato, aceite de coco y mentol, obteniendo una composición estable, segura para uso tópico y con efectividad antimicrobiana comprobada. Se realizaron diversos estudios como son: organolépticos, de pH y de viabilidad microbiológica en un periodo de 21 días en tres distintas condiciones ambientales. Los resultados mostraron ausencia de patógenos como Staphylococcus aureus, E. coli y hongos, además de mantener sus propiedades fisicoquímicas. Por lo cual se concluye que la formulación desarrollada es segura, eficaz y adecuada para aplicación tópica, proponiendo su potencial uso en lesiones leves y enfermedades dermatológicas.

Formulation and quality validation of an antiseptic ointment from Jacaranda Flower [Jacaranda mimosifolia]: A biochemical and microbiological approach.		
Objetivos	Methodology	Contribution
Evaluate quality parameters in the development of an antiseptic ointment from Jacaranda flower extract.	<ul style="list-style-type: none"> • Application of Mexican official Standards [NOMs] • Evaluation of organoleptic, Ph, Microbiological viability and stability • And optimal and effective formulation. 	An effective and safe formulation for topical use in minor injuries and dermatological diseases.

Jacaranda, Antiseptic Ointment, Healing

Formulación y validación de calidad de una pomada antiséptica a base de la flor de Jacaranda [Jacaranda mimosifolia]: Un enfoque bioquímico y microbiológico		
Objetivos	Metodología	Contribución
Evaluar parámetros de calidad en el desarrollo de una pomada antiséptica con extracto de flor de jacaranda	<ul style="list-style-type: none"> • Aplicación de Normas Oficiales Mexicanas. • Evaluación de organolépticos, pH viabilidad microbiológica y estabilidad. • Formulación óptima y efectiva. 	Una formulación eficaz y segura de uso tópico en lesiones menores y enfermedades dermatológicas.

Jacaranda, Pomada Antiséptica, Cicatrización

Area: Dissemination and universal access to science

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Introduction

Nowadays, the development of therapeutic products from natural resources has gained special relevance in the last decades, due to the growing need of having accessible, safe and sustainable alternatives for something as valuable as health care. In this context, medicinal plants have established themselves as promising sources of bioactive compounds with antimicrobial, anti-inflammatory, healing and antioxidant properties. Among them, *Jacaranda mimosifolia*, commonly known as jacaranda, has been traditionally used in Mexican folk medicine for the treatment of dermal diseases, fever, diarrhea, among other ailments [Martínez, 2021; Rodríguez et al., 2020].

Several phytochemical studies show and confirm the presence of phenolic compounds, flavonoids, terpenes and tannins in the flowers of this species, which supports its potential as a raw material for the development of pharmaceutical and dermocosmetic products. In particular, *Jacaranda* flower extracts have been reported to possess antibacterial activity against strains such as *Staphylococcus aureus*, *Escherichia coli* and *Pseudomonas aeruginosa*, microorganisms frequently implicated in skin infections [García-Luna et al., 2019].

Given the challenge posed by antimicrobial resistance and the need to improve wound management practices in communities with limited access to conventional drugs, it is pertinent to explore topical formulations based on natural ingredients. This research is framed within this need, proposing the design and evaluation of an antiseptic ointment that incorporates *Jacaranda* flower extract as active agent, combined with excipients such as petrolatum jelly, coconut oil and menthol, which contribute to the stability of the product, skin moisturization and improvement of the organoleptic properties.

The developed formulation was evaluated under the guidelines established by various Mexican Official Standards [NOM], such as NOM-248-SSA1-2011 [Secretaría de Salud, 2011], related to good manufacturing practices, NOM-259-SSA1-2022 [Secretaría de Salud, 2022], focused on microbiological control, and NOM-073-SSA1-2015 [Secretaría de Salud, 2015], related to the stability of topical medicines.

Likewise, organoleptic tests, pH analysis, and microbiological viability studies were applied under different environmental conditions for a period of 21 days, in order to ensure the quality, efficacy and safety of the product. In a complementary manner, several application tests were carried out on real wounds and skin with lesions, documenting the healing effects, symptomatic relief and the absence of adverse reactions. The use of standardized plant extracts, in combination with traditional vehicles, represents a viable strategy for the development of accessible therapeutic products that address real needs in the field of public health, particularly in regions with limited medical infrastructure [Cristell, 2021].

This research not only seeks to provide scientific evidence on the pharmacological properties of the *Jacaranda* flower, but also to strengthen the link between traditional medicine and technological innovation in the development of dermo-therapeutic solutions based on quality parameters and current sanitary regulations. The integrated approach adopted contributes to the validation of national phytotherapeutic resources, promotes the sustainable use of biodiversity and opens the way to new lines of research and technology transfer in the field of health.

Methodology

The present study was developed in the facilities of the Instituto Tecnológico de Tehuacán, combining qualitative and quantitative methods to ensure the reliability of the proposed product. The experimental design focused on establishing a topical formulation based on *Jacaranda* flower [*Jacaranda mimosifolia*] with antiseptic properties, evaluating physicochemical, microbiological and organoleptic parameters under controlled conditions, in compliance with current Mexican sanitary regulations.

The raw material was collected during the flowering period [March-April], selecting mature, healthy flowers free of contamination. Disinfection was carried out by three different methods: immersion in 0.5% chlorine for 3 minutes, treatment with water at 60 °C for 5 minutes and application of acetic acid [white vinegar] for 10 minutes. Subsequently, the acetic acid method was selected as the most effective for reducing the microbiological load without affecting the sensory properties of the plant material.

The flowers were dried in the sun for three consecutive days, on a metal mesh elevated 1.20 m above the ground, following the guidelines of NOM-007-RECNAT-1997 [SEMARNAT, 1997]. They were stored in amber glass jars, hermetically sealed, to avoid exposure to humidity and direct sunlight.

The formulation of the ointment was carried out by the indirect infusion method in a water bath, using a controlled proportion of petrolatum jelly, coconut oil and menthol, in addition to the dried flower extract. Mixing was carried out at 80 °C for 25 minutes to allow adequate incorporation of the active ingredient. Six different formulations [F.1 to F.6], varying the proportion of the components, were evaluated and subjected to sensory analysis [appearance, odor, texture, spreadability and coloration] to select the optimum formulation, see Table 1.

Box 1

Table 1

Parameters established for the selection of the ideal ointment

Parameter	F1	F2	F3	F4	F5	F6
Aspect	A	A	A	A	A	A
Color	A	A	A	A	A	A
Odor	R	R	A	A	A	A
Consistency	A	A	R	A	R	A
Unctuousness	A	A	A	R	A	A
Lumps	NP	Y	NP	Y	NP	NP
Impurities	Y	NP	NP	NP	Y	NP

Note: Accepted [A], Rejected [R], No submitted [NP], If submitted [Y]

Source: Own elaboration

The selected formulation [F.6] was chosen because it presented better results in terms of homogeneous appearance, pleasant odor, smooth consistency and good dermal adhesion. Subsequently, the stability of the product was evaluated for a period of 21 days in three different environmental conditions: room temperature [25 °C], medium temperature [30 °C] and high temperature [37 °C], simulating real storage scenarios in different regions of the country. Physicochemical tests were carried out, such as pH determination by means of a calibrated potentiometer, observing values between 5.6 and 6.2, suitable for dermal applications. Microbiological analyses were also performed, see Figure 1, under the parameters established in NOM-259-SSA1-2022 and NOM-073-SSA1-2015, determining the absence of pathogenic microorganisms such as aerobic mesophiles, *Staphylococcus aureus*, *Escherichia coli* and filamentous fungi.

Box 2




Disinfection method	Disinfection with dilute acetic acid solution	Disinfection with diluted chlorine solution	Disinfection with hot water
Results			

Figure 1

Microbiological stability

Source: Own elaboration

Samples were seeded in selective culture media and incubated at 37 °C for 48 hours for bacteria, and at 25 °C for 5 days for fungi. The tests were replicated in triplicate to ensure reproducibility of the results. The plate count technique was used for the determination of colony forming units [CFU], concluding that the ointment is safe for topical use in humans.

In addition, the shelf life of the product was evaluated by means of accelerated tests, subjecting it to sudden changes in temperature and humidity, documenting the persistence of its organoleptic properties and structural stability. At the same time, a pilot test was carried out on volunteer patients with minor skin lesions [scratches, slight burns, bites], with the informed consent of each participant. A favorable evolution was observed in the healing, reduction of pain and redness, with no adverse reactions.

Likewise, to guarantee the quality of the product, Good Manufacturing Practices [GMP] criteria were applied in accordance with NOM-248-SSA1-2011, maintaining controls in the cleaning of utensils, sterilization of containers, adequate labeling and use of personal protective equipment during handling. The entire process was supervised by an academic committee of the institute.

Finally, all the results obtained were systematized in laboratory records, using control sheets and comparative photographs that document the behavior of the product throughout the study.

This integral methodology made it possible to ensure that the ointment made with Jacaranda flower extract complies with the quality criteria required for topical use for therapeutic purposes.

Results

The development of the antiseptic ointment based on Jacaranda flower [*J. mimosifolia*] involved a rigorous process of formulation, physicochemical analysis, microbiological evaluation and therapeutic validation. The results obtained during the different stages of the study are presented below, organized by type of analysis and tests.

1. Formulation selection

Six formulations [F.1 to F.6] were prepared, varying the proportions of petrolatum jelly, coconut oil, Jacaranda dried flower extract and menthol. An initial organoleptic evaluation was carried out, considering the following criteria: color, odor, consistency, smoothness and homogeneity. Formulation F.6 stood out for having:

- Uniform texture and pleasant to the touch.
- Characteristic, non-irritating odor.
- Good greasiness without leaving excessive greasy residues.
- Homogeneous appearance without the presence of visible impurities.

These results led to its selection as the optimum formulation to continue with the following phases of the study.

2. Final composition of formulation F.6, see Table 2

Box 3

Table 2

Final composición F.6

Component	Quantity [g]	Percentage [%]	Función
Petrolatum jelly	45	45%	Base vehicle
Coconut oil	35	35%	Moisturizer and emollient
Jacaranda flower	19	19%	Healing Agent
Menthol	1	1%	Organoleptic corrector

3. Stability evaluation

It is worth mentioning that, during 21 days, the F.6 ointment was stored at controlled temperatures of 25 °C, 30 °C and 37 °C. Organoleptic characteristics [color, odor, texture], pH and phase separation were monitored. The results indicated that:

- There were no significant changes in color or odor.
- Texture remained stable under all three conditions.
- There was no evidence of phase separation, indicating good emulsification.
- The pH remained between 5.6 and 6.2, which corresponds to the tolerable range for human dermal use.

4. Microbiological analysis

Tests were performed to detect the presence of pathogenic microorganisms. The analyses included counts of:

- Colony forming units [CFU] of aerobic mesophilic bacteria.
- *Staphylococcus aureus*.
- *Escherichia coli*.
- Molds and yeasts.

The crops were incubated in specific media and optimal conditions according to the type of microorganism. In all cases, the results showed a **total absence of microbial growth**, which indicates that the formulation is **microbiologically safe and safe** for application.

5. Application on real lesions

F.6 ointment was applied on **volunteer patients** with different skin lesions: mild burns, see Figure 2, scrapes, see Figure 3, third-degree wounds, see Figure 4, and initial cases of psoriasis, see Figure 5.

Box 4



Figure 2

Mild burns

Source: Own elaboration

Box 5**Figure 3**

Scratches

Source: Own elaboration

Box 6**Figure 4**

Third degree wounds

Source: Own elaboration

Box 7**Figure 5**

Initial cases of psoriasis

Source: Own elaboration

Follow-up was performed for 7 to 14 days, documenting the following effects:

- **Accelerated healing:** Re-epithelialization was visible from day 3 in most cases.
- **Reduction of inflammation:** Reduction of erythema and edema was evidenced.
- **Relief of pain and itching:** Patients reported a sensation of freshness due to menthol and relief from the first application.
- **Absence of adverse reactions:** No allergies or secondary irritation were reported.

Daily photographic records, clinical records and user satisfaction surveys were included. The qualitative results were consistent with the expected effects of the active principles of Jacaranda flower and coconut oil.

6. Sensory evaluation by user panel

A panel of 10 evaluators rated the ointment on a scale of 1 to 5 considering:

- Ease of application
- Residual odor
- Texture and absorption
- Sensation on the skin

The average scores ranged from 4.2 to 4.8, highlighting the favorable sensory acceptance of the product [Castillo & Paredes, 2022]. The comments collected highlighted its ease of use, natural odor, and smooth, non-greasy texture.

7. Comparison with commercial products

A comparative table was made between formulation F.6 and two commercial antiseptic ointments, considering parameters such as active ingredients, origin, pH, microbiological tests, results on wounds and user acceptance. The developed ointment showed advantages in terms of:

- Lower number of synthetic chemical compounds.
- Proven antimicrobial activity.
- Lower production costs.
- Better dermal tolerance.

Conclusions

The development of an antiseptic ointment based on Jacaranda flower extract [*Jacaranda mimosifolia*] represented an effective, natural and accessible alternative for the treatment of mild skin conditions, such as wounds, burns, bites and incipient cases of psoriasis.

The results obtained in the different phases of the research led to the conclusion that the F.6 formulation, composed of 45% petrolatum jelly, 35% coconut oil, 19% Jacaranda flower and 1% menthol, met the necessary requirements to guarantee its physicochemical stability, microbiological safety and therapeutic efficacy.

From the organoleptic point of view, the ointment presented optimal characteristics in terms of texture, odor, color and smoothness, achieving favorable acceptance both by the technical evaluation panel and by users in the actual application test. The stability of the product was maintained for 21 days under different environmental conditions, without phase separation or sensory alterations, suggesting good durability in storage and future commercialization.

It is important to highlight that the microbiological analysis confirmed the total absence of pathogenic agents such as *Staphylococcus aureus*, *E. coli* and filamentous fungi, evidencing that the formulation process and the manufacturing practices applied were adequate for the production of a safe product for topical use in humans. These results were reinforced by shelf-life tests and simulated storage conditions.

The therapeutic effects observed during application in volunteer patients show that the ointment not only accelerates the healing process but also provides immediate relief from pain, inflammation, and itching. These benefits, attributed to the bioactive compounds in the Jacaranda flower and the synergistic effect with coconut oil and menthol, consolidate its value as a complementary treatment in public health, especially in communities with limited access to conventional medicines [Rodríguez et al., 2020]. In addition to the experimental findings, this research contributes to the rescue of traditional knowledge on the use of Mexican medicinal plants, offering a solid scientific basis for the validation of their therapeutic potential. The study also establishes a methodological precedent for future research focused on phytopharmaceuticals, by applying official Mexican standards in each of the quality evaluation stages.

In conclusion, it is established that the antiseptic ointment based on Jacaranda flower:

- Is microbiologically safe.
- Meets organoleptic and physicochemical quality standards.
- It presents effective therapeutic properties in mild dermal lesions.
- It has the potential to be produced at low cost with accessible raw materials.
- It represents a viable natural alternative with a positive impact on community health.

This evidence opens the possibility of advancing towards new lines of research, such as the expansion of clinical studies, evaluation in populations with specific pathologies and the development of derivative products [gel, cream, topical solution]. Likewise, it is recommended to establish inter-institutional alliances for its productive scaling anditary registration, promoting biotechnological development with a focus on sustainability and social innovation.

Declarations

Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that might have appeared to influence the article reported in this paper.

Authors' Contribution

Gómez-Flores, Nidia Esther: Contributed to experimental development, analysis of results, and technical review.

Hernández-Cortés, Elsa: Contributed to the writing of the manuscript and academic supervision.

Ramírez-Vaquero, Eduardo Osbaldo: Contributed to the conception of the project idea and methodological guidance.

Vásquez-Jiménez, Juan Carlos: Final revision of the article.

Availability of data and materials

Data obtained during this research are available upon request to the corresponding author.

