Proceedings of the 9th World Congress on Mechanical, Chemical, and Material Engineering (MCM'23)
Brunel University, London, United Kingdom - August 06-08, 2023
Paper No. ICMIE 136
DOI: 10.11159/icmie23.136

Evaluation of the Revaluation of the Coffee Husk as Bio-composite

Rosangela Fonseca[1] Maria Elena Perdomo[2]
[1]Universidad Tecnológica Centroamericana (UNITEC)
San Pedro Sula, Cortés, Honduras
r.fonseca@unitec.edu[1], maria_perdomo@unitec.edu[2]

Abstract - In the following experiment, the behaviour of a bio-composite formed from the revaluation of the dry coffee husk from the wet benefit of coffee in the pulping stage has been examined. Bio-composites are created with dried coffee husk as an additive, glycerine as a binder, sodium alginate as a polymeric plasticizer, and purified water as a solvent, using component amounts from a study on coffee bio-composites as a guide. for other uses. The ranges of the mixtures of the experiment were based on the criteria of: less and more than 25% of the total of each component. For the development of the experiment model with mixtures, the Design Expert® program was obtained. 20 runs of coffee husk bio-composites of 100 g each with moulds have been carried out. The bio-composites have been subjected to two mechanical resistance and elongation tests to determine the deformation and elongation that they experienced with an axial load; the resistance and elongation has been calculated to compare the performance of the bio-composites based on their composition, determining that the weight and composition of the bio-composites affect the resistance of the bio-composites. The results of the elongation were not conclusive since the weight of the components must be reduced and the amount of coffee husk must be reduced to obtain more flexible bio-composites. According to the test results, the bio-composites should contain the following amounts of components to optimize their performance: 10 g of vegetable glycerine, 6.12 g of sodium alginate, 39 g of coffee husks, and 44.88 g of purified water. so that the resistance of bio-composites supports up to 5.53 Pa.

Keywords**:** bio-composite, revaluation, coffee husk, traction.

1. Introduction

One of the most important industries in the global food agribusiness is the coffee value chain. Coffee is grown commercially on four continents and consumed on all seven continents [1]. Therefore, coffee is consumed in millions of tons; millions of tons of organic waste are generated throughout the production process of coffee processing that does not represent any commercial value for the market since approximately only 30% of the coffee fruit is part of the final product.

In Honduras, the coffee industry is considered an economic pillar of society. Most of the coffee produced in Honduras is exported, but the residues remain in the country, contaminating the country's environment since only a tiny portion of the residues is used, due to the lack of development of revaluation practices and their management. One of the newest applications and with preliminary studies is the creation of bio-composites from organic waste. Agricultural activities generate annually 140 billion tons of biomass residues in the world [2]. Honduras is economically dependent on the national agricultural industry. Between 2015 and 2020, the country's agricultural sector contributed an average of 14% to the national GDP, positioning the industry in third place in the national economy [3]. According to R. A. Díaz Porras, Gaitán, and David [4], the coffee value chain is extremely relevant for Honduras; the country is positioned among the main producers and exporters in the world.

The advances that have been made in the field of materials science have uncovered the need for further study and analysis of composite materials, especially bio- and nano-composites, which have a greater capacity to meet market requirements compared to monolithic materials [5]. The authors of Khan and Srivastava [6] mention that the development of bio-composite materials can be a solution to the ecological imbalance caused by synthetic materials derived from petroleum, replacing conventional polymeric composites with natural and biodegradable fibres. Numerical analyses have been performed on composite materials with natural fibres from renewable sources to evaluate the behavior of these bio-composites, but in general, it is difficult to predict the effective properties of these composites due to their heterogeneous properties [7]. In the analysis of bio-composites, it has been identified that the properties of the particles that have a better binding capacity with the matrix combine to improve with the properties of the fibres that give resistance to the composite, giving new physical properties to these [8]. Some of the analyses that can be performed on bio composites are their thermal properties determined by thermogravimetric technique and differential calorimetry test and thus determine if the bio composite has thermal stability

[9]. Nano and bio composites present some advantages compared to conventional materials, such as fatigue resistance, impact resistance and stiffness, in addition to corrosion resistance [5].

