04-023

ELABORATION OF BIOMATERIALS FROM COFFEE WASTES

Vega, Shirley [(1)]; Garvizu Auza, Vidfa Carolina [(1)]; Alvizuri-Tintaya, Paola Andrea [(1)]; Soria, Freddy [(1)]; Lo-Iacono-Ferreira, Vanesa Gladys [(2)]

[(1)] Centro de Investigación en Agua, Energía y Sostenibilidad, Universidad Católica Boliviana San Pablo, [(2)] Universitat Politècnica de València

Coffee is one of the most popular drinks worldwide. Although the coffee industry is of great economic importance, it is considered an activity that produces a significant environmental impact. According to studies carried out, organic coffee wastes become a pollutant agent due to the presence of caffeine, polyphenols, and tannins, among the most important. This research proposes a methodology for the elaboration of a biomaterial from the mixture of coffee grounds with natural polymers. The study of the physical characteristics of the material and its biodegradability were developed to analyze its applicability. Results reveal a potential for the use of coffee grounds, being a possible solution to its generation in Bolivia, the fifth most important country in terms of coffee production in South America.

Keywords: coffee; biomaterial; biodegradability

ELABORACIÓN DE BIOMATERIALES A TRAVÉS DEL APROVECHAMIENTO DE RESIDUOS DE CAFÉ

El café es una de las bebidas más populares a nivel mundial. Si bien la industria cafetalera tiene una gran importancia económica, es considerada una actividad que produce un impacto ambiental significativo. Según estudios realizados, los residuos orgánicos generados por la actividad cafetelera, llegan a ser contaminantes por el contenido de agentes tóxicos como la cafeína, poli fenoles y taninos, entre los más importantes. La borra es uno de los residuos principales producto de la destilación del café. La presente investigación plantea una metodología para la elaboración de un biomaterial a partir de la mezcla de la borra de café con polímeros naturales. El estudio de características físicas del material y la biodegradabilidad se desarrollaron para analizar la aplicabilidad del mismo. Los resultados obtenidos exponen una potencialidad de aprovechamiento de la borra de café, siendo una posible solución a su generación en Bolivia, al ser el quinto país más importante en cuanto a la producción de café en América del Sur.

Palabras clave: café; biomaterial; biodegradabilidad

Agradecimientos: Los autores agradecen al Centro de Investigación en Agua, Energía y Sostenibilidad (CINAES) perteneciente a la Carrera de Ingeniería Ambiental de la Universidad Católica Boliviana San Pablo Sede La Paz

1. Introduction

An average of 2.25 billion cups of coffee are consumed daily worldwide, making coffee one of the most consumed products only preceded by water ((Dadi et al., 2018; Preedy, 2014). Although the coffee industry is of economic importance, it also has impacts on the environment. In the cultivation and industrialization process, only 5% of the weight of the fresh fruit is used and the remaining 95% is disposed (Fernández et al., 2020).

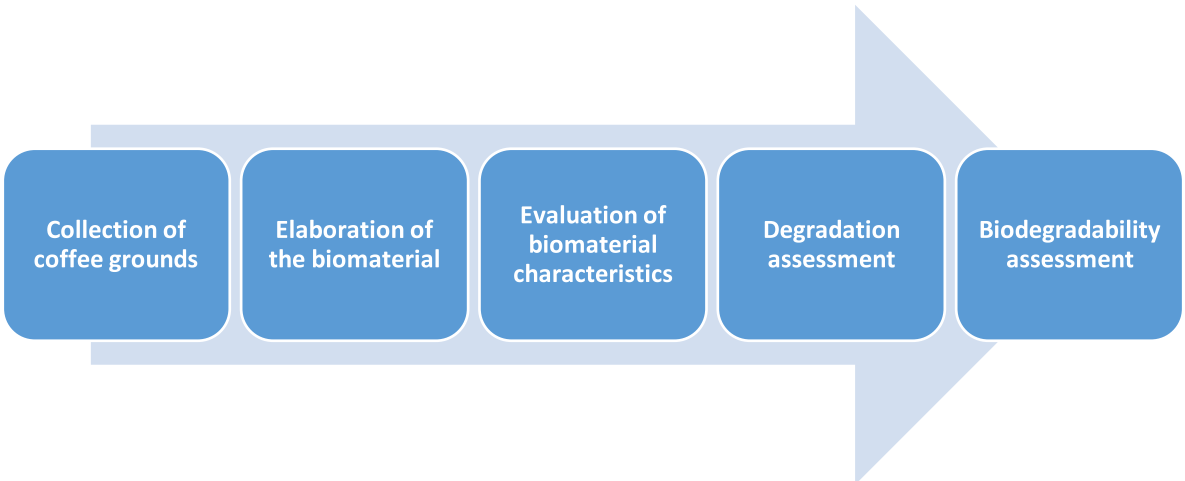
It is estimated that for each ton of coffee processed, 650 kg of lees are generated; for each kg of soluble coffee produced, 2 kg of wet lees are generated, which in turn represents a problem for its disposal (Mussatto et al., 2011). Lees discharged directly into water bodies can cause ecological toxicity, due to the organic compounds contents such as phenols, chlorogenic acids, hydroxycyanamide, and chemical acid derivatives, some of which can be detrimental to plant growth (Kim et al., 2014).