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Abbreviations

GMP	Good Manufacturing Practices
CFU	Colony Forming Units
NOM	Mexican Official Standard
RECNAT	Natural Resources
SEMARNAT	Ministry of Environment and Natural Resources
SSA	Ministry of Health

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Effect of using different types of avocado oil in the production of gelatin-based biopolymers Bloom 300

Efecto del uso de diferentes tipos de aceite de aguacate en la elaboración de biopolímeros a base de grenetina Bloom 300

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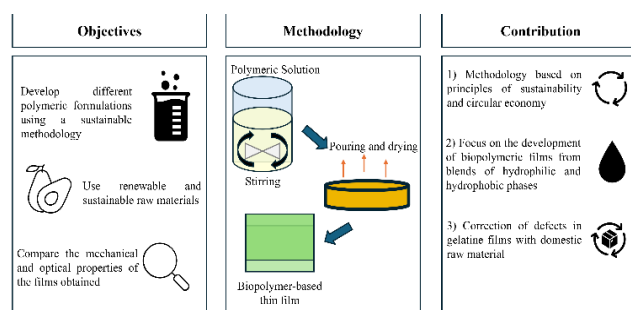


Abstract

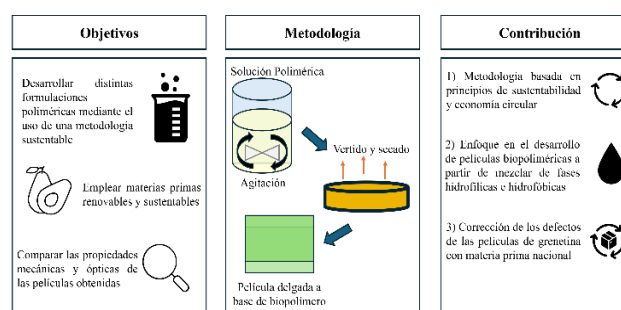
Derived from the high demand in the use of polymers for the preservation or transportation of various products, the need to replace them with environmentally friendly materials arises, thus emerging biopolymers. In the present work, different biopolymers were developed made with avocado oil [commercial, extra virgin and natural], 300° Bloom gelatine and glycerine as a plasticizer. In order to analyse the homogeneity of the plasticized biofilms, they were characterized by UV and infrared, evaluating their absorption, as well as the transmittance in the visible range, in addition the effect of wettability was analysed by measuring the angle of contact on the surface of the biopolymers and by using a thermobalance, the percentage of solids was measured after 90 minutes of exposure. The results showed a good performance, highlighting the films made with Bloom type gelatine and natural oil maintains the best properties.

Resumen

Derivado de la alta demanda en el uso de polímeros para la preservación o transportación de diversos productos nace la necesidad de sustituirlos por materiales amigables con el ambiente surgiendo de esta manera los biopolímeros. En el presente trabajo se desarrollaron diferentes biopolímeros fabricados con aceite de aguacate [comercial, extra virgen y natural], grenetina 300° Bloom y como plastificante glicerina. Con la finalidad de analizar la homogeneidad de las biopelículas plastificadas se caracterizaron mediante UV e infrarrojo evaluando su absorción, así como la transmitancia en rango visible, además se analizó el efecto de la humectabilidad mediante la medición del ángulo de contacto sobre la superficie de los biopolímeros y mediante el uso de termobalanza se midió el porcentaje de sólidos después de 90 minutos de exposición. Los resultados mostraron un buen desempeño, destacando las películas elaboradas con grenetina tipo Bloom y aceite natural mantiene las mejores propiedades.



Biodegradable, Biopolymer, Film



Biodegradable, Biopolímero, Película

Area: Promotion of frontier research and basic science in all fields of knowledge.

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Introduction

Made up of a long chain of repeat units [monomers], polymers are structures with high molecular weights due to their macromolecules [Rudin & Choi, 2025] Polymers have become a fundamental part of everyday life due to their use in the manufacture of various objects and materials.

The excessive use of these materials has made waste disposal increasingly complicated, so efforts to revolutionize waste replacement are receiving significant attention [Nair, Sekhar, Nampoothiri, & Pandey, 2017]

One of the alternatives to reduce the use of synthetic polymers is the production of "biopolymers", biodegradable plastics produced from monomers of biological origin, synthesized by microorganisms or derived from animal or plant biomass [Nair et al., 2017]

The aim has been to generate materials with the ability to form thin films on a surface that come from agro-industrial by-products such as fruits and vegetables, for example, avocado [*Persea americana*]. [Santamaría Juárez, 2025]

Avocado oil represents a vegetable input that stands out for its outstanding physicochemical properties thanks to its high content of fatty acids [oleic acid], tocopherols and carotenoids. It is used in various applications, within gastronomy it has good thermal stability and a mild flavor. The extraction to obtain it can be by various methods, some of them are by solvents, heat pressure or cold pressing, depending on the final application since with the latter method the sensory and bioactive compounds are better preserved. [Woolf et al., 2009]

The factors that directly influence the yield of the extraction are the ripeness of the fruit, the climatic conditions of cultivation, the processes and care after its harvest. The obtaining of oil usually comes from fruits rejected for marketing for human consumption, making it a sustainable strategy, although compared to other vegetable oils its commercial volume is limited. [Woolf et al., 2009]

As mentioned, the extraction process significantly influences the quality of the oil and its chemical profile [Flores et al., 2019]

Cold Press Method

Ideal for the production of extra virgin oil due to the preservation of antioxidants since heat is not applied, it has a low yield, but improves the bioactive profile.

Ultrasound-assisted aqueous extraction

It improves efficiency without chemical solvents as it uses waves to release lipids, the oil obtained has a high content of fatty acids and phenolic compounds.

CO₂ extraction

This method has two variants, the first is supercritical CO₂; The oil obtained contains high bioactive compounds, high oxidative stability, uses carbon dioxide as an ecological solvent but its highest efficiency is found at pressures of 400 bar. The second subcritical CO₂; The oil produced has greater clarity, the content of triacylglycerides and fatty acids is improved, and it also has a lower melting point.

Enzymatic extraction

It improves performance by up to 25% and is a potential method in case of integrating a sensitive compound, enzymes such as pectin or cellulase are used.

Organic solvent extraction

One of the most common methods is Soxhlet which uses mixtures of chloroform and methanol, the oil obtained contains fewer antioxidants, but the fatty acids are preserved, in some cases hexane is used for the formation of specific compounds, but a post-process chemical control is necessary.

Depending on the extraction method, there are multiple technological applications for avocado oil such as the synthesis of structured lipids, the formation of food nano emulsions or the production of biodegradable polymers, becoming very versatile. [Flores et al., 2019]

Within the literature, there have been works by different researchers that directly use the pulp of fruits such as apples [Rojas-Graü et al., 2007], Barbados cherries [Azeredo, Miranda, Rosa, Nascimento, & de Moura, 2012] as film-forming solutions, obtaining potential results in various applications.

Nolasco-Arizmendi, Víctor Alfredo, Rodríguez-Espíndola, Gerardo Daniel, Melo-Máximo, Dulce Viridiana and Melo-Máximo, Lizbeth. [2025]. Effect of using different types of avocado oil in the production of gelatin-based biopolymers Bloom 300. ECORFAN Journal Republic of Nicaragua. 11[19]1-6: e41119106. <https://doi.org/10.35429/EJRN.2025.11.19.4.1.6>

Another example is overripe banana pulp has been investigated as a potential raw material for the production of biodegradable films using plasticizers such as glycerol and pectin as a binder. The biopolymers showed a significant increase in elongation when glycerol was significantly added, but the resistance was reduced, so a greater amount of pectin was added. [Martelli, Barros, & Assis, 2014]

The mango pulp was used for the production of biopolymers reinforced with cellulose nanofibers, the incorporation of the reinforcement increased the mechanical resistance and the elastic modulus by the formation of an internal fibrillar network. Due to the components of the pulp [pectin and starch], plasticizers and binders were not added, however, the materials obtained by their mechanical characteristics are a strong candidate for application in food packaging. [Azeredo et al., 2009]

In the case of avocados, the potential of pulp residues for the production of biodegradable polymeric films has been analyzed. Glycerol was incorporated as a plasticizer additive, cassava starch and microcrystalline cellulose as reinforcement, the characterization shows that by adding starch and glycerol the biopolymers reach an elongation of up to 13.9% and a resistance of 2.70 MPa. [Dalle Mulle Santos et al., 2016]

The incorporation of agro-industrial waste in the production of biopolymers has generated a wide field of research, so taking into account the research already carried out, this work presents the production of biopolymers based on the use of proteins such as gelatin with a plus by increasing their Bloom degrees [standardized measure of the resistance to deformation of a gelatin gel], glycerol as a plasticizer and avocado oil as a film-forming solution.

Methodology

For the elaboration of the biopolymers, a solution of 300° Bloom gelatin was prepared in a ratio of 1:8 in distilled water, then glycerin was constantly added while it was in agitation; Once the solution is homogenized, add avocado oil [commercial, extra virgin and natural] without stopping the agitation.

The solution is poured into a metal mold to let dry. Once the biopolymers are dried, they are carefully unmolded and stored tightly.

Box 1

Table 1

Nomenclature of biopolymer samples according to the oil used

Content	Nomenclature
Grenetin Bloom + Commercial Avocado Oil	BC
Grenetin Bloom + extra virgin avocado oil	BEx
Grenetin Bloom + Natural Avocado Oil	BN

By the basic method of casting, a statistic of the thickness of each biopolymer was performed, as well as the infrared and ultraviolet blocking rate, as well as the visible light transmission of each of the films, they were also characterized by stereoscopy, the contact angle was measured and the percentage of solids in a thermobalance was quantified after 90 minutes at a temperature of 112°C.

Results

A total of three biopolymers were made by varying the type of avocado oil, as can be seen in Figure 1 the BC and BEx samples are transparent, while BN has a greenish-yellow coloration that is attributed to the natural oil content as it did not go through any clarification or washing process.

Box 2

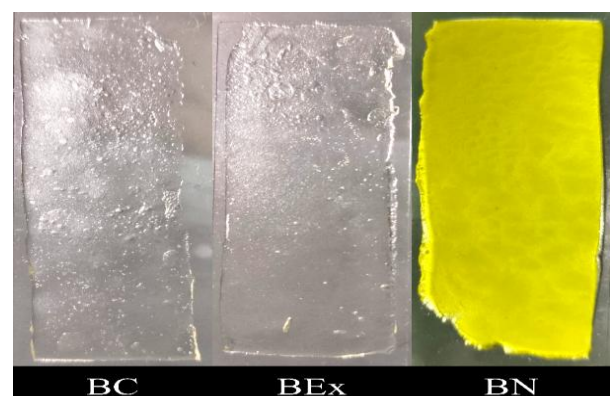


Figure 1

Biopolymer films made with 300° Bloom gelatin and avocado oil

Each one was measured 10 times on each side, adding up to a total of 40 measurements to form a statistic of the thicknesses, in table 2 it is observed that the biopolymers range from 0.5 to 1 millimeter in thickness on average, in addition to the value of the standard deviation BEx is the most uniform sample.

Box 3

Table 2

Statistical data on the thickness of biopolymers

Sample	Media [mm]	Standard deviation
BC	0.527	0.208
BEx	0.757	0.100
BN	1.09	0.156

Figure 3 shows a graph of boxes where it is observed that the greatest variability in thicknesses is present in BC, while BEx had a homogeneous behavior and BN exhibits an intermediate behavior.

Box 4

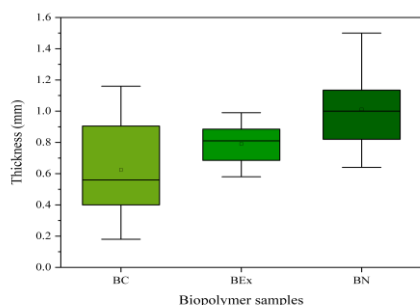


Figure 3

Graph of the variation in the thicknesses of biopolymers with different avocado oils

It was possible to observe that on the surface of the biopolymers there was an excess of avocado oil, each of the samples was characterized by stereoscopy at 40x.

Box 5



Figure 4

Biopolymer surface using 40x stereoscope

As can be seen in Figure 4, the surface contains small bubbles from the manufacturing process due to magnetic agitation for homogenization, however, the BN sample had a considerably smaller amount.

Due to the shades exhibited by the three samples, the rejection rate for Uv and IR and the level of transmittance of visible light were characterized.

As shown in table 3 the BN sample shows high values for Uv and IR rejection, however, the visible light transmission is low, it can be attributed to the opacity that the sample presents since the natural avocado oil gave the biopolymer a green/yellow color that does not allow visible light to pass through freely.

Box 6

Table 3

Values obtained from the characterization of Uv and IR rejection and visible light transmission

Sample	Rejection		Visible transmission
	Uv	IR	
BC	86.1 %	83.2%	14.6%
BEx	60.3 %	46.7%	54.7%
BN	99.7%	95.3%	4.6%

The BEx sample presented lower values compared to the other two samples, however, it has the higher value in the transmission of visible light, this can be attributed to the fact that the extra virgin oil is almost completely free of all the impurities of its extraction in addition to carrying out a clarification process. The contact angle of each of the samples was measured, showing a hydrophilicity phenomenon with values less than 90°.

Box 7

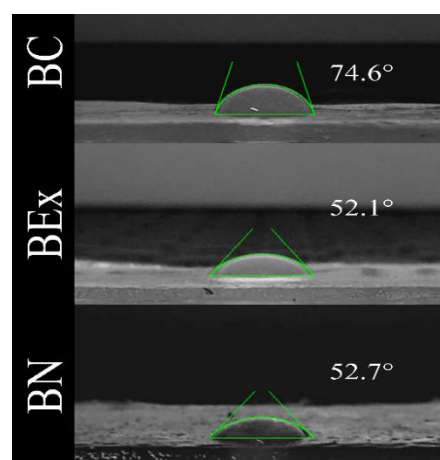


Figure 5

Contact angle of biopolymers

Figure 5 shows that the BC sample has the highest contact angle of the 3 samples with 74.6°.

Figure 6 shows the graph of the change in the percentage of solids in the BN sample since residue was observed on its surface after the drying process.

Box 8

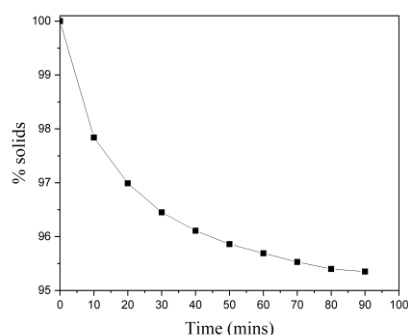


Figure 6

Graph of the change in the percentage of solids in the BN sample over 90 minutes at a temperature of 112 °C.

The test on the thermobalance began with a portion of the sample weighing approximately 5 g, at the end of the test the weight was reduced by 4.65%, obtaining a weight of 4.7 g.

Box 9



Figure 7

Biopolymer after thermobalance test

As a result of the test on the thermobalance, a change in color was obtained in the biopolymer as shown in Figure 7, lighter areas on the surface and a reduction in the sample size are observed.

Conclusions

Natural biopolymers have the advantage of being available, biodegradable and biocompatible, thus contributing to ecological safety.

The biopolymers made with gelatin with 300 degrees Bloom, glycerol and avocado oil showed a homogeneous surface, but contained air bubbles inside that were visible to the naked eye, likewise their thicknesses range from 0.5 to 1 mm presenting variations in their ends.

The significant rejection of Uv and IR is exhibited by the BN sample, however, it does not have a good transmittance for the visible range.

The contact angles are below 90°, being hydrophilic. The change in the percentage of solids decreases by only 4.65% so the biopolymer does not have a considerable loss of mass.

The type of oil influences the morphology and transparency of biopolymers.

Conflict of interest

The authors declare that they have no conflict of interest. They have no known competing financial interests or personal relationships that would have appeared to influence the article reported in this article.