2. Methods

The process of preparing the supplies and tools for the experiment consisted of drying the coffee pulp in the sun for 80 hours between 7:00 a.m. and 5:00 p.m. (10 hours a day for 8 days) in two mosquito nets and a sand filter. After the coffee pulp was dried, it was transformed into coffee husk, the dry weight of which was recorded using the calibrated digital scale. 6 pounds of coffee husks and 1 pound of waste were produced. After calibrating the digital scale, 650 g of coffee husks were weighed in plastic bags in 50 g packages (13 packages in total). Each heavy coffee husk packet was ground in the "ice crush" cycle of the blender timing the grinding time of each. Each packet of coffee husks was ground for 120 s, divided into four 25-s intervals and one 20-s interval, with a 1-min wait between each interval.

In the stage of the computerized design of the experiment, the portions of the components of the study by Vasco Costa Delgado et al. [10] which deals with the creation of bio-composites from organic residues such as coffee husks, modifying the data for the current experiment. A prototype coffee hull bio composite was created with the recommended proportions of the reference study. Each mixture had to weigh 100 g (wet weight) and incorporate each of the components (additive, plasticizer, binder, and solvent). The defined ranges for the components were less than 25% and more than 25% of the total amount used in the reference study. The data obtained in Design Expert® were entered to obtain an I-optimal design with a quadratic model, 10 points of runs, 5 points of lack-of-fit and 5 points of iterations, obtaining 20 runs, which make up the sample of the experiment.

3. Results

Coffee husk was obtained after the coffee pulp finished drying in the sun. The study by Vasco Costa Delgado et al. [10] on the manufacture of bio composites by 3D extrusion from organic waste including coffee grounds was used as a reference in research on the grammage and textile twisting of coffee husk bio composites. The use of the amounts recommended in the study by Vasco Costa Delgado et al. [10] are presented in Table I minimized the arbitrariness of selecting random numbers of components.

Table 1: Quantities of original components from the reference study by Vasco Costa Delgado et al. [10]

Component	Quantity	Unit
glycerine	10.00	mL
Sodium alginate	5.00	g
Coffee husk	20.00	g
Water	75.00	mL

A prototype was fabricated empirically. The methodology used in the reference study produced substantial results for the production of bio composites with a different approach to that used in the research on twisting and textile grammage; The reference units from mL to g were homogenized based on the density of the liquids, the content percentage was calculated to obtain a weight based on 100 g and divided by 4 to obtain bio-compounds weighing 25 g including the 4 components.

Among the main findings of the investigation of the grammage and textile twisting, the ideal amounts of the bio composites with the least presence of textile twisting and loss of grammage after their respective drying and soaking process are presented in Table II and that were used as reference in the present investigation for resistance and elongation.

Table 2: Quantities of original components from the reference study by Vasco Costa Delgado et al. [10]

Component	Quantity	Unit
glycerine	3.21	g
Sodium alginate	1.94	g
Coffee husk	7.77	g
Water	12.078	g
TOTAL	25.00	g

The values obtained in Table II were rounded to whole numbers. The rounded values in Table II were multiplied by 4 to obtain a total weight of 100 g per bio-compound. The lower and upper range of the proportions of the mixtures were selected as less than 25% and more than 25% of the amount of each component. For the lower limit, 25% of the total value of the component was subtracted from its total value, and for the upper limit, 25% of the total value of the component was added to its total value. The component amounts for the experimental mixtures were acquired by entering the ranges into the Design Expert® program as shown in Table III. Also, Table III shows the results of the calculation of resistance and elongation for each of the bio composites manufactured (Resistance and Elongation).