Recently, research has grown regarding the use of coffee grounds composting for biofuel production, natural insecticides, bioplastics, aesthetic treatments, and polymeric materials known as biomaterials (Wong-paz *et al.* 2013; Cogua Barrera, 2019). The purpose of our work is to obtain biomaterials from the use of coffee grounds and natural polymers, with adequate physical characteristics and biodegradability for its usage as domestic products with characteristics similar to common plastic. This work is linked to Sustainable Development Goal 12 "Responsible Production and Consumption" (United Nations, 2015).

2. Methodology

Based on principles referred to manufacturing processes of ceramic materials (Acchar *et al.*, 2017), the methodological sequence begins with the collection of coffee grounds, the elaboration of the biomaterial, the evaluation of its characteristics, and the assessment of the degradation and biodegradability of the final product (Figure 1).

Figure 1: Methodological Process



Source: Own elaboration, 2023.

The coffee grounds are from the Arabica type, collected from a coffee shop in La Paz, Bolivia. Given that the amounts of coffee grounds were not large, the entire waste volume produced during a week was considered for the experiments. For the production of the biomaterial, the amounts of protein and plasticizer to be used in each of the replicates were determined according to Pérez et al. (2016), Fernández (2016), and Meza (2016). Three different combinations of protein and plasticizer (glycerin and gelatin) were selected, using concentration ratios of 5/5, 15/10, and 30/20, which were heated up to 75°C when mixed with coffee grounds. Then, the mixture obtained was cooled in different molds. A factorial design of 23 was determined at this stage under the factors and levels shown in Table 1. The selection of the best mix ratio was based on the coagulation time and the type of mold used.

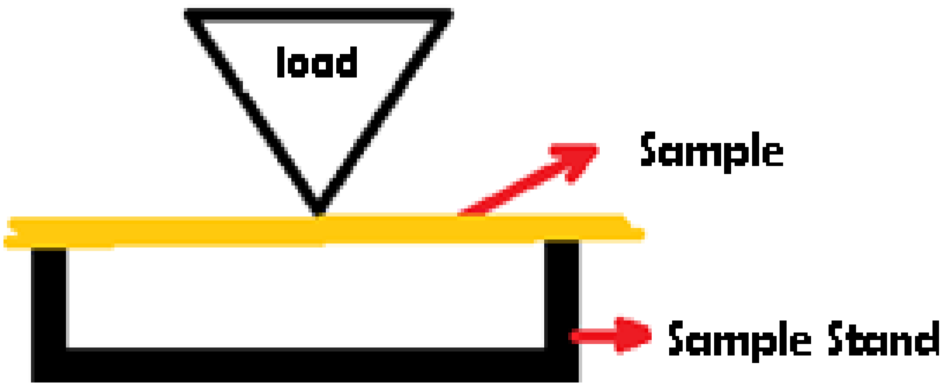
Table 1: Factors and levels for the factorial design on the elaboration of the biomaterial

Factor	Level 1 (N1)	Level 2 (N2)	Level 3 (N3)
Jelly (%)	5	15	30
Glycerin (%)	5	10	20
Coffee grounds (g)		10	
Water (ml)		100	

Source: Own elaboration, 2023.