Authors' contribution

Nolasco-Arizmendi, Víctor Alfredo: Experimentation, characterization, analysis of results, conceptualization, writing.

Rodríguez-Espíndola, Gerardo Daniel: Writing. *Melo Máximo Dulce Viridiana:* advice, characterization, analysis of results, conceptualization.

Melo-Máximo, Lizbeth: Project advice, conceptualization, characterization and analysis of results.

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Determination of chromium as a heavy metal in a surface water body in Frontera, Centla, Tabasco




Determinación del metal pesado cromo en un cuerpo de agua superficial en Frontera, Centla, Tabasco

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Abstract

Water quality is an area that has gained significant attention, as pollution levels around the world are affecting entire ecosystems, including both water and sediments. The main water pollutants are heavy metals such as lead, cadmium, nickel, iron, and chromium, among others. This study aimed to sample surface water in San Pedro, a locality in Frontera, Centla, Tabasco, primarily dedicated to fishing, in order to measure chromium concentrations. The study was carried out by collecting water samples from the section of the river that flows into the sea, marking the end of the aforementioned community, up to 60 meters beyond the bridge, which marks its beginning. Sampling was conducted monthly from March to June, during the dry season. The second sampling period was carried out during the rainy season in 2023, covering the months of September, October, and November. Ten water samples were taken each month and analyzed in the Environmental Chemistry Laboratory of ITS Centla. An evaluation and data correlation were conducted to determine the concentrations of the pollutant, with the expectation of finding the highest levels during the dry season. Likewise, all relevant authorities and the local community will be notified of the findings. In addition, mechanisms and an improvement plan will be proposed based on the results obtained.

Objective	Methodology	Conclusion
This study aimed to sample surface water in San Pedro, a locality in Frontera, Centla, Tabasco, primarily dedicated to fishing, in order to measure chromium concentrations	The study was carried out by collecting water samples from the section of the river that flows into the sea, marking the end of the aforementioned community, up to 60 meters beyond the bridge	In addition, mechanisms and an improvement plan will be proposed based on the results obtained

Resumen

La calidad del agua es un área que actualmente tiene mucho auge dado que los niveles de contaminación en el mundo están afectando ecosistemas completos [agua y sedimentos]. Los principales contaminantes del agua son los metales pesados como plomo, cadmio, níquel, hierro y cromo, entre otros. El presente trabajo optó por muestrear aguas superficiales en San Pedro, una localidad de Frontera, Centla, Tabasco, dedicada principalmente a la pesca, con el fin de medir las concentraciones de cromo. El trabajo se realizó obteniendo muestras de agua del tramo del río que desemboca al mar que es el final de la comunidad antes mencionada hasta 60 metros después del puente que es el inicio de esta, se muestreó de forma mensual empezando desde el mes de marzo hasta junio [Época de estiaje]. El siguiente muestreo se realizó durante el periodo de lluvias en el año 2023, abarcando los meses de septiembre, octubre y noviembre. Se tomaron 10 muestras de aguas por mes, las cuales fueron analizadas en el laboratorio de Química- Ambiental del ITS Centla. Se realizó una evaluación y correlación de datos para determinar las concentraciones del contaminante, esperando encontrar las más altas concentraciones en el periodo de estiaje, asimismo, se notificará a todas las autoridades correspondientes y a la comunidad para su conocimiento. De igual manera se propondrán mecanismos y un plan de mejora con base en los resultados obtenidos.

Objetivo	Metodología	Conclusión
El presente trabajo optó por muestrear aguas superficiales en San Pedro, una localidad de Frontera, Centla, Tabasco, dedicada principalmente a la pesca, con el fin de medir las concentraciones de cromo	El trabajo se realizó obteniendo muestras de agua del tramo del río que desemboca al mar que es el final de la comunidad antes mencionada hasta 60 metros después del puente que es el inicio de esta	De igual manera se propondrán mecanismos y un plan de mejora con base en los resultados obtenidos

Heavy metals, Physicochemical parameters, Water quality

Metales pesados, Parámetros fisicoquímicos, calidad del agua

Area: Promotion of frontier research and basic science in all fields of knowledge.

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Introduction

Throughout history, water has played a fundamental role in human development. Every society has needed to settle near this valuable resource to ensure and maintain the survival of its population. For most ancient civilizations and cultures, water was regarded as a sacred element. Nowadays, however, the situation has changed to such an extent that humankind has gone from being water's greatest admirer to becoming the main agent responsible for its alteration. At present, the rate at which humans contaminate water far exceeds its natural purification rate, which normally occurs through the continuous course of water across the various phases of its cycle [Arauzo, 2003].

Chromium is an element that has been identified both as an essential micronutrient and as a carcinogenic agent, depending on its chemical form. In industrial applications, it is used in tanning agents, pigments, textile preservatives, alloys, antifouling paints, catalysts, anti-corrosive agents, drilling muds, high-temperature batteries, fungicides, wood preservatives, and in metallic coatings and electroplating. Chromium is a naturally occurring element found in rocks, animals, plants, and soil. It can exist in different forms—liquid, solid, or gaseous—depending on its chemical state. The most common forms are chromium [0], chromium [III], and chromium [VI]. Chromium compounds generally have no particular taste or odor [Roig Marino, 2006].

The uncontrolled discharge of chromium into the environment occurs mainly because most wastewater collection systems do not allow for the separation of urban and industrial effluents. As a result, wastewater from urban areas with industrial zones is always mixed. Conventional systems for urban wastewater treatment [primary + secondary treatment] show average removal efficiencies for chromium [and other heavy metals] that are far from being considered effective. The environmental chemistry of chromium compounds involves oxidation–reduction processes, precipitation–dissolution reactions, and adsorption–desorption phenomena. In nature, chromium mainly appears in trivalent [Cr III] and hexavalent [Cr VI] forms, although the trivalent species are the most abundant [Arauzo, 2003].

When chromium enters the environment, it may be found in the air, water, or soil as a result of its release during the manufacturing, use, or disposal of chromium-containing products. Generally, chromium does not remain in the atmosphere; instead, it settles into soil and water. Once there, it can easily transform from one state to another, depending on the surrounding conditions.

Human exposure to chromium occurs through the ingestion of contaminated food or water or by inhaling contaminated air, particularly in occupational environments. High levels of chromium [VI] can damage the nasal passages and cause cancer. Ingesting high concentrations of chromium [VI] may lead to anemia or damage to the stomach and intestines. Chromium [III], on the other hand, is an essential nutrient. Chromium has been detected in at least 1,127 of the 1,669 sites on the National Priorities List identified by the Environmental Protection Agency [EPA, 2024].

The Mexican regulation NOM-001-SEMARNAT-1996 establishes that the maximum permissible concentration of chromium in surface waters is 1 mg/L as a daily average and 0.5 mg/L as a monthly average. These values apply to the protection of aquatic life and public urban use. For agricultural irrigation, the limits are 1.5 mg/L for the daily average and 1.0 mg/L for the monthly average.

This study evaluated compliance with the established quality standards for chromium in a surface water body located in Frontera, Centla, Tabasco [Arauzo, 2003]. The analysis of different compartments of the fluvial ecosystem allowed the identification of possible chromium dispersion pathways, as well as the points where accumulation processes have occurred. This assessment provides essential diagnostic elements for technicians, water utility operators, and health authorities to establish and implement water quality monitoring programs in accordance with current standards and regulations.

Problem Statement

The main economic activity in Frontera, Centla, Tabasco, is fishing. Therefore, it is essential to evaluate the current condition of the local waters, considering in this project the following parameters: temperature, suspended solids, pH, and chromium.

Suarez-García, Sandra Manuela, Zarate, Marco Antonio, Vazquez-Aguilar, Clotilde and Reyes-Hernandez, Guadalupe. [2025]. Determination of chromium as a heavy metal in a surface water body in Frontera, Centla, Tabasco. *ECORFAN Journal Republic of Nicaragua*. 11[19]1-9: e51119109. <https://doi.org/10.35429/EJRN.2025.11.19.5.1.9>

The region also has petroleum-related activities, while a smaller portion of the population is engaged in agriculture. All these activities pose potential risks to water quality due to the presence of various contaminants, such as heavy metals. In particular, this study focused on the heavy metal chromium.

Hexavalent chromium [Cr⁶⁺] is the second most common metal, after lead, found in contaminated aquifers. The main activities associated with its presence are petroleum-related operations, and the potential sources of contamination include solid wastes and liquid effluents. Its negative effects are reflected in human health and in the reduction of biodiversity [Aguilar, 2010].

This study was conducted on surface waters in the community of San Pedro, Frontera,

Centla, Tabasco. Water samples were collected during March, April, and May [dry season], as well as in September, October, and November [rainy season] of 2023. The samples were analyzed in the Environmental Chemistry Laboratory of the Instituto Tecnológico Superior de Centla [ITS Centla], where the concentrations of the contaminant and the physicochemical parameters were evaluated.

This represents the first comprehensive analysis of the heavy metal chromium in the community of San Pedro, where no precise data regarding its presence had previously been reported. Although some studies have been conducted at the state level, this work aims to provide valuable information on the current environmental situation of the area.

General Objective

- To monitor and determine the presence of the heavy metal chromium in surface waters of Frontera, Centla, Tabasco, during the rainy and dry seasons of 2023.

Specific Objectives

- To design and implement a sampling plan for the collection of water samples aimed at determining physicochemical parameters and chromium concentrations.

- To determine the physicochemical parameters — pH, conductivity, total dissolved solids, and turbidity — in order to compare their relationship with chromium concentrations.
- To determine the concentrations of chromium present in the waters of the San Pedro River.
- To compare the two seasons of the year 2023 [dry and rainy] to identify the period with the highest concentration of the heavy metal chromium.

Methodology

a) Description of the Sampling Site

This study consisted of a statistical analysis based on a quantitative research approach. The study area was selected according to specific criteria, including intensive fishing activity, the maintenance of fishing machinery, and its geographically strategic location at the river's mouth where it flows into the sea. These factors make it an ideal environment for conducting this type of research.

Study Universe and Sample

Box 1



Figure 1

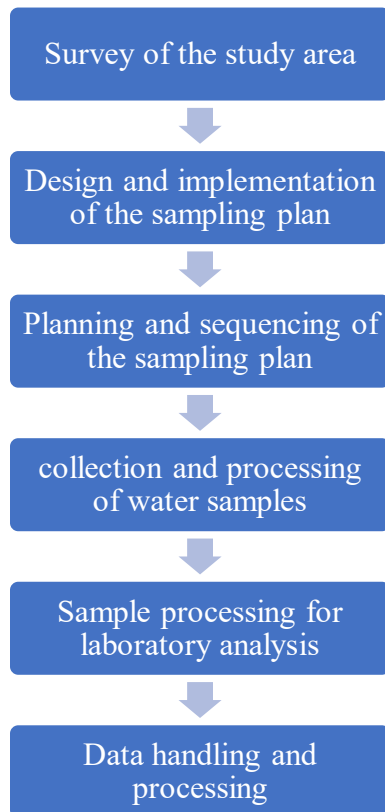
Google Earth

The study was conducted in the locality of **Barra de San Pedro**, located in the municipality of **Centla**, in the state of **Tabasco, Mexico**. The community has approximately **571 inhabitants** and is situated at an elevation of **10 meters above sea level**.

b) Research Development

The following diagram presents the methodological stages carried out during the research. Personal protective equipment [PPE] was used to ensure the safety and integrity of the research team, along with all necessary security measures required for the sampling activities.

Suarez-García, Sandra Manuela, Zarate, Marco Antonio, Vazquez-Aguilar, Clotilde and Reyes-Hernandez, Guadalupe. [2025]. Determination of chromium as a heavy metal in a surface water body in Frontera, Centla, Tabasco. ECORFAN Journal Republic of Nicaragua. 11[19]1-9: e51119109. <https://doi.org/10.35429/EJRN.2025.11.19.5.1.9>



c) Methodological Design of the Information

Description of the Sampling Site at the San Pedro River. The sampling site borders the state of Campeche. **Barra de San Pedro** is located in the municipality of **Centla**, in the state of **Tabasco, Mexico**, and is positioned at the following GPS coordinates:

Longitude [dec]: -92.469722

Latitude [dec]: 18.643333

The locality lies at an average elevation of **10 meters above sea level**.

Box 2

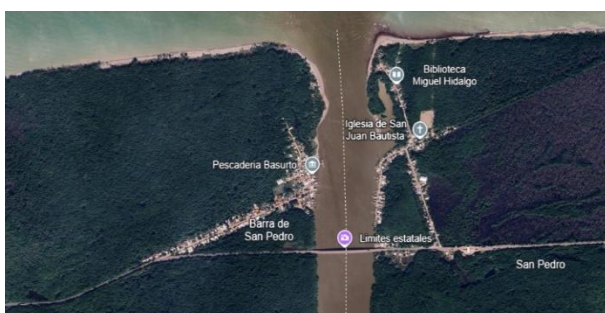


Figure 2

Google Earth

Before sampling, the type of water body, as well as the existing flora and fauna within the study area, were identified. The section of the river analyzed extends from the bridge to its mouth at the sea, where a mixture of freshwater and seawater occurs. The survey was carried out using a boat, taking into consideration the surrounding natural environment.

Based on the exploratory survey, **ten representative sampling points** were established, covering the entire study area. Each point was georeferenced and distributed along the locality — from the river's mouth to the sea, through the main fishing zone, docks, piers, the central area of the community, and the section beyond the bridge connecting Tabasco and Campeche. Water samples were collected at each point and categorized according to two distinct **seasonal periods**: the dry season and the rainy season.

The **first sampling period**, corresponding to the dry season, was conducted on **March 30, April 27, and May 25, 2023**. The **second sampling period**, corresponding to the rainy season, was carried out on **September 28, October 27, and November 30, 2023**.

d) Sampling Plan and Sequence

Box 3

Table 1.

Sampling plan and sequence [Dry and Rainy Seasons].

Dry Season	Rainy Season
March 30	September 28
April 27	October 27
May 25	November 30

e) Collection and Processing of Water Samples

The samples were collected directly from the sampling area using **250 mL sterile glass bottles**. During transportation, they were stored in an ice cooler at **4 °C**, properly labeled to preserve the physical and chemical characteristics of each sample and to ensure accurate identification of the different sampling points. Prior to analysis in the **Environmental Chemistry Laboratory of the Instituto Tecnológico Superior de Centla [ITSCE]**, the samples were kept under refrigeration to maintain their integrity.

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Box 4



Figure 3

Collection and transportation of samples in the field

f) Laboratory Analysis of the Samples

The analysis was conducted in the Environmental Chemistry Laboratory of the Instituto Tecnológico Superior de Centla [ITSCE], using a HACH DR6000 spectrophotometer to determine chromium concentrations in parts per million [ppm]. Additionally, the following physicochemical parameters were measured: **pH, conductivity, and total suspended solids**, as these factors can influence the presence and behavior of the heavy metal chromium in water.

Equipment Procedure

1. To operate in the laboratory, Personal Protective Equipment [PPE] was used, including a lab coat, face mask, gloves, respirator, and safety goggles.
2. The DR6000 spectrophotometer was inspected to ensure it was in perfect working condition.
3. Two 100 mL beakers and distilled water were used.
4. The DR6000 spectrophotometer was calibrated by adding only distilled water into a cuvette.
5. The first water sample was analyzed by placing 25 mL of the water sample and three packets of hexavalent chromium reagent into the cuvette. The cuvette was then inserted into the DR6000 spectrophotometer, and the measurement button on the device's screen was pressed.
6. After obtaining the reading, the cuvette was removed from the spectrophotometer and rinsed with distilled water. The same procedure was then repeated for the remaining samples to obtain the chromium concentration readings for each one.

Results

Based on the work carried out, the results show the **chromium concentration levels** obtained during the months of **March, April, and May 2024**.

