Research Article

# Statistical Study of the Influence of Fiber Content, Fiber Length and Critical Length in the Mechanical Behavior of Polymeric Composites Reinforced with Carica Papaya Fibers (CPFs)

Caroliny Santos*, Thiago Santos, Katia Moreira and Marcos Aquino
Textile Engineering Post Graduate Program (PPGET), Federal University of Rio Grande do Norte, Natal, Rio Grande do Norte, Brazil

Rubens Fonseca Lucas Zillio
Department of Textile Engineering, Textile Engineering Laboratory, Federal University of Rio Grande do Norte, Natal, Rio Grande do Norte, Brazil

* Corresponding author. E-mail: carolinyminely@hotmail.com

DOI: 10.14416/j.asep.2021.07.002
Received: 8 February 2021; Revised: 15 April 2021; Accepted: 1 June 2021; Published online: 7 July 2021

## Abstract

Vegetable fibers are excellent substitutes for manmade fibers because they are resistant and sustentables. This article studied the potencial application of Carica Papaya Fibers (CPF) in polymerics composites of natural resin. A simple model of micromechanical analysis was used for prediction of breaking stress, strain and Young's modulus in composites with short fibers of Carica Papaya and matrix of polyurethane resin obtained from Ricinus Communis vegetable. The fiber contents were varied between 10–35% and fiber lengths were varied between 3–6%. The result analysis was performed using analysis of variance (ANOVA) to assess the influence of variables on the mechanical properties of each composite produced. The results showed that that increased in fiber length promoted increase in stress values, while the increase in fiber content favored the increased in the stiffness of the composite.

**Keywords**: Textile composite, Vegetable fibers, Vegetable resins

## 1 Introduction

Textile fibers are a basic unit, natural or manmade, which has a length at least a hundred times longer than its diameter. The presence of polymers with different structures in their composition results in a wide range of chemical, physical and biological properties [1], [2]. There is a range of fiber properties including strength, flexibility, cohesion, fineness, resilience, uniformity, porosity and commercial availability [2]. In this case, each property depends on a number of factors such as the type of polymer (thermoplastic or thermorigid), composition and classification (natural or manmade). Natural fibers are those found in nature while manmade ones are produced and modified by man [2]–[5]. Figure 1 shows the classification of fibers according to their origin.

Natural fibers have vegetable, animal or mineral origin. The natural fibers with vegetable origin are compound by cellulose and lignin. It can be extracted from various parts of plants such as seeds (for example, cotton and kapok), bast (for example, flax, jute, hemp, kenaf and cane) and leaves (for example, pineapple, banana). These fibers can be from cultivated plants for extraction like cotton, flax, hemp and kenaf fiber or be a vegetable by-product like coconut, cane, banana and

Please cite this article as: C. Santos, T. Santos, K. Moreira, M. Aquino, and R. F. L. Zillio, "Statistical study of the influence of fiber content, fiber length and critical length in the mechanical behavior of polymeric composites reinforced with Carica Papaya Fibers (CPFs)," *Applied Science and Engineering Progress*, vol. 14, no. 4, pp. 719–726, Oct.–Dec. 2021, doi: 10.14416/j.asep.2021.07.002.

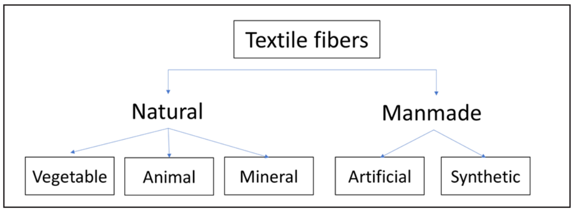

**Figure 1**: Classification of fibers.

pineapple fiber [6]–[9]. Lignocellulose biomass can produces Platform chemicals used in the current market [10]. On than hand, fibers in general have entered in several industrial applications and it's being called technical textiles. Despite the challenge of meeting the final product specifications applied to industrial products, technical textiles are growing and developing quickly in the textile industry. Thus, textiles materials are replacing traditional materials in various sectors of economy such as reinforcements in composite material, with the aim of improving mechanical properties and resistance to exposure to extreme environments [11].