The biomaterial produced was tested for their physical, mechanical and chemical characteristics. Under a 22-factorial design, there were considered two factors in terms of composition: gelatin and glycerin, obtaining 4 experimental combinations. Traction and flexural strength were determined under the scheme shown in Figure 2, following Ibarra (2019). Table 2 shows the description of the tests.

Figure 2: Flexural strength



Source: Adapted from Figure 6-14 of the book by Lokensgard & Richardson (2003, p. 89)

Degradation was evaluated through the gravimetric variation of pieces of the biomaterial with dimensions of 4x4 cm, for a period of 3 months, under ambient conditions during the dry winter of La Paz (average temperature of 13 °C and relative humidity of 50%), following Castellón et al. (2016). The evaluation of the biodegradability of the material was carried out in accordance with the ASTM 6400 standard (ASTM, 2004) and the process adopted by Ibarra (2019) and Oropeza et al. (2016). A burial depth of 10 cm was considered in organic soil with a base of 4 cm of compost and irrigation twice a week, adding the equivalent of water to 5% of the volume of the substrate.

Table 2: Description of the physical, mechanical, and chemical tests

Characteristic evaluated	Description
Density	It was tested under ASTM (1998).
Ignition	Observation test. Consists on incinerating a sample piece of the biomaterial and visually observing changes in the color of the flame, amount of smoke, smell, deformation (Negrin, 2007).
Water absorption	24-hour immersion test, at room temperature, where water absorption percentages and mass loss of the material are evaluated (ASTM, 1998).
Solubility	Qualitative changes using water, thinner, acetone and alcohol as media, are evaluated based on Jangchud (1999), mentioned by Ortiz (2019).
Flexural strength	The flexural resistance follows Ibarra (2019), where different weights were applied to the samples to determine the resistance capacity of the material, during a 5-minute test. The evaluation criteria is: [+]: Good flexural strength resistance (the material does not break when bent) [-]: Can not resist flexural loads (material breaks when bent) [R++]: High elasticity (deformation longer than 2 cm) [R+]: Mid elasticity (deformation between 1.5 and 2 cm) [R]: Moderate elasticity (deformation between 1 and 1.5 cm) [R-]: Low elasticity (deformation less than 1 cm) [R--]: Very low elasticity (no deformation) [NE]: No elongation (increase in length after stretching) [E--]: Very short elongation (increase in length by 0.5 cm and less after stretching) [E-]: Short elongation (increase in length between 0.5 and 1cm after stretching) [E]: Moderate elongation (increase in length between 1 and 1.5 cm after stretching) [E+]: Major elongation (increase in length between 1.5 and 2 cm after stretching) [Ec]: Critical elongation (increase in length of more than 2 cm after stretching)

Source: Own elaboration, 2023.

3. Results and discussion

3.1. Elaboration of the biomaterial

The bioplastic sheets who passed the tests, resulted from a protein/plasticizer composition ratio of 15/10 (N2) and 30/20 (N3) in percentage, respectively. The N2 mixture presented an average drying time of 10 hours and the N3 of 6 hours, equaling the ease of demolding of both combinations in a time after 24 hours. Although the average drying time of the N1 mixture was 72 hours, the fragility of the consolidated structure prevented the corresponding demolding. This ruled out the possibility of evaluation of the characteristics in the next stage. Figure 3 shows a visual comparison among N1, N2, and N3 mixtures.

In accordance to Quintana *et al* (2021), mixture homogeneity in the polymerization process can be achieved in proportions lower than 1:5 of starch and water, which in the present study is verified according to the tests carried out for N1.

Figure 3: Biomaterial in different protein/plasticizer compositions

Source: Own elaboration, 2023.