	March	April	May
Sampling	Chrome Mg/l	Chrome Mg/l	Chrome Mg/l
1	0.155	0.02	0.008
2	0.174	-0.015	0.009
3	0.179	-0.002	-0.08
4	0.22	-0.006	-0.005
5	0.295	-0.84	-0.004
6	0.109	-0.002	-0.008
7	0.261	-0.005	0.026
8	0.186	-0.014	0.011
9	0.308	-0.022	0.014
10	0.263	0.008	-0.013

Box 5

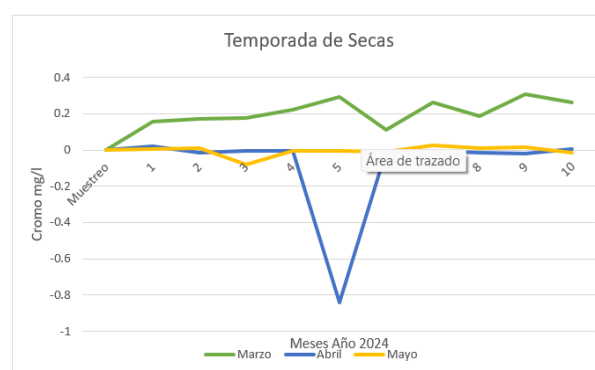


Figure 4

Behavior of hexavalent chromium in San Pedro during the dry season

Based on the data obtained during the dry season, the mean value, as well as the highest and lowest concentrations, were determined.

According to the National Institute of Ecology and Climate Change [INECC, 2022], the dry season corresponds to the months of **April and May**; therefore, **March** was also included, as it is the month closest to this period.

From the data obtained during the dry season, the mean concentration for each month was calculated to determine the central tendency of the results. The mean value for **March** was **0.215 mg/L of chromium**, for **April** it was **-0.0878 mg/L of chromium**, and for **May** it was **-0.00423 mg/L of chromium**. The highest value recorded was **0.308 mg/L of chromium**, corresponding to **sample 9 in March**, while the lowest value was **-0.002 mg/L of chromium**, corresponding to **samples 3 and 6 in April**.

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Therefore, the results represent variable measurements, as the samples differ from one another; however, all concentrations remain **below the Maximum Permissible Limits established by the corresponding environmental standards**

Based on the work carried out, the results obtained show the chromium concentration levels during the months of September, October, and November of 2024.

	September	October	November
Sampling	Chrome Mg/l	Chrome Mg/l	Chrome Mg/l
1	0.181	0.264	0.278
2	0.162	0.3	0.302
3	0.121	0.369	0.402
4	0.154	0.264	0.127
5	0.069	0.304	0.137
6	0.114	0.263	0.184
7	0.132	0.288	0.28
8	0.132	0.241	0.293
9	0.168	0.22	0.267
10	0.152	0.249	0.143

Box 6

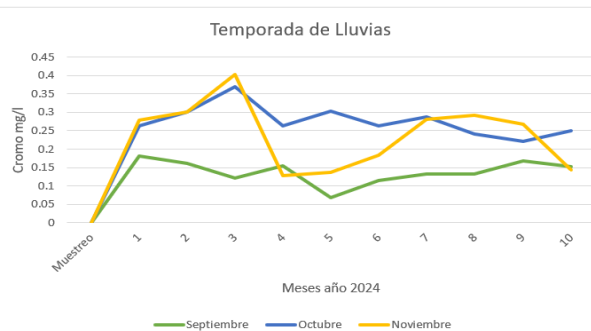


Figure 5

Behavior of hexavalent chromium in San Pedro during the rainy season.

Based on the data obtained during the rainy season, the mean value, as well as the highest and lowest concentrations, were determined.

According to the National Institute of Ecology and Climate Change [INECC, 2022], the rainy season extends from June to November; therefore, only the months of September, October, and November were selected, as they are the rainiest. Based on the data obtained during the rainy season, the mean concentration for each month was calculated to determine the central tendency of the results. The mean value for September was 0.1385 mg/L of chromium, for October it was 0.2762 mg/L of chromium, and for November it was 0.2413 mg/L of chromium.

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The highest concentration recorded was 0.402 mg/L of chromium, corresponding to sample 3 from November, while the lowest concentration was 0.069 mg/L of chromium, corresponding to sample 5 from September.

Therefore, the results represent variable measurements, as the samples differ from one another; however, all concentrations remain below the Maximum Permissible Limits established by the environmental standards.

Comparison of Results

Box 7

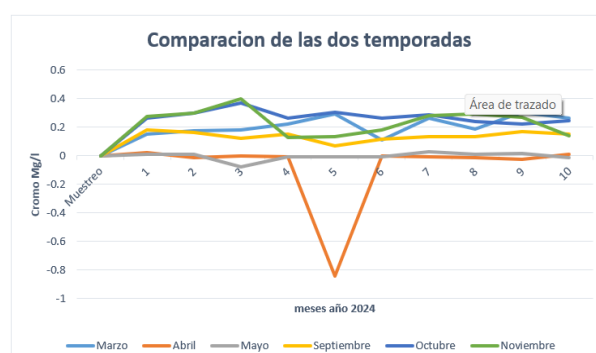


Figure 6

Comparison of hexavalent chromium behavior in San Pedro during the dry and rainy seasons

When comparing the two seasons, it can be observed that the data are highly variable, as no value is identical to another. The highest concentration was recorded during the rainy season with 0.402 mg/L of chromium in November, while the lowest concentration occurred during the dry season with 0.069 mg/L of chromium in April.

Box 8

Table 1

Comparison of data with the Maximum Permissible Limits established by the Standard

Parameter	Mean Chromium [mg/L]	Highest Value Chromium [mg/L]	Lowest Value Chromium [mg/L]	MPL Standard Chromium [mg/L]
March	0.215	0.308	0.109	1.0
April	-0.0878	0.020	-0.022	1.0
May	-0.0042	0.026	-0.013	1.0
September	0.1385	0.181	0.069	1.0
October	0.2762	0.369	0.220	1.0
November	0.2413	0.402	0.127	1.0

The data for each month were compared based on their mean, highest, and lowest values, in relation to the Maximum Permissible Limits [MPL] established by the NOM-001-SEMARNAT-1996 standard.

Comparison of Results with Other Authors

According to the Environmental Protection Agency [EPA, 2024], hexavalent chromium refers to chemical compounds containing the element chromium in its +6 oxidation state. Practically all chromium ore is processed through compounds of hexavalent chromium, particularly sodium dichromate. Other common hexavalent chromium compounds include chromium trioxide and various chromate and dichromate salts.

In their comparative analysis between rainy and dry seasons, the authors found similar seasonal patterns. When comparing the results from the rainy season sampling with the legal framework, it was determined that the water collected during the rainy season did not contain mercury or hexavalent chromium levels exceeding those permitted by regulation. In contrast, other studies have reported cases where industrial effluents showed elevated concentrations above the legal threshold.

Medina [2013] discusses the determination of hexavalent chromium in wastewater discharges from a tannery, in which a total of 16 samples were analyzed over a four-month period [May to August 2009] — corresponding to the time of highest annual production. For quantification, chromium [VI] was extracted following the EPA [2024] method, as stated in the Unified Text of Secondary Environmental Legislation of the Ministry of the Environment [TULSMA, 2015], which corresponds to the environmental quality standard for effluent discharges.

This standard establishes that the maximum permissible limit is 0.5 mg/L for chromium [vi].

Discussion

As a result, it was found that the dry season presented lower concentrations of the heavy metal hexavalent chromium compared to the rainy season, since the highest chromium concentration during the dry season was 0.308 mg/L, while during the rainy season it reached 0.402 mg/L. However, according to the Maximum Permissible Limits [MPL] established by the NOM-001-SEMARNAT-1996, the concentrations did not exceed the regulatory limits in either season.

When comparing our findings with those of Medina [2013] and the EPA [2024], it is evident that the methodological approaches used by these authors are similar to ours. Their studies provide relevant information on the determination of hexavalent chromium concentrations in surface water bodies and their comparison with environmental standards. In this sense, such comparisons allow us to determine whether the chromium concentration exceeds or remains below the maximum permissible limit established by the regulations.

Conclusion and Recommendations

- The sampling and laboratory analyses were successfully carried out.
- In the sampling area, the main local activity is fishing.
- Based on the results obtained and according to the standards NOM-001-SEMARNAT-1996, NOM-014-SSA1-1993, and NOM-230-SSA1-2002, the concentrations did not exceed the Maximum Permissible Limits.

In this population, the hexavalent chromium concentrations obtained and analyzed never exceeded the established regulatory limits. Therefore, it can be concluded that the water quality remains within acceptable parameters for human consumption, agriculture, fishing, and other daily activities, ensuring safe and high-quality water while protecting the health and well-being of the community.

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Vapor cloud explosion [Vce] model, using the TNT equivalent method, to determine impact zones due to overpressure in a natural gas pipeline




Modelo de explosión de nube de vapor [VCE], por método TNT equivalente, para determinar zonas de impacto por sobrepresión en gasoducto con gas natural

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Abstract

This article presents the modeling of a vapor cloud explosion [VCE] in the “Mexi-Gas” pipeline located in the municipality of Ecatepec, State of Mexico, using the equivalent TNT method to determine overpressure impact zones. The study is based on a hypothetical event in which a corrosion failure in the pipeline causes a leak, resulting in an unconfined explosion. Energy equivalence equations between methane and TNT were applied to calculate the equivalent mass, overpressure, and affected radii. The results indicate different zones: lethality at 35.2 m [8.0 psi], risk at 145 m [1.0 psi], and attenuation at 247.5 m [0.5 psi]. It is concluded that the model is an effective tool for identifying chemical-technological risks, allowing the establishment of mitigation strategies, emergency plans, and preventive measures in urban environments with critical gas transportation infrastructure.

Resumen

Este artículo presenta la modelación de la explosión de nube de vapor [VCE], en gasoducto “Mexi-Gas” en el municipio de Ecatepec Estado de México, utilizando el método TNT equivalente, con la finalidad de determinar zonas de impacto por sobrepresión. La investigación se basa en un evento hipotético, donde una falla por corrosión en el ducto genera una fuga originando una explosión no confinada. Se aplicaron ecuaciones de equivalencia energética entre el metano y el TNT para calcular la masa equivalente, la sobrepresión y los radios de afectación. Los resultados indican diferentes zonas: letalidad de 35.2 m [8.0 psi], riesgo de 145 m [1.0 psi] y amortiguamiento de 247.5 m [0.5 psi]. Se concluye que el modelo es una herramienta eficaz para la identificación de riesgos químico-tecnológicos, permitiendo establecer estrategias de mitigación, planes de emergencia y medidas preventivas en entornos urbanos con infraestructura crítica de transporte de gas.

Vapor Cloud Explosion [VCE] model, using the TNT Equivalent method, to determine impact zones due to overpressure in a natural gas pipeline		
Objectives	Methodology	Contribution
The main objective of this work was to model the vapor cloud explosion [VCE] in the gas pipeline named “Mexi-Gas,” located in the municipality of Ecatepec, State of Mexico, using the TNT Equivalent method in order to determine overpressure impact zones.	The methodology used is based on the application of the TNT Equivalent model. However, to carry out this methodology, the study area was identified, the hypothetical event was defined, and subsequently, the hypothetical scenario was established. In the latter, the explosive vapor cloud [VCE] to be studied is generated. Then, the physical parameters of the substance are defined, and with this information, the mathematical modeling is performed to determine the overpressure impact zones.	The results obtained in this article make it possible to delineate overpressure impact zones—areas of lethality, risk, and attenuation, respectively—and to establish mitigation strategies for potential explosion scenarios, supporting decision-making in civil protection, risk management, environmental impact, and urban design.

VCE Model, TNT Method, overpressure

Modelo de Explosión de Nube de Vapor [VCE], por método TNT Equivalente, para determinar zonas de impacto por sobrepresión en gasoducto con gas natural		
Objetivos	Metodología	Contribución
El objetivo principal del presente trabajo fue modelar la explosión de nube de vapor [VCE], en gasoducto con nombre “Mexi-Gas” en el municipio de Ecatepec, Estado de México, utilizando el método TNT Equivalente, con la finalidad de determinar zonas de impacto por sobrepresión.	La metodología utilizada se basa en la aplicación del modelo TNT Equivalente, sin embargo, para poder llevar a cabo dicha metodología, se identificó el área de estudio, se definió el evento hipotético y posteriormente el escenario hipotético, en este último, se genera la nube de vapor explosiva [VCE] a estudiar, después se definen los parámetros físicos de la sustancia, y con esta información se procede a realizar la modelación matemática, para determinar las zonas de impacto por sobrepresión.	Los resultados obtenidos en el presente artículo permiten delimitar zonas de impacto por sobrepresión; áreas de letalidad, de riesgo y de amortiguamiento, respectivamente, y poder establecer estrategias de mitigación ante escenarios potenciales de explosión, apoyando la toma de decisiones en materia de protección civil, gestión de riesgos, impacto ambiental y diseño urbano.

Modelo VCE, método TNT, sobrepresión

Area: Promotion of frontier research and basic science in all fields of knowledge.

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Introduction

Natural gas is primarily a mixture of light hydrocarbons, with methane [CH₄] being the dominant component, typically representing between 70% and 90% of its volume. Likewise, natural gas is defined as a mixture composed of seven pure substances: methane [CH₄], ethane [C₂H₆], propane [C₃H₈], carbon dioxide [CO₂], nitrogen [N₂], hydrogen [H₂], carbon monoxide [CO], and alkanes [C_nH_{2n+2}] [Ying et al., 2019].

The world is witnessing a continuous and growing need for energy sources of all kinds, and natural gas is a major fossil fuel source compared to other alternatives [Al-Abadi, 2024, 2024].

As a clean, efficient, and high-quality energy source, liquefied natural gas [LNG] is widely used in numerous areas, including daily life and industrial production [Wang et al., 2018]

Pipeline transportation is considered a safe and economical means of transporting gas. However, the safe operation of pipelines is threatened by various factors, such as the potentially corrosive characteristics of the transported medium [natural gas may contain hydrogen sulfide, carbon dioxide, free water, dust, and other corrosive substances]; geological, meteorological, and hydrological disasters; defects in pipes and design; operational errors; and damage caused by humans [Luo et al., 2020].

Accidents caused by gas pipeline ruptures represent a significant threat to urban public safety. Due to the physical and chemical characteristics of natural gas and the complexity of the gas pipeline network topology, accidents occurring in gas pipelines differ greatly from other industrial accidents [Weng & Hand, 2011].

It is worth mentioning that, in cities and urban areas, the risks associated with natural gas transportation through pipelines are greater compared to rural areas, due to the difference in population density between the two.

In the case of pipelines, probabilistic assessment focuses on analyzing the likelihood of leaks occurring, while consequence analysis studies the potential outcomes of fires, explosions, and other disasters caused by leaks [Chen et al., 2024].

When a pipeline fails, leading to the release and dispersion of natural gas in unconfined spaces, a fire or explosion can occur if the flammable natural gas cloud encounters potential ignition sources, resulting in the release of energy in the form of heat or overpressure [blast wave].

One of the most devastating and destructive events that can occur at an oil and gas facility is a vapor cloud explosion [VCE]. This explosion occurs due to the ignition of a flammable cloud [Sajid et al., 2021].

Unconfined vapor clouds are generated because of the release of a certain amount of combustible vapor, or from a liquid that will form the vapor; this can occur at a processing plant, during transportation, or due to the rupture of a gas pipeline [Casal et al., 1999].

If this cloud ignites before it dilutes below its lower flammability limit [LFL], a vapor cloud explosion [VCE] or a flash fire will occur [AIChE/CCPS, 2000].

The flame speed in a vapor cloud explosion [VCE] is very high, generating considerable overpressure. Consequently, this overpressure causes significant damage to people, buildings, and properties near the explosion. Additionally, due to its considerable adverse impact, a VCE can trigger a domino effect [Sajid et al., 2021].