Table 3: Data of the quantities of components for each run of the experiment in grams

No. Run	Coffee husk	glycerine	Water	Sodium Alginate	Resistance (N/m^2)	Elongation (m)
1	39	13	40	8	2.41	0.99
2	38	16	36	10	2.93	0.96
3	23	10	60	7	3.82	0.98
4	27	10	53	10	4.11	0.99
5	33.5	15.5	40.8	10	2.63	0.98
6	30.5	12.5	51	6	2.22	0.97
7	23	16	55	6	2.24	0.99
8	39	13	40	8	2.46	0.99
9	39	13	40	8	2.37	0.99
10	39	16	39	6	1.87	0.99
11	26	16	50	8	3.75	0.98
12	23	14	53	10	2.67	0.99
13	33	10	47	10	5.51	0.99
14	28	10	56	6	4.01	0.99
15	23	14	53	10	2.74	0.98
16	30	16	46	8	2.15	0.98
17	35	13	46	6	1.72	1.00
18	30	16	46	8	2.06	0.97
19	30.5	12.5	51	6	2.51	0.99
20	39	10	45	6	5.14	1.00

4. Analysis

Based on the results of the model fit summary from the Design Expert® program (Figure 1a), the linear model of resistance response had the highest no-fit p-value and the highest predicted and fitted R^2 values. According to predicted the model explains 20% of the response variable around its mean and adjusted R^2 determines that 40% of the variance dependent variable can be explained by the independent variable of the model. In addition, the adjusted and predicted values have a difference of approximately 0.20, which means that there is no reasoning problem with the data or the model. According to the fit summary of the model of the elongation response of coffee hull bio composites from the Design Expert® program (Figure 1b), neither model is significant since the p-value of lack of fit is greater than 0.05, the predicted R^2 values are all negative; no model fits and the variance, if any, of the response variable cannot be explained by the independent variable of the model.

a.

Source	Sequential p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Linear	**0.0084**	**< 0.0001**	**0.4174**	**0.2067**	**Suggested**
Quadratic	0.0070	0.0004	0.7961	-0.7544	
Special Cubic	**0.0249**	**0.0017**	**0.9341**	**-60.9304**	**Suggested**
Cubic	0.0017		0.9908		**Aliased**

b.

Source	Sequential p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Linear	**0.0991**	**0.2779**	**0.1885**	**-0.1093**	**Suggested**
Quadratic	0.2508	0.3336	0.3322	-1.1511	
Special Cubic	0.2927	0.3457	0.4584	-102.1615	
Cubic	0.3457		0.4658		**Aliased**

Fig. 1: (a) Resistance and (b) elongation response model

In the ANOVA analysis of the resistance response of the coffee hull bio composites from the Design Expert® program (Figure 2a), the p value of 0.0084 of the models indicates that the independent variable is correlated to the dependent variable, that is, in other words, the number of components affect the performance of bio composites with an F value of 5.54 and there is less than 0.84% probability that said F value is obtained due to statistical noise. In the ANOVA of the elongation response of the coffee husk bio-composites from the Design Expert® program (Figure 2b), the p value of 0.0991 of the models indicates that the independent variable is not correlated to the dependent variable, that is, that the quantity of components does not affect the performance of bio composites with an F value of 2.47; It is not significant. The results represent a non-significant lack of fit; there is no obvious violation of the linearity assumption. The model does not predict correctly.

a.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	11.03	3	3.68	5.54	0.0084	significant
(1)Linear Mixture	11.03	3	3.68	5.54	0.0084	
Residual	10.62	16	0.6638			
Lack of Fit	10.57	11	0.9607	91.30	< 0.0001	significant
Pure Error	0.0526	5	0.0105			
Cor Total	21.65	19				

b.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0007	3	0.0002	2.47	0.0991	not significant
(1)Linear Mixture	0.0007	3	0.0002	2.47	0.0991	
Residual	0.0015	16	0.0001			
Lack of Fit	0.0012	11	0.0001	1.75	0.2779	not significant
Pure Error	0.0003	5	0.0001			
Cor Total	0.0022	19				

Fig. 2: ANOVA of the (a) resistance and (b) elongation response

In the lack of fit of the model, the results represent a significant lack of fit; the variation of the points from their predicted values is greater than the variation of the replicates from their mean values and therefore the model may not predict correctly, the replicate runs are so good that their variance is small, or some combination of both, so the residual plot should be studied to understand the behavior of the data.