However, the concern over the growing use of non-renewable raw materials is increasing the interest in a new material concept that takes into account environmental issues such as biodegradability, renewability and environmental impact [12]. The increase in environmental awareness also tends to decrease the oil supply. However, it is known natural fibers can take technical applications due to its excellent properties, such as light weight and relatively low costs [13]. Vegetable fibers can replace chemical fibers, as they supply the expected needs, being used in several scientific and commercial projects in the application in geotextiles, automobiles and composites, being important in the sustainable and ecofriendly future [14]–[18].

As already mentioned, vegetable fibers have the possibility to enter the polymeric composites market. However, not all fibers have been frequently investigated in this area, such as the case of the carica papaya fibers (CPF). However, many studies describe CPF fiber performing its characterization [9], [19]–[21].

CPF is fiber extracted from bast in a region between the epidermis and the cortex of the plant [9]. As sisal is a fiber with potential for use in polymeric composites [22]–[24], CPF can also have potential for use in polymeric composites with natural resin.

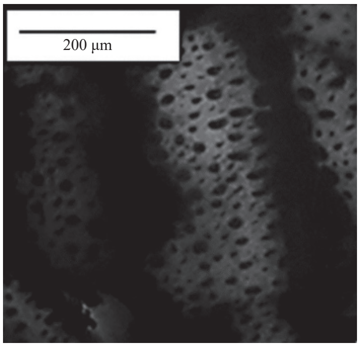

**Figure 2**: Pores of CPF's.

This light fiber has density between 0.62–1.19 g/cm$^3$ depending on the region of the bast where it was extracted and also depending on the chosen method that can be by microbiological or retting action and by physical action as described in work of [9]. This lightness is due to the presence of numerous pores in its cross section which is inherent to the fiber and does not depend directly on the extraction method used [9]. Figure 2 shows the pores present in the cross section of papaya fibers by physical extraction. The physical extraction process is based on the use of pressure and temperature that dissolve non-fibrous compounds, facilitating the extraction of fibers from the papaya tree [9]. This figure was made using passing the fibers through the hole of a perforated steel plate. Then the fibers were cut and subjected to optical micrograph analysis, using the Leica analysis microscope.

Natural fibers can be used in combination with resins which can result in a low-cost composite, with low density and high specific properties [3].

The polyurethane used in this study is a material derived from the *Ricinus communis* oil, a species of shrub. From this vegetable it is possible to produce a series of substances that include a polyurethane resin. Due to its biocompatibility, this resin is investigated in the production of biocomposites [25], [26].

## 2 Materials and Methods

Initially, CPF were extracted by the physical method performed by [9] as shown in Figure 3.

Then, a stress/strain test was performed on these fibers using the ASTM D 3822 standard, as used by [9]. The methodology applied in this work was the same used by [27] in which a micromechanical analysis of the composites was performed. This step was crucial

**Figure 3**: Carica Papaya Fibers (CPF).

because data were manipulated using the design of experiment (DoE), analysis of variance (ANOVA) and response surface methodology (RSM) and the response properties (stress, strain and MOE) were evaluated, analyzed and deeply discussed by analysis of variance (ANOVA) in which includes the coefficient of determination $R^2$, F-value and significance probability (value-$\rho$) in addition to the 3D response surface methodology (RSM) on the Design Expert software for statistical validation of the study. The combination of analysis of variance (ANOVA) and micromechanical analysis was used to analyze and validate the mechanical properties, as used by [22], [23]. The study variables were fiber content, critical length and fiber length, as shown in Tables 1 and 2. All the experimental planning was performed using a factorial design $(2^3)$ of variables with 5 central points and 3 repetitions on the Design Expert version 12 software as shown in Table 1 [28], [29].