The standard method for assessing vapor cloud explosions involves using explosion curve correlation models. These are "simple" models such as Baker-Strehlow-Tang [BST], Congestion Assessment Method [CAM], and the TNO multi-energy model, among others. Explosion curve models predict overpressure and impulse impacts based on the distance from the explosion center. This data is used to define the maximum lateral overpressure and corresponding impulse that a building may experience in a given scenario [Marx, & Werts, 2012].

Background

Globally, natural gas has become an important energy source due to the abundance of reserves and environmental factors, as it emits less carbon dioxide than oil.

To carry out the distribution of natural gas, it is transported through pipelines. In Mexico, the National Pipeline System [Sistema Nacional de Gasoductos, SNG] has a length of 8,610.797 km, crossing various states of the country. The system consists of pipelines ranging from 4" to 48" in diameter, 9 compression stations with a total installed power of 256,400 HP, as well as 359 sectionalizing valves, 142 pig launchers, 141 pig receivers, and 121 Regulation and Measurement Stations [ERM] that distribute natural gas to different users [SNG, 2025].

The safe transportation of natural gas through transmission pipelines is crucial; however, these pipelines frequently experience accidents due to various factors, resulting in significant economic losses, energy waste, and even fatalities [Ma et al., 2023].

Leaks in pipelines can cause fires, gas poisoning, or explosions, resulting in numerous injuries and property damage.

Explosion effect models predict the impact of overpressure waves as well as projectiles on people and structures. When simulating overpressure risk scenarios, the high-risk zone, the intermediate safeguard zone, and the buffer zone must be determined [CGPC, 2018].

Likewise, this document determines the simulation of a possible explosion risk resulting from a corrosion failure in the Mexi-Gas pipeline, which transports natural gas. This simulation is considered in an urban area of the municipality of Ecatepec, State of Mexico, through which the pipeline passes.

The purpose of this simulation is to model an unconfined explosion based on a hypothetical scenario and, using the Vapor Cloud Explosion model with the TNT Equivalent method, to determine the possible impact zones caused by the pressure wave.

It is worth mentioning that these zones and their respective overpressure parameters are defined based on the Civil Protection Technical Standard NTE-002-CGPC-2018. The mentioned zones correspond to determining the radii for the lethality zone [8.0 psi], risk zone [1.0 psi], and buffer zone [0.5 psi].

Methodology

To carry out the present VCE model using the TNT Equivalent method and identify overpressure impact zones in a natural gas pipeline, the following procedure has been established:

- Identify the study area
- Define the hypothetical event
- Define the hypothetical scenario
- Define the physical parameters of the substance to be analyzed
- Apply the VCE mathematical model using the TNT Equivalent method
- Analyze the results of the VCE model using the TNT Equivalent method

Study Area

The study area for the present modeling is located in the municipality of Ecatepec, State of Mexico. The georeference of the failure to be analyzed is at the coordinates 19°33'25.76" N latitude and 99°2'36.19" W longitude. See Figure 1. The average temperature considered is 14.55 °C, and the average annual atmospheric pressure is 771.813361 mm Hg.

Box 1



Figure 1

Study Area: Mexi-Gas Pipeline Failure, Ecatepec, State of Mexico.

Source: Own elaboration

Hypothetical Event 1

Natural gas leak due to corrosion failure in the Mexi-Gas pipeline, which passes through the municipality of Ecatepec, State of Mexico. The pipeline has a diameter of 10" [254 mm].

It is considered that the corrosion failure creates an approximate hole of 25 mm in diameter through which the substance escapes.

Considering that the leak lasts for 20 minutes, the equivalent mass of the fluid corresponds to 1,472.94016 kg.

Hypothetical Scenario 1

As a result of this leak, it is considered that, as the gas cloud disperses, it reaches its lower flammability limit [LFL], encounters an ignition source, and generates a vapor cloud explosion [VCE].

Physical Parameters of the Substance

Since methane [CH₄] is the main substance in the chemical composition of natural gas, the physical parameters of this substance have been considered for the purposes of this modeling, which are as follows:

- Heat of combustion = 53.6 MJ/kg
- Empirical explosion efficiency = 0.03 [dimensionless]
- Heat of combustion of TNT = 4500 kJ/kg
- Mass [released in 20 minutes] = 1472.94016 kg

Mathematical Model of VCE Using the TNT Equivalent Method

The TNT equivalent model is based on the assumption of equivalence between the flammable material and TNT, scaled by an explosion efficiency factor [AIChE/CCPS, 2000]:

$$W = \frac{\eta M E_c}{E_{TNT}} \quad [1]$$

where:

- W is the equivalent mass in TNT [kg or lb]
- η is an empirical explosion efficiency [dimensionless]
- M is the mass of the hydrocarbon [kg or lb]
- E_c is the heat of combustion of the flammable gas [kJ/kg or Btu/lb]
- E_{TNT} es el calor de la combustión de TNT is the heat of combustion of TNT [4437–4765 kJ/kg or 1943–2049 Btu/lb]

To calculate the overpressure, the important parameters are: peak overpressure or maximum overpressure p^0 , arrival time t_a , positive phase duration time t_d , and overpressure impulse i_p , which is defined as the area under the positive phase pulse [Ayala, 2015].

Impulse is an important aspect of the damage-causing capability of explosion structures, as it indicates the total energy contained within the blast wave. The above parameters can be scaled using the following equations [AIChE/CCPS, 2000]:

$$p_s = \frac{p^0}{W^{\frac{1}{3}}} \quad [2]$$

$$i_s = \frac{i_p}{W^{\frac{1}{3}}} \quad [3]$$

$$\tau_d = \frac{t_d}{W^{\frac{1}{3}}} \quad [4]$$

$$\tau_a = \frac{t_a}{W^{\frac{1}{3}}} \quad [5]$$

The explosion effects for a TNT charge are well documented, and the data used in the equation are shown in Figure 2 and Figure 3, respectively. Various explosion parameters are correlated as a function of the scaled distance Z . The scaled distance is defined as the distance R , divided by the cube root of the TNT mass [kg] [Ayala, 2015]:

$$Z = \frac{R}{W^{\frac{1}{3}}} \quad [6]$$

It is worth mentioning that the scaled distance R , is the distance to the receptor from the point of explosion origin. The functions are tabulated using the following functional form:

$$\log_{10} \phi = \sum_{i=0}^n c_i [a + b \log_{10} Z]^i \quad [7]$$

where:

- ϕ is the function of interest
- c_i , a , and b are constants given in Figure 2 and Figure 3, respectively
- Z is the scaled distance

Box 2

C o n s t	R a n g o	Función			
		Sobrepresión p ^o (kPa)	Impulso i _p (Pa s)	Tiempo de duración t _d (ms)	Tiempo de llegada t _e (ms)
	1 2 3	0.0674 ≤ Z ≤ 40	0.0674 ≤ Z ≤ 0.955 0.955 ≤ Z ≤ 40	0.178 ≤ Z ≤ 1.01 1.01 ≤ Z ≤ 2.78 2.78 ≤ Z ≤ 40	0.0674 ≤ Z ≤ 40
a	1 2 3	-0.214362789151	2.06761908721 -1.94708846747	1.92946154068 -2.12492525216 -3.53626218091	-0.20242571617800
b	1 2 3	1.3503424999300	3.0760329666 2.40697745406	5.25099193925 9.2996288611 3.46349745571	1.37784223635000
c0	1 2 3	2.7806916577000	2.52455620925 1.67281645863	-0.61422760359 0.315409245784 0.686906642409	-0.05916342880460
c1	1 2 3	-1.6958988741000	-0.502992763686 -0.0384519026965	0.130143717675 -0.0297944268976 0.0933035304009	1.35706496258000
c2	1 2 3	-0.0154159376846	0.171335645235 -0.0260816706301	0.134872511954 0.030632955288 -0.0005849420883	0.05249279864500
c3	1 2 3	0.5140607305930	0.0450176963051 0.0059579875382	0.0391574276906 0.0183405574086 -0.00226884995013	-0.19656395408600
c4	1 2 3	0.09885543652740	-0.01118964626402 0.014544526107	-0.00475933664702 -0.0173964666211 -0.00295908591505	-0.06017700522880
c5	1 2 3	-0.29391262303800	-0.06632893347340	-0.00428144598008 -0.00106321963633 0.00148029868929	0.06963602708910
c6	1 2 3	-0.02681123450190	-0.00284189327204	0.005620600309770	0.02152974900920

Figure 2

Table: Data for TNT Equivalence

Source: [Sergio Garza, 2015]

In the following Figure 3, the continuation of Table 2: Data for TNT Equivalence is shown.

Box 3

C o n s t	R a n g o	Función			
		Sobrepresión p ^o (kPa)	Impulso i _p (Pa s)	Tiempo de duración t _d (ms)	Tiempo de llegada t _e (ms)
c7	1 2 3	0.10303949642100	0.00136448162270	0.00016182174990	-0.01616589307850
c8	1 2 3	0.00162846756311		-0.00068601889440	-0.00232531970294
c9	1 2 3	-0.02146310302420			0.00147752067524
c10	1 2 3	0.00014567233820			
c11	1 2 3	0.00167847752266			

Figure 3

Table 4.7 Data for TNT Equivalency [continued]

Note: The number of significant figures is a function of the curve-fitting method only and is not indicative of the accuracy of the method [Table taken from Lees, 1996].

Source: [Ayala, 2015]

Results

To determine the impact radii [scaled distances R], the lethality zone was defined with an overpressure threshold of 8.0 psi, the risk zone with a threshold of 1.0 psi, and the buffer zone with a threshold of 0.5 psi, respectively.

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It is worth mentioning that these zones and overpressure thresholds are based on the Technical Civil Protection Standard NTE-002-CGPC-2018.

Lethality zone [8.0 psi]

To determine the scaled distance R based on the lethality zone corresponding to an overpressure of 8.0 psi, the results from the Vapor Cloud Explosion mathematical model are presented in Table 1.

Box 4

Table 1

Lethality zone: 8.0 psi

Vapor Cloud Explosion [VCE] Model
Method used: Equivalent TNT method
RESULTS
Scaled distance [R] = 35.2 m
Parameter Formula Result

Scaled distance	$Z = \frac{R}{W^{1/3}}$	Z= 4.359698459 m/kg^{1/3}
------------------------	-------------------------	--

Only valid for:
0.0674 ≤ Z ≤ 40

Overpressure Calculation [p^o]	$\log_{10} p^o = \sum_{i=0}^n c_i [a + b \log_{10} Z]^i$	p^o= 55.22299096 kPa p^o = 8.00 psi
---	--	--

Only valid for:
0.955 ≤ Z ≤ 40

Specific impulse [i_p]	$\log_{10} i_p = \sum_{i=0}^n c_i [a + b \log_{10} Z]^i$	i_p= 66.89461437 Pa-s
---	--	--

Only valid for:
2.78 ≤ Z ≤ 40

Duration time [t_a]	$\log_{10} t_a = \sum_{i=0}^n c_i [a + b \log_{10} Z]^i$	t_a= 3.571323232 Pa-s
--------------------------------------	--	--

Únicamente válido para:
0.955 ≤ Z ≤ 40

Arrival time [t_a]	$\log_{10} t_a = \sum_{i=0}^n c_i [a + b \log_{10} Z]^i$	t_a= 6.6492354 m*s
-------------------------------------	--	-------------------------------------

a) Risk Zone: 1.0 psi

To determine the scaled distance R based on the risk zone corresponding to an overpressure of 1.0 psi, Table 2 shows the results corresponding to the VCE mathematical model.

Box 5

Table 2

Lethality zone: 1.0 psi		
RESULTS		
Vapor Cloud Explosion [VCE] Model		
Method used: Equivalent TNT method		
Scaled distance [R] =		145 m
Parameter	Formula	Result
Scaled distance	$Z = \frac{R}{W^{1/3}}$	Z 17.95898513 m/kg ^{1/3}
Only valid for: 0.0674 ≤ Z ≤ 40		
Overpressure Calculation [p°]	$\log_{10} p^0 = \sum_{i=0}^n c_i [a + b \log_{10} Z]^i$	p°= 6.941877743 kPa p° = 1.00 psi
Only valid for: 0.955 ≤ Z ≤ 40		
Specific impulse [i _p]	$\log_{10} i_p = \sum_{i=0}^n c_i [a + b \log_{10} Z]^i$	i _p = 160872986 Pa-s
Only valid for: 2.78 ≤ Z ≤ 40		
Duration time [t _d]	$\log_{10} t_d = \sum_{i=0}^n c_i [a + b \log_{10} Z]^i$	t _d = 5.753877168 Pa-s
Únicamente válido para: 0.955 ≤ Z ≤ 40		
Arrival time [t _a]	$\log_{10} t_a = \sum_{i=0}^n c_i [a + b \log_{10} Z]^i$	t _a = 4400123234 m*s

Source: Own elaboration

b) Buffer Zone: 0.5 psi

To determine the scaled distance R based on the risk zone corresponding to an overpressure of 0.5 psi, Table 3 shows the results corresponding to the VCE mathematical model.

Box 6

Table 3

Zona de letalidad: 0.5 psi		
RESULTS		
Vapor Cloud Explosion [VCE] Model		
Method used: Equivalent TNT method		
Scaled distance [R] =		247.5 m
Parameter	Formula	Result
Scaled distance	$Z = \frac{R}{W^{1/3}}$	Z= 30.65412979 m/kg ^{1/3}
Only valid for: 0.0674 ≤ Z ≤ 40		
Overpressure Calculation [p°]	$\log_{10} p^0 = \sum_{i=0}^n c_i [a + b \log_{10} Z]^i$	p°= 3.453168788 kPa p° = 0.500 psi
Only valid for: 0.955 ≤ Z ≤ 40		
Specific impulse [i _p]	$\log_{10} i_p = \sum_{i=0}^n c_i [a + b \log_{10} Z]^i$	i _p = 10.39823763 Pa-s
Only valid for: 2.78 ≤ Z ≤ 40		
Duration time [t _d]	$\log_{10} t_d = \sum_{i=0}^n c_i [a + b \log_{10} Z]^i$	t _d = 6.644066179 Pa-s
Only valid for: 0.955 ≤ Z ≤ 40		
Arrival time [t _a]	$\log_{10} t_a = \sum_{i=0}^n c_i [a + b \log_{10} Z]^i$	t _a = 8079347645 m*s

Source: Own elaboration

c) Summary of risk zones by overpressure

It is worth mentioning that the VCE model, using the Equivalent TNT method, also provides other parameters, such as the arrival time t_a and the duration time of the positive phase t_d . Table 4 below presents the technical risk summary, considering only the determination of zones affected by overpressure. These zones are determined based on the scaled distance R.

Box 7

Table 4

Risk zones due to overpressure

Explosives, Overpressure [psi]	Lethality Zone [m]	Risk Zone [m]	Buffer Zone [m]
8.0	35.2		
1.0		145	
0.5			247.5

Source: Own elaboration

Based on the overpressure results obtained for the lethality zone [8.0 psi], risk zone [1.0 psi], and buffer zone [0.5 psi], respectively, Figure 4 below shows the relationship of the overpressure values of these zones with respect to the scaled distance or impact radii.