In the residuals plot (Figure 3) of the Design Expert® program, the points are distributed close to the plotted line. The data show little variation between them. Although the linear model fits the model points significantly, the points fit better than the model points; creates a significant lack of fit. It must be taken into account that the pure error could have been underestimated, the selected model does not fit all the points and an inverse transformation must be considered (Figure 4) or the number of runs must be increased to estimate additional terms. In the residual graph (Figure 3b) resulting from the Design Expert® program, it can be seen that the data have minimal variation between them and are mostly dispersed in the centre of the line. The results of the Design Expert® program do not suggest any transformation of the model, so model adjustment by said means is ruled out. This suggests that there is a problem with the data.

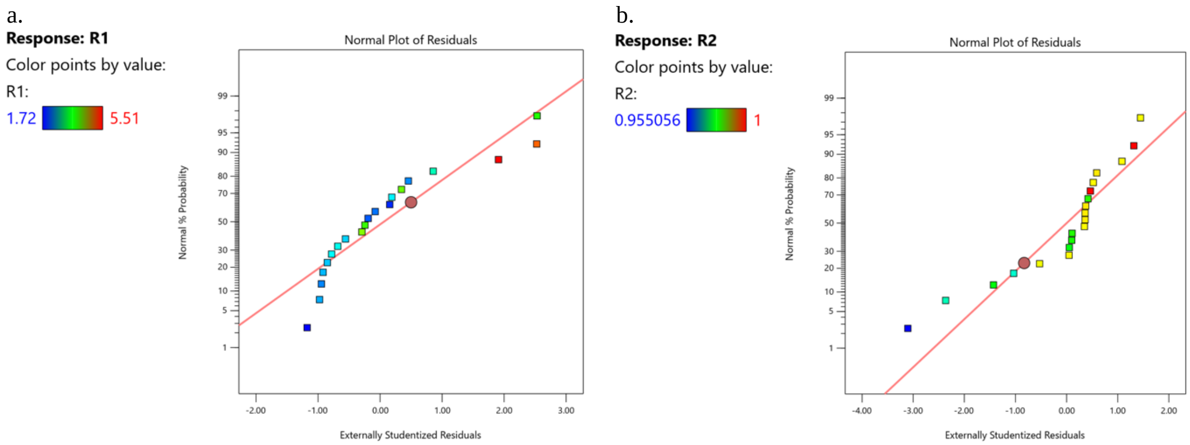

Fig. 3: Normal plot of (a) resistance and (b) elongation response residuals

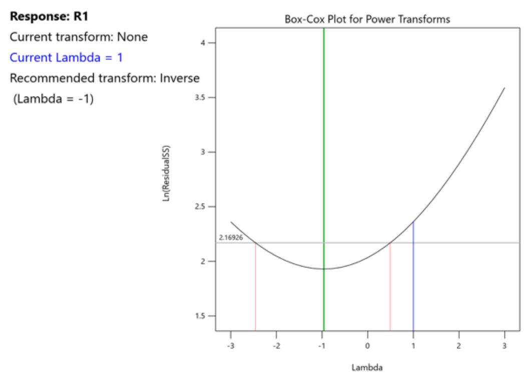

Fig. 4: Suggested transformation plot of resistance response

In the plot of residuals versus predicted (Figure 5a) resulting from the Design Expert® program, no outliers are observed. It is ruled out that the lack of fit comes from outliers that do not fit the model well. Variations between data can be caused by human factors in the bio composite manufacturing process or test setup. Factors other than the independent factors studied affected to some extent the response studied in the data. In the plot of residuals versus predicted (Figure 5b) resulting from the Design Expert® program, no outliers are observed. However, much data is overlapping with minimal variance. In addition, it is observed that the data does not present a clear graphic form related to any of the models studied.

a. b.