**Table 1**: Factorial Planning $(2^3)$ of variables (factors)

| Run | A – Fiber Content | B – Fiber Length | C – Critical Length |
|---|---|---|---|
| 1 | 1 | –1 | –1 |
| 2 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 |
| 5 | 1 | 1 | 1 |
| 6 | 1 | 1 | –1 |
| 7 | –1 | –1 | 1 |
| 8 | 1 | –1 | –1 |
| 9 | 1 | –1 | –1 |
| 10 | 1 | –1 | 1 |
| 11 | 0 | 0 | 0 |
| 12 | –1 | –1 | –1 |
| 13 | –1 | –1 | –1 |
| 14 | –1 | 1 | –1 |
| 15 | –1 | 1 | –1 |
| 16 | 1 | 1 | –1 |
| 17 | –1 | –1 | 1 |
| 18 | 0 | 0 | 0 |
| 19 | –1 | 1 | 1 |
| 20 | –1 | –1 | –1 |
| 21 | 1 | 1 | 1 |
| 22 | 1 | 1 | 1 |
| 23 | 1 | 1 | –1 |
| 24 | 1 | –1 | 1 |
| 25 | –1 | –1 | 1 |
| 26 | –1 | 1 | 1 |
| 27 | –1 | 1 | 1 |
| 28 | 1 | –1 | 1 |
| 29 | –1 | 1 | –1 |

The variables and conditions of the study are described in Table 2.

**Table 2**: Variables and experimentals conditions

| Variables | Type | Low | High |
|---|---|---|---|
| A – Fiber content | Numeric | 10 | 35 |
| B – Fiber length | Numeric | 3 | 6 |
| C – Critical length | Numeric | 5 | 10 |

The power of design of this study is important to analyze, before carrying out the experimental planning, because it provides the power of responses (stress, strain and MOE) for the variables fiber content, critical length and fiber length. Therefore, the ideal is to obtain percentages of power response over than 80% to acquire significant efficiency in the statistical analysis of the variables and their respective experimental conditions. Table 3 shows the power of design [30].

**Table 3**: Power of design response studied

|  | Units | Delta (Signal) | Sigma (Noise) | Signal/ Noise | Power of A, B and C |
|---|---|---|---|---|---|
| Stress | MPa | 2 | 1 | 2 | 99.7% |
| Strain | % | 2 | 1 | 2 |  |
| MOE | MPa | 2 | 1 | 2 |  |

## 3 Results and Discussion

Figure 4 shows the results of stress of CPF composite for the critical length (Lc) of 5, 7.5 and 10. It is evident that the fiber content negatively influences the stress results of the composite. Thus, by increasing fiber content from 10% to 35% [Figure 4(a) and (b)], stress decreases significantly for any fiber length, which can be less than 29%. This value can be less than 29% [Figure 4(c) and (d)], and can be up to approximately 31% [Figure 4(e) and (f)]. On the other hand, when fiber length increases, the result of stress suffers a positive variation, increasing its value for any fiber content, which can be more than 9.1% [Figure 4(a) and (b)], up to approximately 4.2%, [Figure 4(c) and (d)] and which can be up to approximately 5% [Figure 4(e) and (f)]. From what has been observed, it is evident that for any critical length (5, 7.5 or 10), fiber content has a negative influence on stress, varying from 29 to 31% while fiber length influences positively in the stress, which can vary from 4.2 to 9.1%. Thus, to Lc = 5 composite was the composite that most influenced positively in relation to fiber length (9% increase in stress value). The Lc = 10 composite was the composite that most negatively influenced the fiber content (31% decrease in stress value). The content of natural fibers strongly influences the mechanical properties of polymeric composites and can increase or decrease the mechanical strength. When fiber content is high and the amount of resin is low, the fibers may not be fully saturated due to insufficient filling of the polymer amount [31]. On the other hand, when fiber content is in the appropriate amount, the mechanical strength of the composite increases, as noted by [32]. Therefore, it is important to observe the maximum and minimum values required for fiber content to increase the mechanical strength of composite. For fiber length, the effects on the mechanical properties of short fiber reinforced composites generally increase the mechanical strength with the increase in fiber length [33], [34], confirming what was observed in this work for the stress results.