3.2. Tests on the biomaterial characteristics

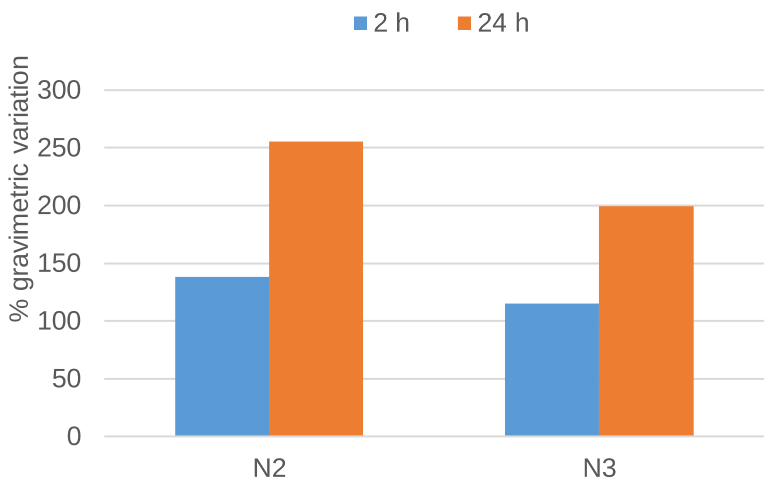
For density tests, the volume of water displaced by the material resulted in an average density of 1.35 g/cm^3 for N2 and 1.19 g /cm^3 for N3. Regarding ignition, results in Table 3 indicate that the biopolymer obtained does not present a level of flammability of conventional plastic when exposed to the ignition process.

Table 3: Ignition Tests Results

Parameter evaluated	N2	N3
Burns easily	Yes	Yes
Flame color	Blue with Yellow	Blue
Combustibility	Continues to burn after removing the flame	Self-extinguishing
Amount of smoke	Without smoke	Practically nil
Fusion type	Melts without dripping	Melts without dripping
Smell	Burnt coffee	Toasted rice
pH	6	6
Deformation	Slow	Before 1 minute
Burn within the flame	Yes	Yes

The percentage of water absorption after 2 and 24 hours was tested considering the gravimetric variation of the material after the period of immersion in water. Variations as a function of time shown in Figure 4, indicate an average increase of 138% in the weight of the N2 mixture and 115% for the N1 mixture, after a 2-hour immersion, as well as 256% and 200% respectively, after a 24-hour immersion. According to this, a better hydrophilic character of the N3 mixture is determined.

Figure 4: Gravimetric percentage variation as a function of immersion time in the water



Source: Own elaboration, 2023.

The behavior of the biopolymer samples in different media was determined through the solubility test, after 15 minutes of immersion in each try. According to the results presented in Table 4, water was the only substance with which the biomaterial presented changes, after that detachments of coffee ground particles were observed.

Table 4: Solubility Tests Results

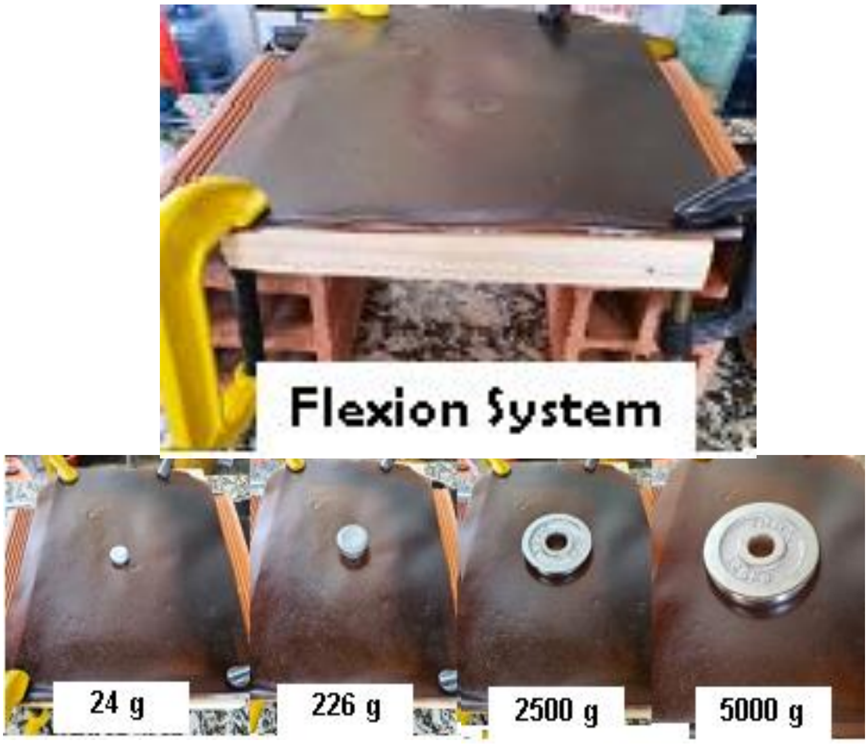
Media	N2	N3
Water	There is a slight detachment of the coffee	Slight disintegration of coffee particles
Alcohol	slight discoloration	Slight change
Thinner	No change	No change
Acetone	No changes in the structure are observed.	No changes observed.