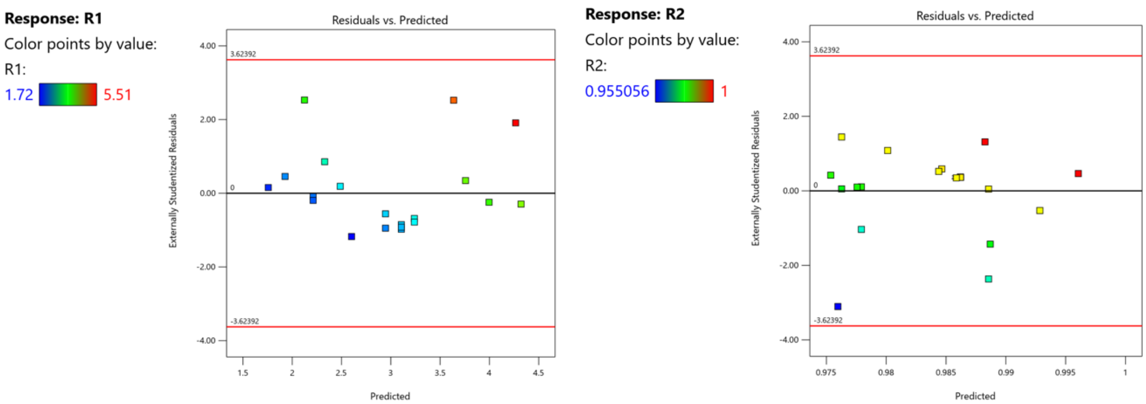

Fig. 5: Plot of residuals and predicted values of the (a) resistance and (b) elongation response

In the graph of residuals versus runs (Figure 6a) resulting from the Design Expert® program, it is verified that there are hidden variables that could have influenced the response during the experiment of the coffee hull bio composites since there is no completely random dispersion, instead the runs of the experiment present a cyclical pattern between data groups. In the plot of residuals versus runs (Figure 6b) resulting from the Design Expert® program, there is a random scatter with scattered values.

a. b.