Figure 5 shows the results of strain of CPF composite for the critical length (Lc) of 5, 7.5 and 10. For Lc = 5 Figure 5(a) and (b)] the increase in fiber length decreases strain by 1.38% and the increase in fiber content increases strain by 2.7%. For Lc = 7.5 [Figure 5(c) and (d)], the increase fiber lenght increases strain by 5.94% and the increase in fiber content decreases strain by 2.25%. For Lc = 10 [Figure 5(d) and (e)], the increase in fiber length increases strain by 12% and the increase in fiber content decreases strain by 6.6%. For any critical length (Lc) and fiber length, strain is increased by increasing fiber content. For any fiber content, strain is decreased by increasing the fiber length. In other words, the increase in fiber length tends to decrease strain, while fiber content tends to increase strain.

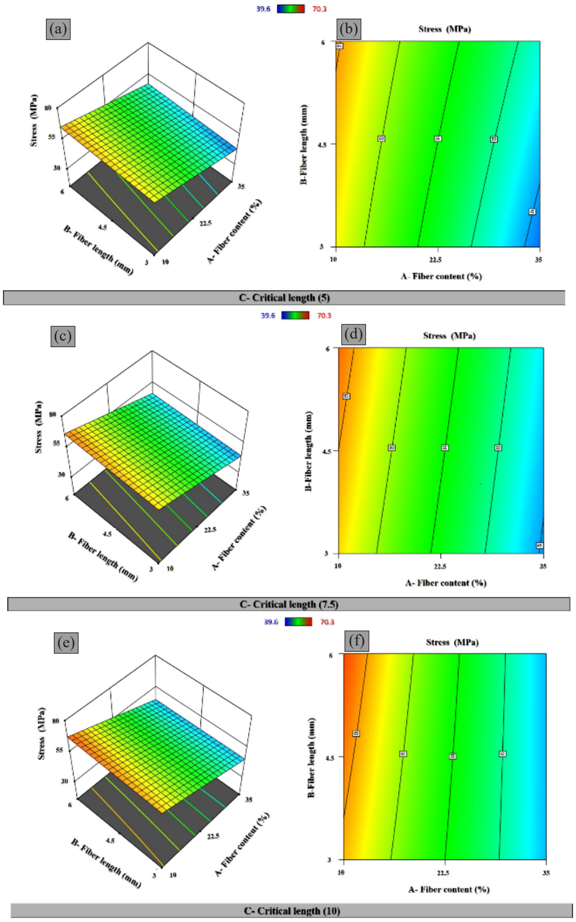

**Figure 4**: Stress for all the Critical lengths.

Figure 6 shows the results of MOE of the CPF composite for the critical length (Lc) of 5, 7.5 and 10. For Lc of 5 [Figure 6(a) and (b)], it is evident that when fiber length increases, MOE also increases by approximately 12.19%. For Lc of 7.5, [Figure 6(c) and (d)], when fiber length increases to any fiber content value, MOE decreases by 4.4%, approximately. For