Box 8

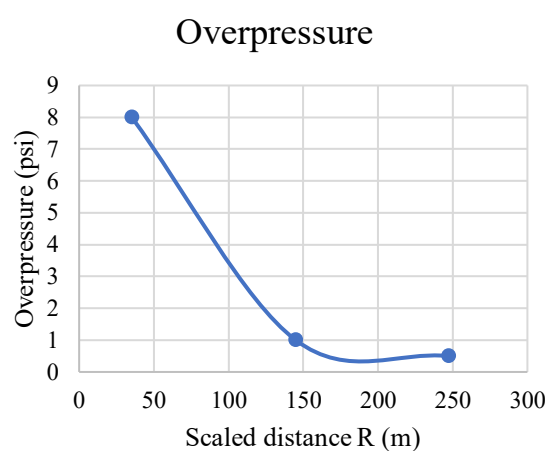


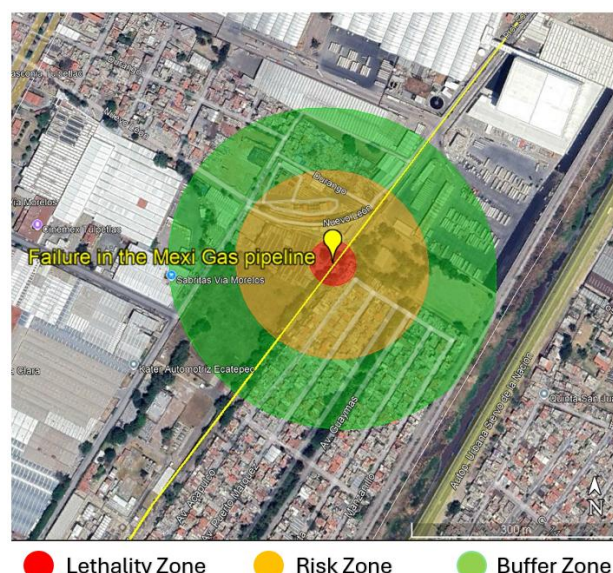
Figure 4

Relationship of overpressure by VCE with respect to the affected distance

Source: Own elaboration

Likewise, in the following Figure 5, the georeferenced risk zones due to overpressure at the study site are shown, delimiting the zones or radii of possible impact using colors.

Box 9



● Lethality Zone ● Risk Zone ● Buffer Zone

Figure 5

Overpressure risk zones in a georeferenced manner

Source: Own elaboration

It is worth mentioning that, as part of the present analysis, a chain projection is carried out, considering a radius of 500 m from the origin of the failure, in order to identify possible risk zones in case of a domino effect along the pipeline under study. This can be seen in Figure 6.

Box 10

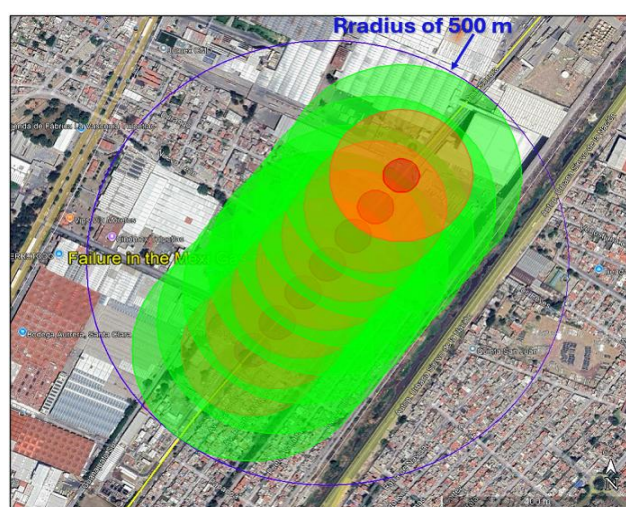


Figure 6

Risk zones due to possible domino effect in the pipeline

Source: Own elaboration

On the other hand, the considered overpressure values [8.0 psi, 1.0 psi, and 0.5 psi] indicate possible structural damage based on the determined impact radii. Table 5 shows the estimation of potential damage based on overpressure; it is worth mentioning that these values should only be used as approximate estimates.

Torres-Valle, José Bernardo, Sánchez-Carmona, Fernando, Hernández-Borja, Carlos and García-Trinidad, Enrique. [2025]. Vapor cloud explosion [Vce] model, using the TNT equivalent method, to determine impact zones due to overpressure in a natural gas pipeline. ECORFAN Journal Republic of Nicaragua. 11[19]1-9: e61119109.

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Box 11**Table 5**

Estimation of structural damage based on overpressure

Pressure		Damage
psig	kPa	
0.5 - 1.0	3.4 - 6.9	Large and small windows usually shattered; occasional damage to window frames.
1.0	6.9	Partial demolition of houses. made uninhabitable.
7 - 8	48.2 - 55.1	Brick panels, 8-12 inches thick, not reinforced, fail by shearing or flexure.

Recurso: AIChE/CCPS, 2000

Conclusions

Based on the development of the present research and the results obtained, the following conclusions are drawn:

- The VCE mathematical model, based on the Equivalent TNT method, proved to be an effective tool for estimating impact zones due to overpressure in hypothetical pipeline failure events—specifically due to corrosion—providing results consistent with the current civil protection standard NTE-002-CGPC-2018 of the State of Mexico.
- The simulation carried out for the Mexi-Gas pipeline in Ecatepec, State of Mexico, showed that a sustained natural gas leak lasting 20 minutes could generate significant impact zones: lethality zone [8.0 psi] up to 35.2 m, risk zone [1.0 psi] up to 145 m, and buffer zone [0.5 psi] up to 247.5 m, highlighting the vulnerability of densely populated urban areas.
- The use of the Equivalent TNT model allows for accurate quantification of the energy released in the form of a blast wave in the event of gas cloud ignition, translating this energy into a TNT charge to facilitate the calculation of parameters such as overpressure, specific impulse, and the arrival and duration times of the explosive event.

- The results obtained make it possible to delineate lethality, risk, and buffer zones, respectively, and to establish mitigation strategies for potential explosion scenarios, supporting decision-making in civil protection, risk management, environmental impact, and urban planning.
- The georeferencing of impact zones and the projection of domino effect scenarios along the pipeline highlight the importance of having predictive and preventive studies, as well as emergency response plans—particularly in urban areas, as in the present case study involving critical natural gas transportation infrastructure.
- Overall, this model contributes to strengthening industrial and urban safety and can be integrated into vulnerability and risk analysis studies, emergency plans, and public policies aimed at preventing disasters caused by chemical-technological disruptive events.

Declarations**Conflict of interest**

The authors declare no conflicts of interest. They have no known financial interests or personal relationships that could have influenced the work presented in this article.

Authors' Contribution

Torres-Valle, José Bernardo: Contributed to the project idea and research method. Assisted in the development of the VCE modeling using the Equivalent TNT method. Performed data and results analysis, as well as the writing of the article.

Sánchez-Carmona, Fernando: Assisted in the development of the introduction, background, and preparation of the maps. Also contributed to the review of the article.

Hernández-Borja, Carlos: Assisted in the development of the VCE modeling using the Equivalent TNT method, results analysis, and translation of the document.

García-Trinidad, Enrique: Assisted in the development of the VCE modeling using the Equivalent TNT method, results analysis, and translation of the document.

Availability of Data and Materials

Satellite images to determine the study area, impact zones or radii, and possible domino effect were obtained from the free platform Google Earth Pro. It is worth mentioning that for the satellite image of the possible domino effect, AutoCAD 2024 Student Version software was also used.

Abreviaturas

VCE	Vapor Cloud Explosion
TNT	Trinitrotoluene
GNL	Liquefied Natural Gas
LFL	Lower Flammability Limit
CAM	Congestion Assessment Method
TNO	Multi-energy Model
SNG	National Pipeline System
ERM	Regulation and Measurement Station
NTE	State Technical Standard
CGPC	General Coordination of Civil Protection
Psi	Pounds per square inch

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Effect of nitrogen plasma on the mechanical and surface properties of a biopolymer





Efecto de un plasma de nitrógeno en propiedades mecánicas y de superficie de un biopolímero

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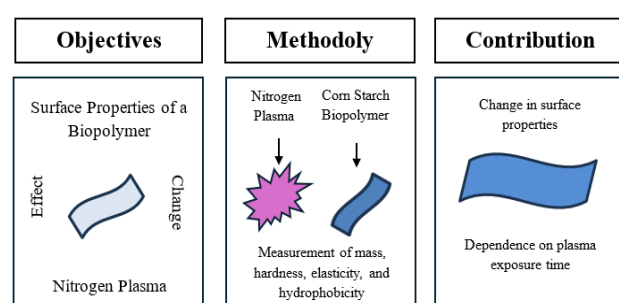


Abstract

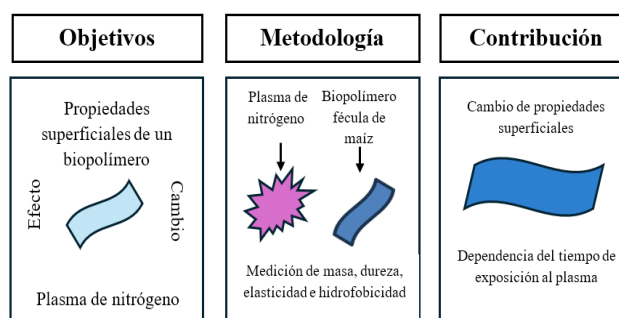
Samples of a corn starch-based biopolymer subjected to low-pressure nitrogen plasma were studied to analyze treatment-induced surface changes. The samples measured 2.8 cm × 1.0 cm × 0.05 cm. Twelve samples were evaluated: one control and five samples with different exposure times, each with two replicates. Mass, contact angle, hardness, and elasticity were measured before and after treatment. The plasma was generated in a vacuum chamber with a high-voltage source [5000 V, 50 mA] and nitrogen at 5.0 Torr. Exposure times were 0.5, 1.0, 2.5, 3.0, and 4.0 minutes. The results show mass loss, increased hardness, variations in Young's modulus, and changes in hydrophobicity. In summary, the nitrogen plasma modifies the polymer surface through simultaneous degradation and crosslinking. The exposure time determines the equilibrium between these mechanisms and, therefore, the final properties of the material.

Resumen

Se estudiaron muestras de un biopolímero a base de fécula de maíz sometidas a plasma de nitrógeno a baja presión para analizar cambios superficiales inducidos por el tratamiento. Las muestras midieron 2.8 cm × 1.0 cm × 0.05 cm. Se evaluaron 12 muestras: una de control y cinco para diferentes tiempos de exposición, con dos repeticiones. Antes y después se midieron masa, ángulo de contacto, dureza y elasticidad. El plasma se generó en una cámara de vacío con una fuente de alto voltaje [5000 V, 50 mA] y nitrógeno a 5.0 Torr. Los tiempos de exposición fueron 0.5, 1.0, 2.5, 3.0 y 4.0 minutos. Los resultados muestran pérdida de masa, aumento de dureza, variaciones del módulo de Young y cambios de hidrofobicidad. En síntesis, el plasma de nitrógeno modifica la superficie del polímero por degradación y reticulación simultáneas. El tiempo de exposición determina el equilibrio entre estos mecanismos y, por tanto, las propiedades finales del material.



Ablation, hydrophobicity, mass loss



Ablación, hidrofobicidad, pérdida de masa

Area: Promotion of frontier research and basic science in all fields of knowledge.

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Introduction

Plastics are now indispensable in modern society. Most plastics come from fossil fuels. Their versatility and durability attract many industries, including packaging, construction, electronics, and medicine [Leal et al., 2025]. However, plastic waste causes serious environmental and health problems worldwide. Micro- and nanoplastics add to these issues [Cheng et al., 2025; Sulaimani et al., 2025].

Therefore, sourcing materials from renewable resources is an alternative. Biopolymers offer advantages because they are derived from living organisms, such as animals, fungi, bacteria, and plants, as well as ribonucleic acid and deoxyribonucleic acid. Being biodegradable and biocompatible, biopolymers are used in medical implants, drug delivery, energy storage, and other applications [Edo et al., 2025].

Starch-based biodegradable films are widely studied. They are isotropic, colorless, tasteless, odorless, non-toxic, and biodegradable [Díaz, 2022]. Despite their use in food packaging, these films have several limitations: low mechanical strength, high moisture absorption, poor oxygen barrier properties, and a lack of active film functions [Guo et al., 2025]. Surface modification techniques, such as wet-chemical processing, exist but require large quantities of hazardous chemicals and water [Vajpayee et al., 2021].

Plasma technology is an appealing alternative in fields like food, wastewater treatment, medicine, and surface modification [Gupta et al., 2022; Deng et al., 2025; Pournemati et al., 2024; Miebach et al., 2025; Jiang et al., 2025].

Plasma, the fourth state of matter after solids, liquids, and gases, is a highly energized, electrically conductive mixture of ions, free radicals, ultraviolet radiation, and intense electric fields [Tanzooei and Karimi, 2025].

Non-thermal plasma is widely used to modify biopolymer surfaces. Reactive species in plasma, such as ions, radicals, electrons, photons, and X-rays, can alter surface properties with minimal or no effect on the material [Dashtbozorg et al., 2022].

This research studies how low-pressure nitrogen plasma changes the physical and structural properties of a corn starch-based biopolymer. Mass, hardness, elasticity, and hydrophobicity were measured before and after treatment.

Methodology

Corn starch samples

Cornstarch samples measuring 1.0 cm × 2.8 cm were used. One control sample [untreated] and five samples exposed to nitrogen plasma for varying exposure times were used.

Experimental system.

The experimental setup [shown in Figure 1] was a sealed glass chamber with two aluminum electrodes. It included a digital vacuum gauge [CPS], a vacuum pump [LABCONCO], and a plasma generator [Spellman, SL600].

Box 1

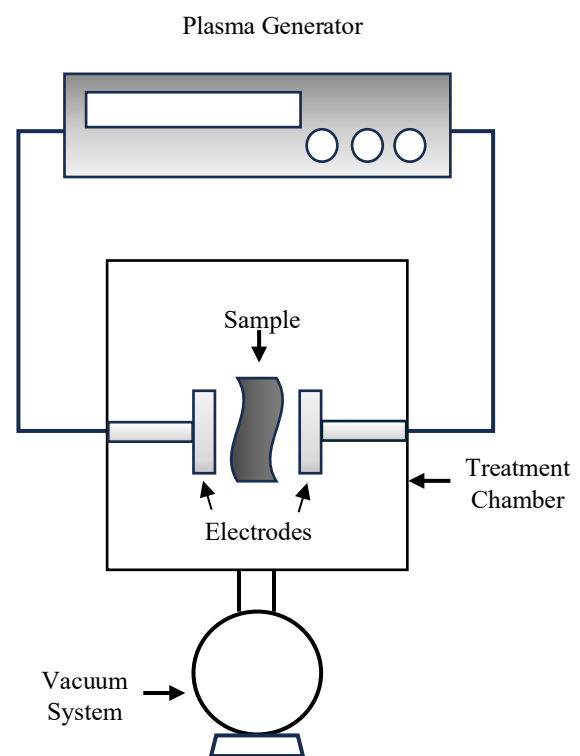


Figure 1

Schematic of the experimental system for plasma treatment.

Source: Own elaboration

Plasma treatment.

Samples were exposed to low-pressure [5 Torr] nitrogen plasma for various durations [0.5, 1, 2.5, 3, and 4 min].

Alarcón-Hernández, Fidel Benjamín, Fuentes-Albarrán, María del Carmen, López-Ávila, Jaciel Amisadai and Sandoval-González, Antonia. [2025]. Effect of nitrogen plasma on the mechanical and surface properties of a biopolymer. ECORFAN Journal Republic of Nicaragua. 11[19]1-13: e71119113.

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Plasma was generated at 5000 V and 50 mA with an electrode separation of 3 cm. Two replicates were performed for each sample. The reported results are the average of the replicates.

Measurement of parameters of interest.

The variables measured were mass [Analytical balance, AE-ADAM, Model PW254], hardness [Shore A durometer, 0–100 HA], elasticity [MS-A09L dynamometer], and hydrophobicity [sessile droplet, digital microscope 1600X black].

Hydrophobicity was measured by the angle between the sample surface and a drop of distilled water. A small angle shows hydrophobicity; a large angle shows hydrophilicity.

To determine elasticity, the Young's modulus equation was used: $E = F/A\Delta l$

Where:

E = Young's modulus

F = Force applied to the sample.

A = Surface area of the sample

Δl = Change in length

l_0 = Initial length of the sample

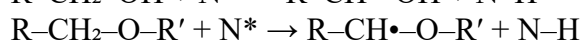
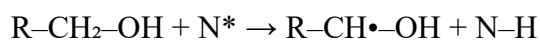
Results and Discussion.