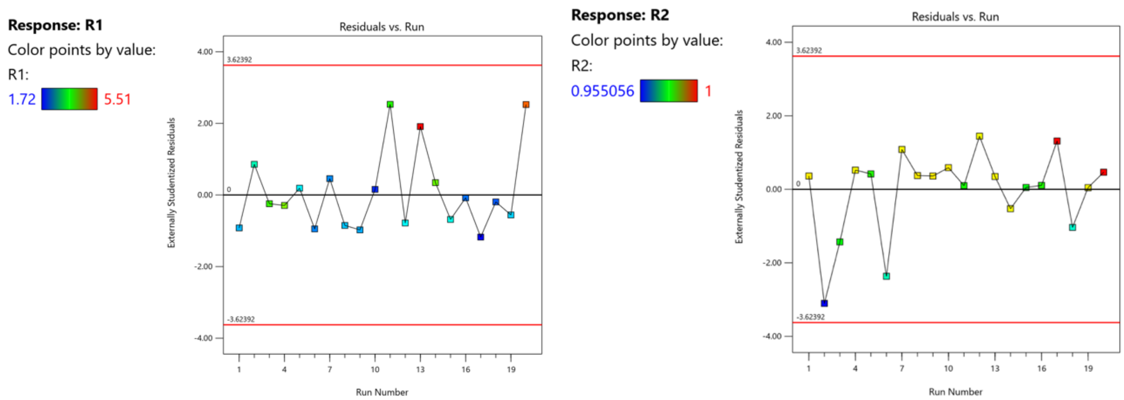

Fig. 6: Plot of residuals and runs of (a) resistance and (b) elongation response

The experimental space of the resistance response of the experiment according to the results of the Design Expert® program (Figure 7a) presents sections with neutral incidence at the ends and in the centre. All components affect to some extent the performance of bio composites. There is no component with a greater incidence in the experimental space with the exception of the coffee husk; the results are based on that variable. The experimental space of the elongation response of the experiment according to the results of the Design Expert® program (Figure 7b) presents a section with a slight incidence at the end of the coffee husk and a lesser influence of sodium alginate and glycerin. Therefore, due to the amounts of coffee husk, it is possible that the model is not suitable for the elongation test and these amounts must be decreased to optimize the response results.

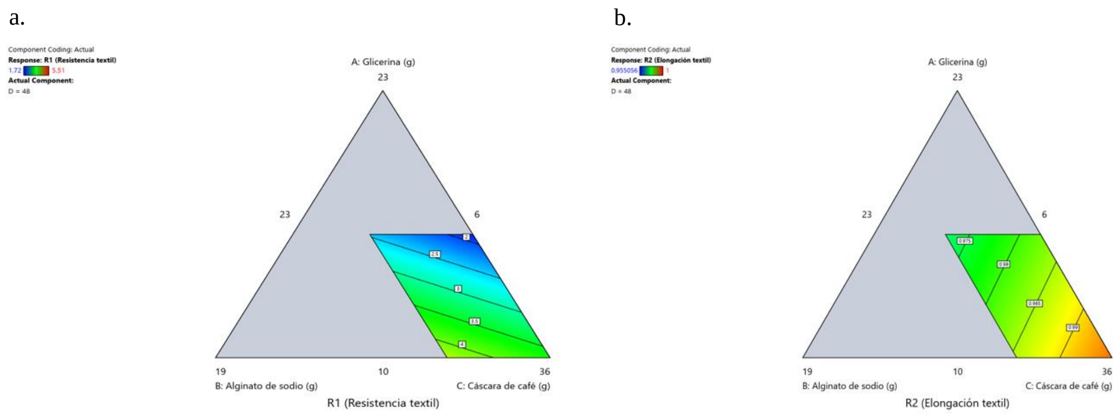

Fig. 7: Experimental space of the (a) resistance and (b) elongation response

Despite the inconclusive results of the elongation of the coffee husk bio composites, a solution was obtained through the Design Expert® program (Figure 8), with which it is intended to optimize the performance of the bio composites by maximizing its strength and elongation. It was obtained that the amounts to be used should be the following: 10 g of glycerine, 6.12 g of sodium alginate, 39 g of coffee husks and 44.88 g of purified water so that the resistance of the bio composites supports up to 5.53 Pa.

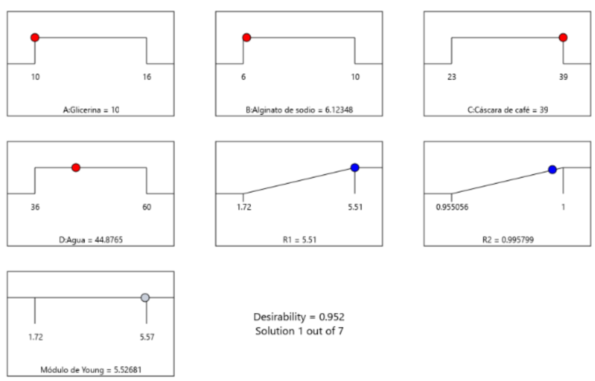

Fig. 8: Optimized response of the quantities of bio composites

4. Conclusion

A series of bio composites were created as an alternative material using coffee husk, a binder (glycerine), plasticizing polymer (sodium alginate) and a solvent (purified water) with the results obtained from an experimental model of grammage and twisted from coffee husk bio-composites. The various compositions of the bio composites were statistically analysed and it was possible to understand how the interactions between the components of the bio composites affect mechanical characteristics of tensile strength and elongation. An objective interpretation of the statistical analysis was carried out on the impact that the proportions of each component generate in the final behaviour of the biomaterial, highlighting potential areas for improvement, solutions to problems that occurred during the experimental phase and future applications. The mechanical characteristics of coffee husk bio composites were revealed. With the amounts of 10 g of glycerine, 6.12 g of sodium alginate, 39 g of coffee husk and 44.88 g of purified water, the optimization of the resistance of up to 5.53 Pa of the coffee husk bio composites is suggested. As future work, the sample of 20 tests should be increased to characterize the material with a higher level of confidence.