Source: Own elaboration, 2023.

Although there are no studies related to the determination of the solubility of bioplastics made from coffee grounds, Morocho-Pilataxi et al (2021) determine a solubility of up to 60.94% in a bioplastic made from wheat and 50.77% of a bioplastic made from barley. In our experiments, higher percentages of solubility were obtained, which defines an obstacle on the use of bioplastics when exposed to water, reminding the hydrophilic nature of the biomaterial.

During the flexural strength test, the loads that were tested on the N2 and N3 samples, for 5-minute intervals were 24, 226, 2500 and 5000 grams. A graphic description of the experimental process is shown in Figure 4, and the results for both N2 and N3 tests are shown in Table 5. Both N1 and N2 presented resistance to the different loads tested, with no fractures in the biomaterial structure. Regarding elongation, the results do not vary for N2 and N3 samples under the different loads. The evaluation of the restitution of the biomaterial shape presented better results for N3.

Figure 4: Variation of loads in the bending system



Source: Own elaboration, 2023.

Table 5: Flexural strength tests results

Sample	24 g	226 g	2500 g	5000 g
N2	[+] [NE]	[+][E--] [R++]	[+] [E-] [R]	[+] [E] [R]
N3	[+] [NE]	[+][E--] [R++]	[+] [E-] [R++]	[+] [E] [R+]

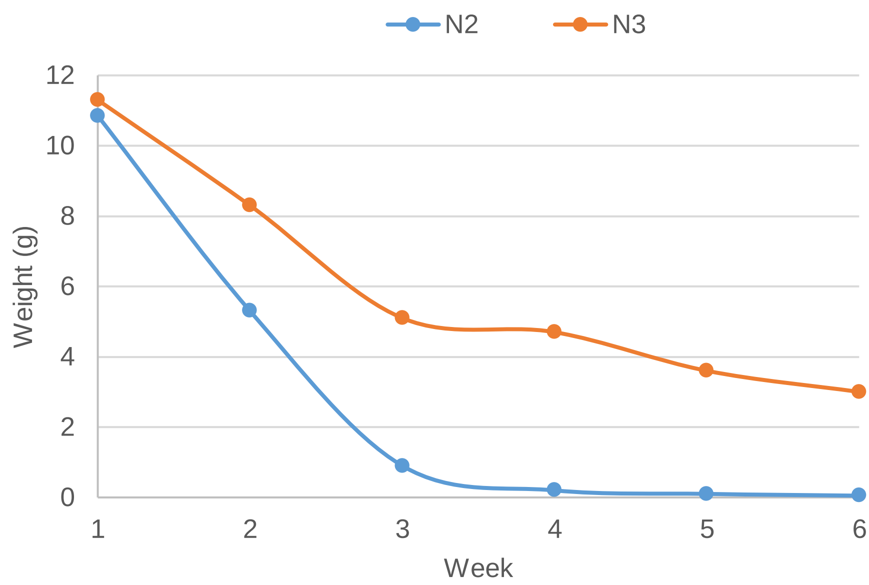
Source: Own elaboration, 2023.

On the degradation of the biomaterial, both the N2 and N3 samples showed shrinkage and a change in color tones, which had an impact on the gravimetric variation of the samples. For the N2 samples, an average mass loss of 0.52% was recorded, and 0.95% of average mass loss for the case of N3, which shows that the biomaterial with the mixture of 10% protein and 15% plasticizer is more resistant to the effect of the environmental conditions tested.

Biodegradability is an important characteristic around the evaluation of the importance of the production of bioplastics. Cevada & Rodríguez (2019) indicate that after 150 days in earthen pots, both the bioplastic made from avocado seeds and corn starch degraded by 100%.