Results from plasma-treated corn starch polymers are presented and analyzed to identify surface differences. Comparing the conditions reveals how plasma alters the polymers' properties.

In particular, exposing corn starch polymers to nitrogen plasma produces a sequence of surface and subsurface physicochemical transformations, due to the action of energetic species such as excited atomic nitrogen [N^*], N_2^+ ions, UV radiation, and residual oxygen [O^* , O_2]. These transformations can be understood through five main mechanisms: [1] radical initiation, which generates highly reactive polymer radicals; [2] cleavage degradation, in which glycosidic bonds are broken; [3] oxidation, where radicals react with residual oxygen to form new functional groups; [4] crosslinking, resulting from recombination of polymer radicals; and [5] ablation or volatilization, in which low molecular weight fragments are removed from the material.

1. Initiation: Generation of Polymer Radicals

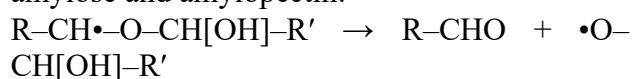
The initial step of the process involves the abstraction of hydrogen atoms from the hydroxyl groups [$-OH$] and $C-H$ bonds of the starch chain, promoted by excited plasma species. This process leads to the formation of highly reactive carbon-centered radicals [Perumal et al., 2022; Pankaj et al., 2017]:



The generation of these radicals is the starting point for both the biopolymer's degradation and structural crosslinking.

2. Degradation and mass loss: cleavage of glycosidic bonds [Vangala et al., 2017; Zhang et al., 2015]

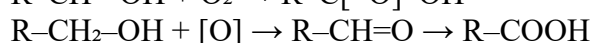
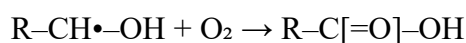
The radicals formed can undergo β -cleavage, causing the rupture of glycosidic bonds [$C-O-C$] that link the glucose units in amylose and amylopectin:



This process generates fragments of lower molecular weight, reducing ends [aldehydes], and short oligosaccharides. The subsequent oxidation of these fragments leads to their decomposition into volatile species [CO , CO_2 , H_2O , and light organic compounds], which desorb under vacuum, thereby explaining the progressive mass loss.

3. Surface Oxidation and Chemical Functionalization [Goiana et al., 2024]

In the presence of residual oxygen, polymer radicals react to form carbonyl and carboxyl groups:

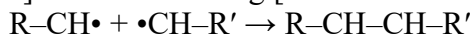


These functional groups increase surface polarity, modify surface energy, and contribute to the observed changes in the material's wettability [hydrophobicity/hydrophilicity]. Experimental evidence for this process is observed as increased $C=O$ and $COOH$ signals in FTIR and XPS analyses.

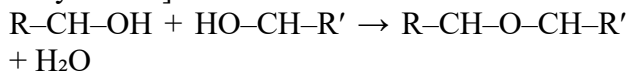
4. Crosslinking: hardening and elastic changes [Muhammad et al., 2018]

In parallel with degradation, radicals can recombine between chains, resulting in a more compact polymer network. Several types of crosslinking are identified:

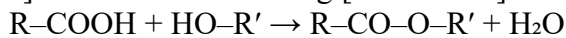
a) C–C crosslinking [radical recombination]:



b) C–O–C crosslinking [ether bridges by dehydration]:



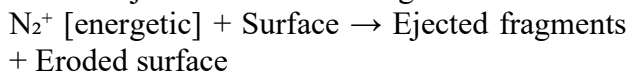
c) Oxidative crosslinking [ester bonds]:



These processes increase the density of interchain bonds, restrict molecular mobility, and explain the progressive increase in hardness and the non-monotonic evolution of Young's modulus, resulting from the balance between structural degradation and network densification.

5. Physical ablation and sputtering [Perumal et al., 2022; Muhammad et al., 2018]

In addition to chemical reactions, N_2^+ ions and energetic neutral species cause the ballistic ejection of surface fragments:



This mechanism is especially relevant in the early stages of exposure, when the surface has not yet been densified by cross-linking, and contributes significantly to the initial mass loss.

Mass

All samples subjected to plasma treatments showed mass loss as a function of exposure time, as shown in Figure 2. This mass loss behavior indicates a progressive ablation process in which the active plasma species [ions, electrons, and nitrogen radicals] remove surface material from the biopolymer.

Similar changes have been observed and documented in recent studies on the treatment of biopolymers with plasmas of different or similar characteristics [Vassallo et al., 2024; Pillai et al., 2023; Tampieri et al., 2023].

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Box 2

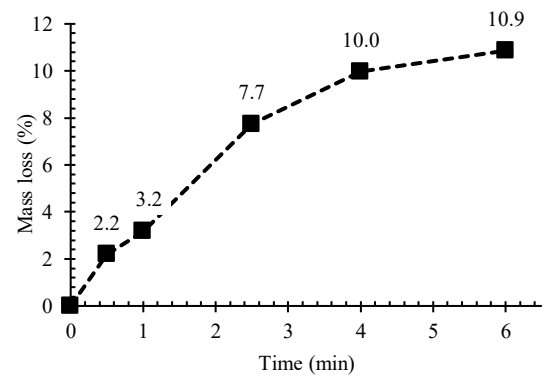


Figure 2

Mass loss of the samples as a function of the exposure time to nitrogen plasma.

Source: Own elaboration

In particular, the mass loss of the study material exhibits a specific behavior. During the first minute, the moderate increase suggests preferential removal of amorphous material, plasticizers, and molecules with low cohesion, which is consistent with contemporary assessments showing that the amorphous phases of biopolymers are particularly susceptible to the initial attack of the plasma [Vassallo et al., 2024]. Subsequently, between 1 and 2.5 minutes, a more rapid increase occurs, associated with greater surface sensitivity and the detachment of partially degraded regions or short chains, a behavior observed in natural biopolymers subjected to reactive nitrogen plasmas [Laput et al., 2023]. Finally, from 2.5 to 6 minutes, the increase in mass loss slows again, suggesting that once the weakest layer is removed, the plasma interacts with a denser, more resistant surface, reducing the ablation rate [Dors., 2025; Bertin et al., 2024]. Overall, the observed upward trend reflects a time-dependent process, beginning with the selective ablation of the most susceptible areas of the material and progressing toward slower erosion on a progressively hardened surface, consistent with previous studies of biopolymer modification using low-pressure plasmas [Dufour, 2023; Siow, 2018].

During the initial phase, approximately 0 to 4 minutes of exposure, the polymer surface exhibits a high density of reactive sites, including readily accessible glycosidic bonds, hydroxyl [-OH] groups, and C–H bonds. Furthermore, the semicrystalline structure of the starch, composed of ordered regions of amylopectin and more amorphous areas rich in amylose, remains intact, without modified surface layers that could act as a barrier.

Alarcón-Hernández, Fidel Benjamín, Fuentes-Albarrán, María del Carmen, López-Avila, Jaciel Amisadai and Sandoval-González, Antonia. [2025]. Effect of nitrogen plasma on the mechanical and surface properties of a biopolymer. ECORFAN Journal Republic of Nicaragua. 11[19]1-13: e71119113.

<https://doi.org/10.35429/EJRN.2025.11.19.7.1.13>

Under these conditions, energetic species generated in the nitrogen plasma, such as N_2^+ ions, excited atomic nitrogen, and energetic neutral molecules, directly impact the material surface. As a result, physical ablation processes occur simultaneously via momentum transfer [Goiana et al., 2024], along with hydrogen abstraction and chemical bond breaking [Muhammad et al., 2018], and surface oxidation induced by residual oxygen [Vangala et al., 2017]. The combination of these mechanisms explains the high rate of mass loss observed at this stage, reaching values close to 10% in the first 4 minutes of treatment [Zhang et al., 2015; Vangala et al., 2017].

Once this initial stage is overcome, the system enters a stabilization regime, observable between 4 and 6 minutes of exposure, where the mass loss rate decreases significantly. This behavior is attributed to the depletion of the most labile surface material, namely the amorphous regions and the weakest bonds that have already been removed [Zhang et al., 2015]. Additionally, the formation of an oxidized surface layer, rich in carbonyl and carboxyl groups, acts as a partial barrier, limiting the access of reactive plasma species to deeper layers [Vangala et al., 2017].

The morphological modification of the surface, characterized by increased roughness, also reduces the efficiency of plasma etching [Goiana et al., 2024]. Consequently, the remaining material exhibits a lower density of reactive sites and requires a higher activation energy to continue degrading [Zhang et al., 2015], leading to a much smaller mass loss and an asymptotic trend in the process.

From a chemical perspective, nitrogen plasma generates a variety of reactive species that interact with starch. These include accelerated molecular nitrogen ions [N_2^+], energetic neutral molecules [N_2], and highly reactive species such as excited atomic nitrogen and NH radicals. These species can abstract hydrogen atoms from the C–H and O–H bonds of the polymer, forming carbon-centered radicals [Goiana et al., 2024; Muhammad et al., 2018]. These radicals propagate degradation via β -cleavage reactions, leading to the rupture of the glycosidic [C–O–C] bonds that connect the glucose units. As a result, lower-molecular-weight oligosaccharide fragments, reducing ends, and progressive depolymerization of both amylose and amylopectin are generated [Zhang et al., 2015; Srangsomjit, 2021].

The unavoidable presence of residual oxygen in the system [O_2 , O^*], even in nominally pure nitrogen plasmas, plays a key role in the secondary oxidation of polymer radicals. These radicals react with molecular oxygen or excited oxygenated species to form carbonyl [C=O] and carboxyl [COOH] groups, the presence of which has been widely confirmed by spectroscopic techniques such as FTIR and XPS [Vangala et al., 2017]. The low-molecular-weight oxidized fragments generated during this process subsequently decompose into volatile products, such as CO, CO₂, H₂O, and low-molecular-weight organic compounds, which desorb from the surface and contribute directly to the experimentally measured mass loss [Muhammad et al., 2018]. Simultaneously, N_2^+ ions and energetic neutral species continue to produce physical ablation through sputtering, a particularly relevant mechanism in the early stages of treatment [Goiana et al., 2024].

At the structural level, these processes induce significant changes in starch at both the molecular and supramolecular scales. A reduction in average molecular weight is observed, with amylopectin being more susceptible to depolymerization due to its highly branched structure and the greater number of bonds [Srangsomjit, 2021] that act as preferential attack sites. Amylose, although it also degrades, shows greater relative resistance due to its more compact linear structure [Zhang et al., 2015].

Similarly, the concentration of oxygenated functional groups increases, resulting in greater water solubility and modifications to the material's thermal properties [Zhang et al., 2015]. At the supramolecular level, the disruption of semicrystalline regions and the disorganization of molecular packing lead to a decrease in crystallinity [Zhang et al., 2015; Goiana et al., 2024], while the surface acquires a rougher morphology, with the presence of pores, cracks, and cavities [Goiana et al., 2024].

Quantitative analysis of the experimental data confirms this two-phase behavior, showing a maximum rate of mass loss in the initial moments of exposure and a progressive reduction over longer periods, with approximately a 90% decrease between the initial and final stages.

This pattern is consistent with a two-phase kinetic model, in which the initial degradation is governed by first-order surface-controlled kinetics, while the subsequent stage is limited by diffusion and the availability of accessible reactive sites. Overall, the results obtained are consistent with recent reports in the literature on the modification of starches by cold plasma, confirming that the observed mass loss responds to a rapid surface attack process followed by progressive stabilization of the system [Goiana et al., 2024; Srangsomjit, 2021; Thirumdas et al., 2017].

Hardness.

Figure 3 shows the behavior of the change in sample hardness as a function of plasma exposure time.

In general, the samples' hardness increases with longer plasma exposure time. The film hardness increases steadily with nitrogen plasma exposure time [from 60.25 to 74 units between 0 and 6 min]. This increase can be explained by several plasma-induced surface and supramolecular processes that act simultaneously, with their balance resulting in greater surface stiffness as treatment time increases.

Box 3

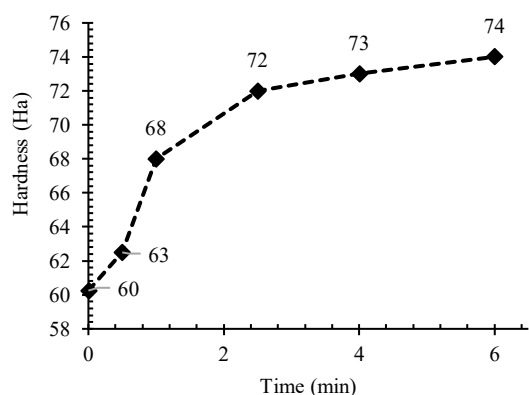


Figure 3

Change in sample hardness as a function of exposure time to nitrogen plasma.

Source: Own elaboration

In general, cold plasma generates a high concentration of energetic species [excited atomic nitrogen [N*], molecular ions [N₂⁺], ultraviolet radiation, and oxidizing species derived from residual oxygen [O*]] that interact with the functional groups of starch.

These species abstract hydrogen from the hydroxyl groups on the glucose units of amylose and amylopectin, generating highly reactive polymeric radicals on the material's surface.

These radicals constitute the initiating step in a cascade of chemical reactions that leads to the observed hardening.

Plasma treatment simultaneously induces two competing processes: crosslinking and chain-break degradation [Perumal et al., 2022; Thirumdas et al., 2015]. At short and moderate exposure times, crosslinking dominates the system's behavior. This process involves the formation of covalent bonds between adjacent polymer chains, which drastically reduces molecular mobility, increases the elastic modulus, and results in increased surface hardness. In contrast, at longer treatment times or under more severe conditions, chain cleavage intensifies, reducing molecular weight and potentially negatively affecting mechanical properties. In the analyzed system, the predominance of crosslinking up to 6 minutes of treatment explains the net increase in hardness measured experimentally.

The crosslinking of starch treated with nitrogen plasma occurs through various complementary mechanisms. The most relevant is the direct recombination of polymer radicals, which forms carbon-carbon bonds. These bonds have high bond energies and are irreversible at room temperature, forming a rigid polymer network that is highly resistant to deformation.

The formation of these bonds explains the substantial increase in the material's hardness and mechanical modulus [Perumal et al., 2022]. Additionally, plasma facilitates condensation reactions between neighboring hydroxyl groups, leading to the formation of ether bridges [C–O–C] between polymer chains. The energy supplied by the plasma lowers the activation barrier for these reactions, while the continuous evacuation of the system promotes the removal of the water produced, shifting the equilibrium towards the formation of covalent bonds.

These ether bridges significantly increase the rigidity of the polymer network [Perumal et al., 2022].

Another relevant mechanism is oxidative crosslinking. The oxidizing species in the plasma progressively transform the hydroxyl groups of starch into carbonyl and carboxyl groups. These functional groups, in addition to being structurally more rigid than hydroxyls, can participate in interchain esterification reactions, forming ester bonds that serve as additional crosslinking points [Perumal et al., 2022; Pankaj et al., 2017].

Spectroscopic evidence reported in the literature, such as the increase in bands associated with C=O groups and the increase in the O 1s signal of carbonyls, supports the occurrence of these processes [Thirumdas et al., 2015; Kaur et al., 2024].

Potentially, although still with limited evidence in corn starch systems, nitrogenous species from the plasma can be incorporated into the polymer structure through amination reactions or imine formation. These C–N or C=N bonds, if experimentally confirmed, would act as additional crosslinking points and contribute to the material's stiffness [Haleem et al., 2025].

In addition to chemical modifications, the plasma induces significant densification of the polymer's surface layer. Selective ablation removes amorphous and low-density regions, while crosslinking stiffens the polymer chains into compact configurations. As a result, a highly crosslinked surface layer, with a thickness on the order of tens of nanometers, forms, acting as a rigid surface that contributes to the resistance to deformation measured in hardness tests [Perumal et al., 2022; Kaur et al., 2024].