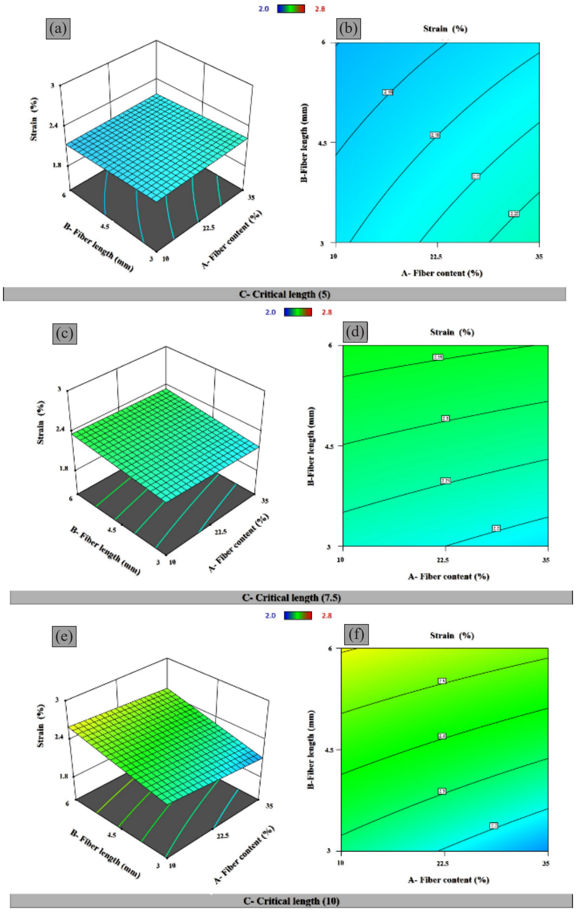

**Figure 5**: Strain for all the Critical lengths.

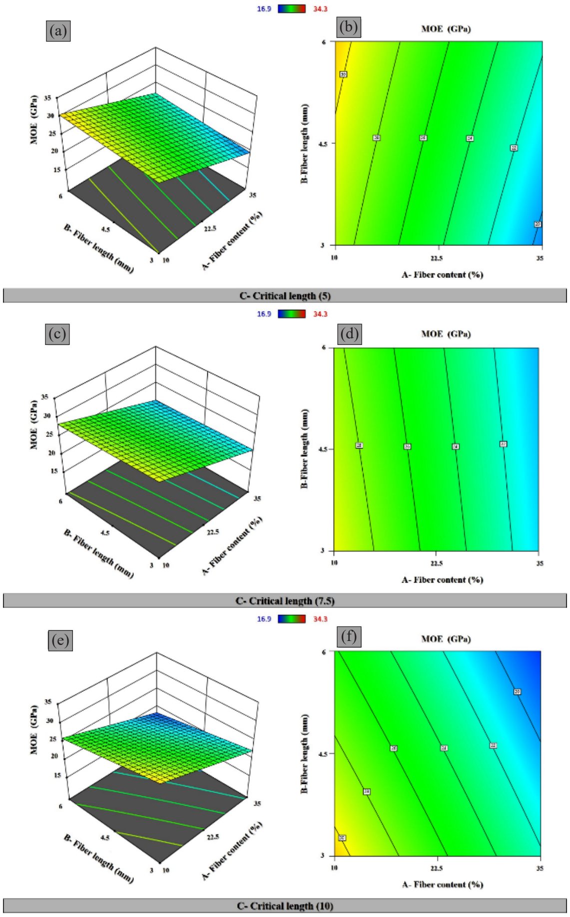

**Figure 6**: MOE for all the Critical lengths.

Lc = 10 [Figure 6(d) and (e)], the MOE decreases when the fiber content increases.

On the other hand, when fiber content increases, MOE decreases for any critical length (Lc) value can be up to approximately 30.37%. It is concluded that, for the critical length of 10, the highest MOE is found in the shortest fiber length with the lowest fiber content in this composite [30].

The F-value model of stress (34.68), strain (2.97) and MOE (13.34) implies the model is significant. There are only 0.01%, 2.65% 0.01% (stress, strain and MOE, respectively) chance that a F-value larger as this could occur due to noise. Further, $\rho$-values less than 0.0500 indicates the model terms are significant. In this case A, B were significant model terms for stress, in the case of strain property B, C, BC were significant, as well as, for MOE property A, BC were significant model terms as shown in Table 4. However, for each response studied using Design of Experiments (DoE) it is noticed that the studied properties are able to describe the mechanical behavior of the studied reinforcement with CPF composites. Thus, the average obtained from stress (56.03 ± 3.08 MPa), strain (2.32 ± 0.19%) and MOE (25.47 ± 2.34%) were significant standard deviations due to the low dispersion of the data. Then, the coefficient of variation (CV%), stress (5.49%), strain (7.93%) and MOE (9.19%) of this statistical model is significant. Finally, from the variables studied (A- fiber content, B- fiber length and C- critical length) and the interactions (AB, AC, BC and ABC), it was possible to evaluate the mechanical behavior and mechanical improvement of the composites manufactured with carica papaya fibers. All the response variables studied showed good correlation