Likewise, Riera (2020) claimed to have obtained a degradation of 89.40% according to the ASTM D-6400 and D-5988 standards, in an evaluation for a sample of corn starch bioplastic period of 42 days. In our experiments, root growth and a significant biodegradation speed of both the N2 and N3 samples was evidenced, which had an impact on their gravimetric variation. Figure 5 shows the weekly average gravimetric variation of the samples tested, both for N2 and N3. After the evaluation period, the N2 sample shown a better behavior in terms of biodegradability, with an average difference of 30% in relation to the average results of the N1 samples. The N2 sample has a higher rate of degradation, and this may be due to the small contents of protein and plasticizer used.

Figure 5: Gravimetric variation during the biodegradability test



Source: Own elaboration, 2023.

The biodegradability results obtained with the bioplastics made from coffee grounds exceed the values obtained in Riera (2020) and equals those obtained by Cevada & Rodríguez (2019). Although the materials used differ from those used in our experiments, it establishes a reference associated with the potential of the characteristics presented by the bioplastics obtained, mainly referred to the protein content and plasticizers used in the preparation.

4. Conclusions

Through an initial exploratory methodology, a biopolymer of different compositions N1, N2 and N3 was synthesized. Regarding the quality of the material obtained, the biomaterial made with the highest proportion of polymer and plasticizer (N2 and N3) presented greater homogeneous mixture and better structure in its elaboration; the properties evaluated were density, water absorption, ignition, solubility, degradation and biodegradability, following processes validated by ASTM (1998) and ASTM (2004).

A 100% biodegradation rate was obtained in less than six weeks in the combinations tested. It also highlights the solubility of the samples in water due to the interaction of the protein with the plasticizer, confirming the hydrophilic characteristic of the material, which constitutes a negative result towards its use as a domestic product.

On the other hand, the material tested under temperatures of up to 70ºC did not show structural damage, contrary to standard common plastics which presents deformation in its structure. In addition, the adequate resistance to weights, and the fact that it can support loads of up to 5 kg without presenting fractures or elongations that can damage its structure, suggests that the material could also be used for the manufacture of bags. The density and resistance characteristics are better for N2 (values that are similar to PVC), the N3 sample exceeds the biodegradability of N2 by 5%, factors that can define the selection of the best combination.

Although this is an initial study initiative for the evaluation of the main characteristics of the bioplastic made from coffee grounds, more tests must be established for other types of parameters such as torsion or deformation, which can be fully verified the resemblance to conventional plastic.

5. References

Acchar, W. & Dultra, E. J. V. (2017). Ceramic Materials from Coffee Bagasse Ash Waste. Springer International Publishing.

American Society of Testing Materials International ASTM (2004). *ASTM, D6400-04. Standard Specification for Compostable Plastics*. Washington, D.C.: ASTM

ASTM (1998). *Standard Test Method for Water Absorption of Plastics1 (ASTM 570-98)*. Washington, D.C.: ASTM

Castellón, C., Tejeda, L., & Tejeda, L. (2016). Evaluación de la degradación ambiental de bolsas plásticas biodegradables. *Informador Técnico (Colombia), 80*, 1, 24–32. Retrieved from https://dialnet.unirioja.es/servlet/articulo?codigo=5767278

Cogua Barrera, H. (2019). *Estudio de la borra de café para su uso en formulaciones de liberación controlada de nutrientes*. (Master's thesis, Universidad Nacional de Colombia, 2019). Retrieved from https://repositorio.unal.edu.co/handle/unal/76039

Dadi D., Mengistie, E., Terefe, G., Getahun, T., Haddis, A., Birke, W., Beyene, A., Luis, P., & Van der Bruggen. (2018) Assessment of the effluent quality of wet coffee processing wastewater and its influence on downstream water quality. *Ecohydrol Hydrobiol*, *18*, 2. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S1642359317300848

Fernández, L. (2016). *Desarrollo de materiales bioplásticos proteicos con elevada capacidad de absorción de agua*. (Doctoral thesis, Universidad de Sevilla, 2016) Retrieved from https://idus.us.es/handle/11441/47788

Fernández-Cortés, Y., Sotto-Rodríguez, K.D., & Vargas-Marín, L.A. (2020). Impactos ambientales de la producción del café, y el aprovechamiento sustentable de los residuos generados. *Producción + Limpia*, *15*, 1, 93-110. Retrieved from http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S1909-04552020000100093

Ibarra, J. (2019). Elaboración de Bioplástico utilizando Residuos de Naranja. (Doctoral thesis, Universidad Católica Boliviana San Pablo, 2019). Retrieved from https://www.bibvirtual.ucb.edu.bo/opac/Record/101005519/Details