This densification is accompanied by the collapse of the material's initial microporosity, resulting in smoother, more compact surfaces, as commonly observed using scanning electron microscopy [Kaur et al., 2024; Pankaj et al., 2017].

In parallel, the effect of plasma on crystallinity depends on the severity of the treatment. Under mild to moderate conditions, as used in this study, preferential removal of amorphous regions can maintain or even slightly increase relative crystallinity [Kaur et al., 2024], consistent with the observed progressive hardening.

Kinetic analysis of the hardness increase reveals an initial rapid-hardening stage, associated with a high radical concentration and a high probability of radical-radical recombination. Subsequently, the hardening rate gradually decreases due to the depletion of accessible reactive sites, increased local viscosity from prior crosslinking, and competition from oxidative degradation processes. This evolution leads to asymptotic behavior, where hardness approaches a maximum value near 74 y 75 Ha, indicating saturation of surface crosslinking.

These results are highly consistent with the literature, confirming plasma crosslinking mechanisms [Perumal et al., 2022; Kaur et al., 2024; Pankaj et al., 2017].

Elasticity

The evolution of the Young's modulus of the corn starch polymer exposed to a low-pressure nitrogen plasma exhibits non-monotonic behavior: an initial increase, followed by a progressive decrease, and, finally, a significant increase at prolonged treatment times, as shown in Figure 4.

This pattern reflects the coexistence and competition of various plasma-induced physicochemical processes, mainly surface crosslinking, chain cleavage, and structural reorganization of the modified layer. In the initial state, the untreated polymer has a Young's modulus close to 4.46 MPa, a typical value for starch-rich polymer matrices with high molecular mobility and a high contribution from amorphous regions plasticized by water and other low-molecular-weight components [Perumal et al., 2022].

Box 4

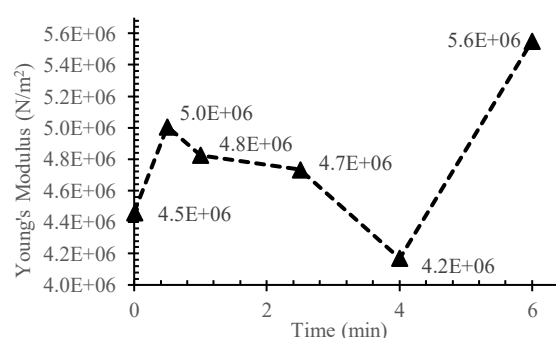


Figure 4

Change in Young's modulus of the studied samples as a function of plasma exposure time.

Source: Own elaboration

During the initial moments of plasma exposure [0–0.5 min], the Young's modulus increases by approximately 12%, reaching values close to 5.01 MPa. This increase is primarily associated with the rapid generation of free radicals on the polymer surface, resulting from interaction with energetic nitrogen plasma species, such as excited atomic nitrogen, molecular ions, and ultraviolet radiation. These species abstract hydrogen from the starch hydroxyl groups, forming highly reactive polymer radicals that tend to recombine, leading to interchain covalent bonds.

This crosslinking process reduces the segmental mobility of the chains and promotes the formation of a denser, more rigid surface layer, thereby increasing the elastic modulus. Simultaneously, the removal of adsorbed water and surface plasticizers contributes to the material's initial stiffening [Perumal et al., 2022; Carneiro de Oliveira et al., 2021].

At intermediate treatment times [0.5–4 min], Young's modulus decreases gradually, from 5.01 to 4.17 MPa. This behavior indicates that, although crosslinking continues, competing degradation processes begin to dominate, particularly radical-induced chain cleavage and progressive oxidation of the polymer matrix. Breaking bonds in the starch backbone reduces the average molecular weight and generates smaller fragments, weakening the material's mechanical integrity and decreasing its resistance to elastic deformation.

Likewise, the formation of structural defects and microporosity associated with surface ablation reduces the measured effective modulus, especially when the characterization technique includes both the modified surface layer and the underlying, less crosslinked regions.

This regime, in which chain cleavage can partially counteract net crosslinking, has been previously reported in starch films and other biopolymers treated with cold plasma under similar conditions [Pankaj et al., 2017; Rao et al., 2023].

In prolonged exposures [4–6 min], the Young's modulus increases sharply to approximately 5.55 MPa, even exceeding the values recorded in the early stages of treatment.

This late increase is attributed to the formation of a highly densified and strongly crosslinked surface layer, resulting from the accumulation of interchain covalent bonds and condensation and oxidation processes that favor the generation of more rigid structures, such as ether and ester bonds, and potentially, partially carbonized regions. At these timescales, ablation has removed much of the weaker surface material, leaving a residual layer of greater density and rigidity that dominates the overall elastic response.

Similar phenomena, characterized by hardening and an increase in modulus after longer plasma treatments, have been observed in both polysaccharide-based biopolymers and synthetic polymers, where surface densification and deep crosslinking overcome the negative effects of previous degradation [Chiper & Borcia, 2023; Goiana et al., 2024].

Taken together, the results indicate that the Young's modulus response of the corn starch polymer to nitrogen plasma is governed by a dynamic equilibrium between crosslinking and degradation. In early stages, rapid surface crosslinking increases stiffness; in intermediate stages, chain scission and oxidation reduce the modulus; and finally, at prolonged exposure times, the formation of a densified, highly crosslinked surface layer restores and enhances the material's stiffness.

This nonlinear behavior is consistent with proposed kinetic models for plasma modification of polymers, in which the competition between crosslinking and chain scission is strongly dependent on exposure time, plasma energy, and the chemical nature of the substrate [Perumal et al., 2022; Carneiro de Oliveira et al., 2021; Chiper & Borcia, 2023].

Hydrophobicity

The evolution of the hydrophobicity of the corn starch polymer treated with low-pressure nitrogen plasma, as measured by contact angle, shows a non-monotonic behavior [a sequence of decreases, increases, decreases, and increases] with exposure time. This pattern reflects the overlap of several plasma-induced physicochemical processes, including surface chemical functionalization, secondary oxidation, molecular reorganization, and morphological changes associated with surface ablation and densification.

Alarcón-Hernández, Fidel Benjamín, Fuentes-Albarrán, María del Carmen, López-Ávila, Jaciel Amisadai and Sandoval-González, Antonia. [2025]. Effect of nitrogen plasma on the mechanical and surface properties of a biopolymer. ECORFAN Journal Republic of Nicaragua. 11[19]1-13: e71119113.

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Box 5

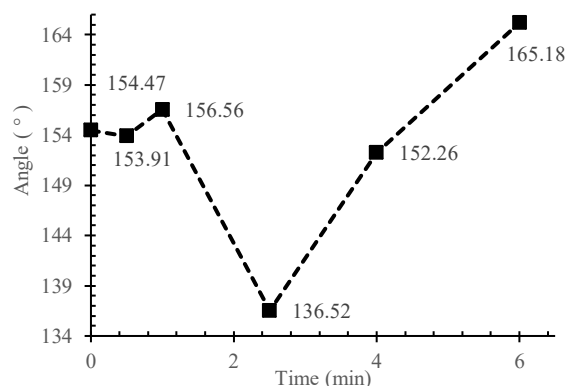


Figure 5

Modification of the hydrophobicity of the samples after plasma treatments.

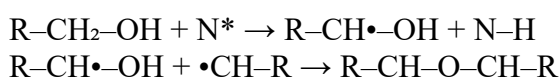
Source: Own elaboration

Under the adopted experimental criteria, high contact angles [$\approx 150\text{--}165^\circ$] are associated with a highly wettable [hydrophilic] surface, consistent with the high density of polar groups available to interact with water in polysaccharide-rich matrices.

In the initial state [0 min], the polymer exhibits a contact angle close to 154.5° , indicating a markedly hydrophilic surface. This behavior is typical of starch-based materials, whose structure is dominated by anhydroglucose units rich in hydroxyl groups [–OH], which can form multiple hydrogen bonds with water. Furthermore, the presence of bound water and residual plasticizers promotes segmental mobility and exposes these polar groups at the solid-liquid interface [Thirumdas et al., 2015; Perumal et al., 2022].

After a short exposure to nitrogen plasma [0.5 min], a slight decrease in the contact angle [$\approx 153.9^\circ$] is observed, which, according to this criterion, indicates a moderate reduction in hydrophilicity. This effect can be attributed to the rapid surface activation induced by the plasma, which generates free radicals on the starch chain through hydrogen abstraction.

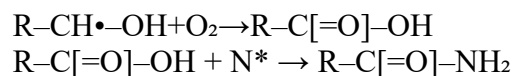
These radicals tend to recombine with each other, leading to initial surface crosslinking processes that reduce the availability of free –OH groups to interact with water [Carneiro de Oliveira et al., 2021; Dufour, 2023]. Schematically, this process can be represented as:



where R represents the polysaccharide chain and N^* corresponds to excited nitrogen species. The formation of interchain ether bonds decreases the effective surface polarity and, therefore, wettability.

After an exposure time of 1 min, the contact angle increases again to approximately 156.6° , indicating a recovery and even a slight increase in hydrophilicity. This behavior suggests that, in addition to crosslinking, secondary chemical functionalization reactions begin to dominate. Although the plasma used is N_2 , the unavoidable presence of residual oxygen and moisture allows the formation of highly polar carbonyl, amide, and carboxyl groups, thereby increasing the material's surface energy [Chiper & Borcia, 2023; Goiana et al., 2024].

The associated reactions can be described as:



The incorporation of these nitrogenous and oxygenated functional groups enhances water affinity, as evidenced by the increase in the contact angle under the adopted hydrophilic criterion.

During intermediate treatment times [2.5 min], the contact angle decreases significantly to approximately 136.5° , indicating a marked decrease in hydrophilicity. At this stage, the effects of surface ablation and densification of the treated layer intensify. The selective removal of amorphous regions rich in hydroxyl groups, along with increased crosslinking, leads to a more compact surface with a lower density of accessible polar sites.

Additionally, plasma-induced molecular reorganization may favor the refolding of polar groups into the matrix, reducing their contribution to water interaction [Carneiro de Oliveira et al., 2021; Dufour, 2023].

Finally, at prolonged exposure times [4–6 min], the contact angle gradually increases again, reaching a maximum value of approximately 165.2° at 6 min, which again corresponds to a highly hydrophilic surface. This behavior can be attributed to the formation of a chemically stabilized surface layer, in which oxidative and nitrogen functionalization overcome the effects of ablation.

The accumulation of stable polar groups, such as carboxyls and amides, along with possible morphological changes that increase the effective solid-liquid contact area, promotes interaction with water and explains the recovery of hydrophilicity in advanced stages of treatment [Perumal et al., 2022; Goiana et al., 2024].

Overall, the evolution of the contact angle of the corn starch polymer treated with nitrogen plasma reflects the dynamic equilibrium between crosslinking, ablation, molecular rearrangement, and surface chemical functionalization.

According to the adopted experimental criteria, higher contact angles indicate greater hydrophilicity, and the variations observed with exposure time are consistent with the surface modification mechanisms reported for polysaccharide biopolymers subjected to cold plasma.

Conclusion

In conclusion, the results obtained demonstrate that low-pressure nitrogen plasma is a highly effective and versatile tool for the surface modification of corn starch polymers, allowing for the controlled adjustment of their physicochemical and mechanical properties without significantly altering the material's volume. Progressive exposure to the plasma induces a series of simultaneous processes [radical initiation, chain cleavage, oxidation, crosslinking, and ablation], the balance of which is strongly dependent on the treatment time. This complex interaction explains the nonlinear behavior observed in mass loss, hardness, Young's modulus, and hydrophobicity, showing that small variations in exposure time can lead to substantial changes in the biopolymer's performance.

In particular, the recorded mass loss confirms that the plasma primarily acts at the surface, first eliminating amorphous regions, plasticizers, and low-molecular-weight fragments, and subsequently evolving toward a stabilization regime associated with the formation of a denser, more resistant surface layer.

In parallel, the sustained increase in hardness and the biphasic behavior of the Young's modulus reflect the competition between degradation and crosslinking: while chain cleavage temporarily reduces mechanical integrity, radical recombination and the formation of interchain covalent bonds generate more rigid networks that dominate at prolonged exposure times. Likewise, the changes in hydrophobicity, interpreted according to the adopted experimental criteria, demonstrate the ability of nitrogen plasma to modulate the surface chemistry of starch through the incorporation and rearrangement of polar functional groups.

From an applied perspective, these findings are particularly relevant for the development of biodegradable materials based on corn starch with properties that can be adjusted according to their end use. Nitrogen plasma treatment is emerging as a clean, chemical-free alternative, compatible with sustainability principles, for improving mechanical strength, controlling wettability, and optimizing the surface stability of biopolymers intended for applications in packaging, coatings, biomaterials, and controlled-release systems.

Overall, the study confirms that nitrogen plasma not only modifies the surface of starch but also enables the functional design of its properties, opening up opportunities to expand the use of renewable polymers in higher-value-added technological applications.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this research.

Author contribution

Contribution of each researcher in the points developed for this work:

Alarcón-Hernández, Fidel Benjamín: Designed the idea of the project, the methods and the applied research techniques. Supported the development of the experimentation, performed the data analysis, and wrote the article.

Article

Fuentes-Albarrán, María del Carmen: Contributed to the design of the research, type of research, laboratory analysis, analysis of data collected and writing of the article.

López-Ávila, Jaciel Amisadai: Supported the application of the research methods and techniques and contributed to the laboratory analysis and the revision of the article.

Sandoval-González, Antonia: Support with laboratory analysis. Collaboration in the writing of the article.

Availability of data and materials

All data used to support the findings of this study are included within the article.

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Abbreviations

FTIR	Fourier Transform Infrared Spectroscopy
XPS	X-ray Photoelectron Spectroscopy
UV	Ultraviolet
UV – VIS	Ultraviolet-visible

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Text in TNRoman No.12, single space.

General explanation of the subject and explain why it is important.

What is your added value with respect to other techniques?

Clearly focus each of its features.

Clearly explain the problem to be solved and the central hypothesis.

Explanation of sections Article.

Development of headings and subheadings of the article with subsequent numbers

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In the article content any table and figure should be editable formats that can change size, type and number of letter, for the purposes of edition, these must be high quality, not pixelated and should be noticeable even reducing image scale.

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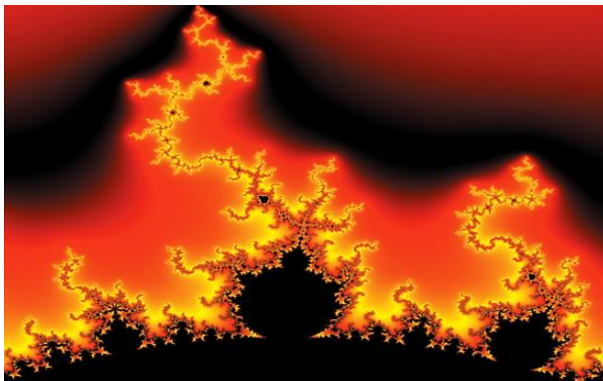


Figure 1

Title [Should not be images-everything must be editable]

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Box

Table 1

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The maximum number of Boxes is 10 items

For the use of equations, noted as follows:

$$Y_{ij} = \alpha + \sum_{h=1}^r \beta_h X_{hij} + u_j + e_{ij} \quad [1]$$

Must be editable and number aligned on the right side.

Methodology

Develop give the meaning of the variables in linear writing and important is the comparison of the used criteria.

Results

The results shall be by section of the article.

Conclusions

Clearly explain the results and possibilities of improvement.

Annexes

Tables and adequate sources.

The international standard is 7 pages minimum and 14 pages maximum.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

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Specify the contribution of each researcher in each of the points developed in this research.

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Benoit-Pauleter, Gerard: Contributed to the project idea, research method and technique.

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Indicate the availability of the data obtained in this research.

Funding

Indicate if the research received some financing.

Acknowledgements

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Abbreviations

List abbreviations in alphabetical order.

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ANN Artificial Neural Network

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