**Table 4**: ANOVA of stress, strain and MOE results of the reinforcement of CPF composites studied

| | **Stress (MPa)** | | **Strain (%)** | | **MOE (MPa)** | |
|---|---|---|---|---|---|---|
| | **Value - F** | **Value - p (Prob > F)** | **Value - F** | **Value - p (Prob > F)** | **Value - F** | **Value - p (Prob > F)** |
| Model | 34.68 | < 0.0001 | 2.97 | 0.0265 | 13.34 | < 0.0001 |
| A – Fiber content | 235.29 | < 0.0001 | 0.2492 | 0.6231 | 79.61 | < 0.0001 |
| B – Fiber length | 4.39 | 0.0491 | 4.58 | 0.0449 | 1.09 | 0.3098 |
| C – Critical length | 0.4412 | 0.5141 | 6.88 | 0.0163 | 1.09 | 0.3098 |
| AB | 0.0866 | 0.7716 | 0.0284 | 0.8679 | 0.1315 | 0.7207 |
| AC | 0.7769 | 0.3885 | 1.30 | 0.2682 | 0.1315 | 0.7207 |
| BC | 0.6993 | 0.4129 | 7.63 | 0.0120 | 11.33 | 0.0031 |
| ABC | 1.06 | 0.3147 | 0.0938 | 0.7626 | 0.0037 | 0.9521 |
| Standard dev. | 3.08 | | 0.19 | | 2.34 | |
| Mean | 56.03 | | 2.32 | | 25.47 | |
| C.V. % | 5.49 | | 7.93 | | 9.19 | |
| $R^2$ | 0.93 | | 0.51 | | 0.83 | |

coefficient ($R^2$) between the experimental data and the statistical model used [35], [36].

## 4 Conclusions

Natural fiber composites are one of the many types of textile composite more studied for researchers. Then, on the statistical study of carica papaya fiber composites was concluded that the increase in fiber content, for stress results, in any Critical Lenght, promoted a significant reduction in stress values. On the other hand, the increase in fiber lenght promoted a significant increase in stress, mainly for Lc = 5. It was observed also that the mechanical behavior of strain is significantly influenced by the values of Lc (5, 7.5 and 10). For Lc = 7.5 and Lc = 10, the increase in fiber content favored the decrease in the strain of the samples. When evaluating the fiber length and the Lc, it was observed that these variables favor increase and improve the mechanical behavior (strain) in a directly proportional way. Significantly higher values were obtained for the results of the MOE in samples with Lc = 5, with greater fiber lenght (6 mm) and less fiber content (10%). Significantly lower MOE results were obtained for the other samples (Lc = 7.5 and Lc = 10), where it was observed that the increase in fiber content and fiber lenght results in lower values of MOE. Thus, for any value of Lc, the MOE is significantly reduced when the fiber content and fiber lenght values increase.

## Acknowledgments

This research was supported by our Lord. We thank our col-leagues at the Textile Quality Control Laboratory - LABCTEX and Textile Engineering Post Graduate Program - PPgET at theFederal University of Rio Grande do Norte.

## References

[1] Y. Qin, "A brief description of textile fibers" in *Medical Textile Materials*. Amsterdam, Netherlands: Elsevier, 2016, pp. 23–42.

[2] H. V. S. Murthy, "Fibre characteristics," in *Introduction to Textile Fibres*. New Delhi, India: Woodhead Publishing, 2016. pp 1–25.

[3] D. N. Saheb and J. P. Jog, "Natural fiber polymer composites: A review," *Advances in Polymer Technology*, vol. 18, pp. 351–363, 1999.

[4] C. Santos, T. Santos, R. Fonseca, K. Melo, and M. Aquino, "Phenolic resin and its derivatives" in *Phenolic Polymers Based Composite Materials*. Singapore: Springer, 2020, pp. 1–11.

[5] T. Santos, C. Santos, R. Fonseca, K. Melo, and M. Aquino, "Natural fibres based phenolic composites" in *Phenolic Polymers Based Composite Materials*. Singapore: Springer, 2020, pp. 65–75.

[6] M. El-Kashouti, S. Elhadad, and K. Abdel-Zaher, "Printing technology on textile fibers: Review,"

*Journal of Textiles Coloration and Polymer Science*, vol 16,, pp. 129–138, 2019.