References

[1] J. Morris, *Coffee: a global history*. London, UK: Reaktion Books, 2019.

[2] M. Ángel Hidalgo-Salazar, J. Pablo Correa-Aguirre, J. Manuel Montalvo-Navarrete, D. Fernando Lopez-Rodriguez, y A. Felipe Rojas-González, "Recycled Polypropylene-Coffee Husk and Coir Coconut Biocomposites: Morphological, Mechanical, Thermal and Environmental Studies", en *Thermosoftening Plastics*, G. Akın Evingür, Ö. Pekcan, y D. S. Achilias, Eds., IntechOpen, 2020. doi: 10.5772/intechopen.81635.

[3] A. P. Colon-García, G. Catari-Yujra, y E. Alvarado, "Senderos productivos de la bioeconomía: El caso Honduras", *Rev Iberoam Bioecon Cambio Clim*, vol. 7, núm. 14, pp. 1713–1726, nov. 2021, doi: 10.5377/ribcc.v7i14.12820.

[4] R. A. Díaz Porras, G. L. Gaitán, y S. B. David, "Institucionalidad en las Cadenas de Café en Centroamérica", en *Economía, Gobarnanza y Sustentabilidad en América Latina*, 1a ed.México: Universidad Autónoma de Zacatecas "Francisco García Salinas", 2021. [En línea]. Disponible en: https://repositorio.una.ac.cr/bitstream/handle/11056/19409/Institucionalidad%20en%20las%20Cadenas%20de%20Café.pdf?sequence=1&isAllowed=y

[5] M. S. Ali, A. A. Al-Shukri, M. R. Maghami, y C. Gomes, "Nano and bio-composites and their applications: A review", *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1067, núm. 1, p. 012093, feb. 2021, doi: 10.1088/1757-899X/1067/1/012093.

[6] M. Z. R. Khan y S. K. Srivastava, "Development, Characterization and Application Potential of Bio-composites: A Review", *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 404, núm. 1, p. 012028, ago. 2018, doi: 10.1088/1757-899X/404/1/012028.

[7] M. R. Narayana, "Management of Leaf Rust Disease by Household Coffee Farmers in India: Evidence and Implications for Price and Income Effects on Chemical Control", *Agric. Res.*, vol. 5, núm. 1, pp. 43–50, mar. 2016, doi: 10.1007/s40003-015-0191-5.

[8] D. O. Rachmawati y P. Widiarini, "Physical Properties of Bio-Composite Board Reinforced with Shell Particle and Coconut Fiber", *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1115, núm. 1, p. 012068, mar. 2021, doi: 10.1088/1757-899X/1115/1/012068.

[9] M. Athmalingam y W. V. Vicki, "Investigation on Thermal Properties of Kenaf Fibre Reinforced Polyurethane Bio-Composites", *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 303, núm. 1, p. 012011, ene. 2018, doi: 10.1088/1757-899X/303/1/012011.

[10] C. Vasco Costa Delgado, G. A. Da Cunha Santos Forman, y R. L. Antoinette Breuer, "Organic Waste Bio-Based Materials for 3D Extrusion: Eggshells, Shells Sand and Coffee grains with Sodium Alginate", *Converg. - J. Res. Arts Educ.*, vol. 15, núm. 29, pp. 77–87, may 2022, doi: 10.53681/c1514225187514391s.29.133.