Kim, M-S., Min, H-G., Koo, N., Park, J., Lee, S-H., Bak G-I., Kim, J-G. (2014). Effectiveness of spent coffee grounds and its biochar on the amelioration of heavy metals-contaminated water and soil using chemical and biological assessments. *Journal of Environmental Management*, *146*, 124-130. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0301479714003338

Meza, P. (2016). Elaboración de bioplásticos a partir de almidón residual obtenido de peladoras de papa y determinación de su biodegradabilidad a nivel de laboratorio.

(Undergraduate thesis, Universidad Agraria La Molina, 2016) Retrieved from http://repositorio.lamolina.edu.pe/handle/20.500.12996/2016

Morocho-Pilataxi María Cruz, Dalgo-Flores Violeta Maricela, Flores-Fiallos Linda Mariuxi Chango-Lescano Gabriela Cristina (2021). Physical-chemical and mechanical characterization of bioplastics obtained from wheat and barley. Dom. Cien., ISSN: 2477-8818 Vol 7, núm. 4, Agosto Especial 2021, pp. 623-637.

Mussatto, S., Machado, M.S., Martins, S., Teixeira, J.A. (2011). Production, Composition, and Application of Coffee and Its Industrial Residues. *Food Bioprocess Technol*, 4. 661–72. Retrieved from https://findit.dtu.dk/en/catalog/62eb182276b9e1a4400cccc4

Negrin, Y. (2007). Diseño virtual de la práctica de laboratorio "Identificación de sustancias orgánicas ". (Undergraduate thesis, Universidad Central "Marta Abreu" de las Villas, 2007) Retrieved from: http://hdl.handle.net/123456789/313 (20/03/2023).

Ortiz, M. (2019). Evaluación de un bioplástico de almidón de semillas de mango (mangifera indica) con aplicación potencial en envases. (Undergraduate thesis, Universidad El Bosque, 2019) Retrieved from https://repositorio.unbosque.edu.co/handle/20.500.12495/2106

Quintana DN, Sanabria D P, Castro H F, Roa K L, Paredes R A and Vargas Y C (2015). Physical characterization of biopolymers with starch from potato and cassava organic wastes polymerized in water. Journal of Physics: Conference Series, Volume 2139, 8th International Week of Science, Technology & Innovation (8th IWSTI) 21 - 24 September 2021, San José de Cúcuta, Colombia. Retrieved from https://iopscience.iop.org/article/10.1088/1742-6596/2139/1/012015/meta#references

Riera, María Antonieta (2020). Obtaining Bioplastic from Corn Starch (*Zea mays L.*). Universidad Técnica de Manabí, Portoviejo, Ecuador. Facultad de Ciencias Matemáticas, Físicas y Químicas. Departamento de Procesos Químicos. Retrieved from https://revistas.up.ac.pa/index.php/revista_colon_ctn/article/view/1134

Rodríguez- Sandoval Pedro, Medina Sánchez Andrés Felipe, Ariza Oscar Eduardo (2018). Evaluation of the results of the degradation of a bioplastic subjected to composting processes according to ASTM D-6400 and D-5988. Memorias del IV Simposio de Materiales Poliméricos, Cali 13 y 14 de septiembre de 2018 pág. 112-115.

V.R. Preedy (Ed.) (2014). Coffee in health and disease prevention. Academic Press. United Nations. The General Assembly Adopts the 2030 Agenda for Sustainable Development. (2015). Available online: https://www.un.org/sustainabledevelopment/es/2015/09/la- asamblea-general-adopta-la- agenda-2030-para-el-desarrollo-sostenible/ (25/02/ 2023).

Wong-paz, J. E., Sylvain Guyot, P., Rodríguez Herrera, R., Gutiérrez Sánchez, G., Contreras Esquivel, J. C., Saucedo Castañeda, G., & N. Aguilar, C. (2013). Alternativas actuales para el manejo sustentable de los residuos de la Industria del café en México. *Revista Científica de la Universidad Autónoma de Coahuila*, *5(10)*, 34. Retrieved from http://www.actaquimicamexicana.uadec.mx/?p=538

Communication aligned with the Sustainable Development Goals