[7] I. Markova, "Natural cellulosic fibers" in *Textile Fiber Microscopy: A Practical Approach*. New Jersey: Willey, 2019, pp. 1–30.

[8] A. Jain, D. Rastogi, and B. Chanana, "Bast and leaf fibres: A comprehensive review," *International Journal of Home Science*, vol. 2, no. 1, pp. 313–317, 2016.

[9] C. Santos, "Extração e caracterização das fibras do mamoeiro," M.S. thesis, Engenharia Têxtil, Universidade Federal do Rio Grande do Norte, Rio Grande do Norte, Brazil, 2019.

[10] Y.-S. Cheng, P. Mutrakulcharoen, S. Chuetor, K. Cheenkachorn, P. Tantayotai, E. J. Panakkal, and M. Sriariyanun, "Recent situation and progress in biorefining process of lignocellulosic biomass: Toward green economy," *Applied Science Engineering Progress*, vol. 13, no. 4, pp. 299–311, 2020, doi : 10.14416/j.asep.2020.08.002.

[11] H. Jamshaid, "Basalt fiber and its applications," *Textile Engineering and Fashion Technology*, vol. 1, pp. 254–255, 2017.

[12] S. Amico, "Vegetable fibers as multifunctional materials," *Matéria (Rio Janeiro)*, vol. 15, pp. 355–363, 2010.

[13] R. Dunne, D. Desai, R. Sadiku, and J. Jayaramudu, "A review of natural fibres, their sustainability and automotive applications," *Journal of Reinforced Plastics and Composites*, vol. 17, pp. 1041–1050, 2016.

[14] C. R. Costa, A. Ratti, and B. Curto, "Product development using vegetable fibers," *International Journal of Design & Nature and Ecodynamics*, vol. 9, pp. 237–244, 2014.

[15] K. Moreira, T. Santos, C. Santos, R. Fonseca, M. Melo, and M. Aquino, "Analysis of the physical and mechanical properties of a biobased composite with sisal powder," in *Biobased Composites: Processing, Characterization, Properties, and Applications*. New Jersey: Wiley, 2021, pp. 143–151.

[16] K. Melo, T. Santos, C. Santos, R. Fonseca, N. Dantas, and M. Aquino, "Influence of Fiber content in the water absorption and mechanical properties of sisal fiber powder composites," in *Hybrid Fiber Composites*. New Jersey: Wiley, 2020, pp. 369–380.

[17] K. Melo, T. Santos, C. Santos, R. Fonseca, N. Dantas, and M. Aquino, "Experimental analysis of styrene, particle size, and fiber content in the mechanical properties of sisal fiber powder composites," in *Hybrid Fiber Composites*. New Jersey: Wiley, 2020, pp. 351–367.

[18] A. Saravanakumaar, A. Senthilkumar, S. S. Saravanakumar, S. M. Rangappa, and A. Khan, "Impact of alkali treatment on physico-chemical, thermal, structural and tensile properties of Carica papaya bark fibers," *International Journal Polymer Analysis and Characterization*, vol, 23, pp. 529–536, 2018.

[19] A. Kempe, A. Göhre, T. Lautenschläger, A. Rudolf, M. Eder, and C. Neinhuis, "Evaluation of bast fibres of the stem of *Carica papaya* L. for application as reinforcing material in green composites," *Annual Research & Review in Biology*, vol 6, pp. 245–252, 2015.

[20] A. S. Kumaar, A. Senthilkumar, T. Sornakumar, S. S. Saravanakumar, and V. Arthanariesewaran, "Physicochemical properties of new cellulosic fiber extracted from *Carica papaya* bark," *Journal of Natural Fibers*, vol. 16, pp. 175–184, 2017.

[21] K. Melo, T. Santos, C. Santos, R. Fonseca, N. Lucena, J. Medeiros, and M. Aquino, "Study of the reuse potential of the sisal fibers powder as a particulate material in polymer composites," *Journal of Materials Research and Technology*, vol. 8, pp. 4019–4025, 2019.

[22] L. Zílio, M. Dias, T. Santos, C. Santos, R. Fonseca, A. Amaral, and M. S. Aquino, "Characterization and statistical analysis of the mechanical behavior of knitted structures used to reinforce composites: Yarn compositions and float stitches," *Journal of Materials Research and Technology*, vol. 9, pp. 8323–8336, 2020.

[23] P. Joseph, K. Joseph, and S. Thomas, "Effect of processing variables on the mechanical properties of sisal-fiber-reinforced polypropylene composites," *Composites Science and Technology*, vol. 59, no. 11, pp. 1625–1640, 1999.

[24] L. Rohen, F. Margem, S. Monteiro, C. Vieira, B. Madeira de Araujo, and E. Lima, "Ballistic efficiency of an individual epoxy composite reinforced with sisal fibers in multilayered armor," *Materials Research*, vol. 18, pp. 55–62, 2015.

[25] T. Sousa, M. Costa, R. Guilherme, W. Orcini, L. Holgado, A. Magdalena, S. Cantazaro-Guimarães, and A. Kinoshita, "Polyurethane derived from *Ricinus Communis* as graft for bone defect treatments," *Polímeros*, vol. 28, pp. 246–255, 2018.

[26] M. Laranjeira, C. Rezende, M. Sá, and C. Silva, "Implantes de resina de poliuretana vegetal (*Ricinus communis*) na tração linear, fixação e fusão vertebral no cão: Estudo experimental," *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, vol. 56, pp. 602–609, 2004.

[27] A. Casaril, E. Gomes, M. Soares, M. Fredel, and H. Al-Qureshi, "Análise micromecânica dos compósitos com fibras curtas e partículas," *Matéria (Rio Janeiro)*, vol 12, pp. 408–419, 2007.

[28] T. Santos, C. Santos, M. Aquino, F. Oliveira, and J. Medeiros, "Statistical study of performance properties to impact of Kevlar® woven impregnated with Non-Newtonian Fluid (NNF)," *Journal of Materials Research and Technology*, vol. 9, pp. 3330–3339, 2020.

[29] R. Nonato and B. Bonse, "A study of PP/PET composites: Factorial design, mechanical and thermal properties," *Polymer Testing*, vol 56, pp. 167–173, 2016.

[30] L. Á. Olveira, J. Santos, T. Panzera, R. Freire, L. Vieira, and J. Rubio, "Investigations on short coir fibre–reinforced composites via full factorial design," *Polymers and Polymers Composites*, vol 26, pp. 391–399, 2018.

[31] S. Salman, Z. Leman, M. Sultan, M. Ishak, and F. Cardona, "Influence of fiber content on mechanical and morphological properties of woven kenaf reinforced PVB film produced using a hot press technique," *International Journal of Polymer Science*, vol. 2016, pp. 1–11, 2016.

[32] D. Romanzini, A. Lavoratti, H. Ornaghi, S. Amico, and A. Zattera, "Influence of fiber content on the mechanical and dynamic mechanical properties of glass/ramie polymer composites," *Materials & Design*, vol. 47, pp. 9–15, 2013.

[33] C. Capela, S. Oliveira, J. Pestana, and J. Ferreira, "Effect of fiber length on the mechanical properties of high dosage carbon reinforced," *Procedia Structural Integrity*, vol. 5, pp. 539–546, 2017.

[34] S. Rangappa, S. Siengchin, and H. Dhakal, "Green-composites: Ecofriendly and sustainability," *Appliede Science Engineering Progress*, vol 13, no. 3, p. 183, 2020, doi: 10.14416/j.asep.2020.06.001.

[35] S. Thiagamani, S. Krishnasamy, and S. Siengchin, "Challenges of biodegradable polymers: An environmental perspective," *Applied Science and Engineering Progress*, vol 12, vol. 3, p. 149, 2019, doi: 10.14416/j.asep.2019.03.002.

[36] M. Jawaid and S. Siengchin, "Hybrid composites: A versatile materials for future," *Applied Science and Engineering Progress*, vol 12, no. 4, p. 223, 2019, doi: 10.14416/j.asep.2019.09.002.