Influence of Carnauba Wax on the Physical and Mechanical Properties of PBS/PLA/Vegetable Fibers Blend Composites

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Polymeric composites with vegetable fibers have attracted academic and industrial attention due to their ease of obtaining, combination of intrinsic properties, and environmental concerns. PBS/PLA blends reinforced with vegetable fibers from the coffee industry enhance sustainability and circular-economy characteristics. To increase the hydrophobicity and surface quality of polymer composites, carnauba wax proved an excellent alternative, given its organic nature, versatility, and compatibility with biopolymers. Therefore, this study had the objective to evaluate the influence of wax addition on the physical and mechanical wettability properties of PBS/PLA/vegetable fiber blend composites. The presence of wax in the 40% vegetable fiber formulation improved fiber cohesion and distribution, resulting in greater flexibility. Furthermore, in both formulations containing wax, an improvement in the contact angle was observed, with only the one containing 40% fiber reaching an angle greater than 90°, characteristic of hydrophobic materials, corroborating the theory of the wax's plasticizing action in this formulation.

Keywords: Polymer Blends. Carnauba Wax. PBS. Barrier Agent.

Polymeric blends have attracted significant attention, both from an academic and an industrial point of view, due to the relative ease of obtaining and developing new synthetic routes at relatively low cost through combinations of polymers with the properties of interest [1,2].

So, biopolymers have highlighted blend technology, as their properties can be improved and their processability enhanced. The PBS/PLA/Vegetable Fiber blend is an example of this, as PLA has several advantages such as a large processing scale, good rigidity, and resistance, however, it has a high cost, low capacity to absorb energy, low deformation to the point of rupture and, therefore, at levels of high mechanical demand, its use is limited [3].

To minimize these limitations, PBS is added, a biodegradable aliphatic polyester with good thermal stability and resistance to solvents and other chemicals, excellent processability, and low production cost [4,5]. Vegetable fiber, originating from coffee processing residues, aims to add distinct mechanical and organoleptic characteristics to the material, in addition to serving as a sustainable and economically viable alternative for disposing of these residues, since, when in environments conducive to degradation, it degrades through the action of microorganisms.

Aiming at the application of this polymeric blend in the packaging industry, the great challenge focuses on improving the permeability property to water vapor, since the transfer of moisture, whether through loss or gain of water with the external environment, favors the formation of lumps and microbial growth, in addition to reducing the crispiness of food, when it is destined for the food sector [6]. Conversely, for the plastics industry, the application challenge focuses on improving product surface quality, dispersing fillers and pigments, enhancing resistance to degradation, and improving material flexibility.

Carnauba wax is an excellent proposed solution, offering versatility, high compatibility, low molecular polarity, cost reduction, increased competitiveness in the current market, and being a natural product derived from organic, renewable sources that causes progressively smaller environmental impact [7].

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This study evaluated the effect of wax addition on the physical and mechanical properties and wettability of PBS/PLA/vegetable fiber blend composites, verifying its potential as a barrier agent for applications in the packaging and surface sectors.

Materials and Methods

The methodological process adopted for this study included drying and dehumidifying the raw materials, processing and molding the compounds, and, finally, characterizing and testing the specimens. PBS and vegetable fiber from coffee processing were dried at 90 °C for 48 hours, while PLA was dried at 70 °C for 4 hours. The extrusion process occurred using the formulations presented in Table 1, using an IMACOM twin-screw co-rotational extruder, Figure 1A - model DRC 30:40 IF, screw diameter of 30 mm, and L/D ratio of 40 - screw speed 116 rpm, and temperature zones equal to Z1 and Z2: 80 °C, Z3: 90 °C, Z4: 115 °C, Z5 and Z6: 150 °C, Z7: 160 °C, Z8: 155 °C, Z9: 160 °C, Z10: 145 °C and Z11: 33 °C.

Results and Discussion

Vegetable fibers can act as structural reinforcements within the polymer matrix, improving the tensile strength of the compound by providing high specific resistance, which contributes to the material's ability to withstand loads. However, Table 2 shows that the formulation containing 40% fiber (FR40) had a decrease in maximum stress and specific deformation, while the modulus of elasticity increased compared to the formulation containing 30% fiber (FR30).

A possible explanation is that, when passing certain "acceptable" filler levels, not all particles were allowed to be wetted by the polymeric matrix in the molten state, indicating that the chemical interaction at the fiber-matrix interface was less efficient than expected [8]. As a result of a possible

Table 1. Composition of formulations.

Formulations	(%)			
	PBS	PLA	Vegetable Fibers	Carnauba Wax
FC40	50	10	39.5	0.5
FC30	60		29.5	
FC40	50		40	0
FC30	60		30	

Figure 1. Equipment for processing and testing composites. A) IMACOM extruder; B) ROMI injection molding machine; C) Universal mechanical testing machine; D) Impact testing equipment.

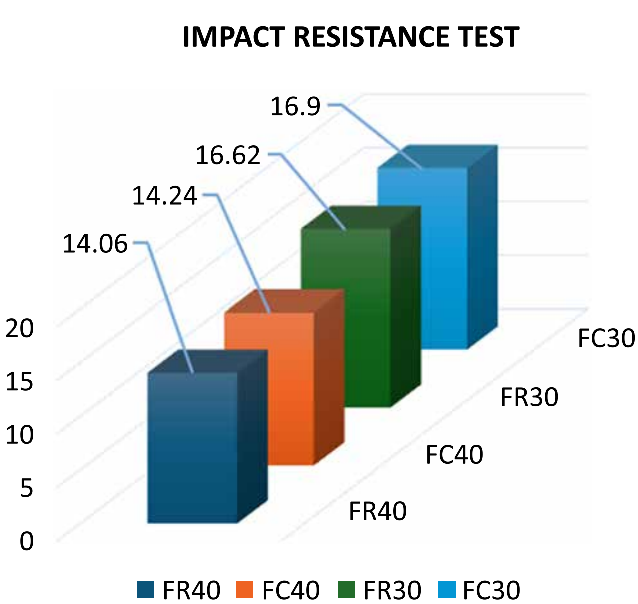
Table 2. Data from mechanical tests: Maximum strength, modulus of elasticity, and specific rupture strain.

Composition	Tension Force Max. (MPa)	Modulus of elasticity (MPa)	Def. Spec. breaking (%)
FC40	15.73 ± 0.61	1675 ± 63.61	3,162 ± 0.30
FR40	16.25 ± 0.37	1638 ± 40.14	2,940 ± 0.18
FC30	17.47± 0.35	1460 ± 39.45	3,648 ± 0.16
FR30	17.35± 0.34	1439 ± 50.92	3,741 ± 0.36

non-uniform distribution of the fiber in the matrix, some agglomerates of poorly cohesive fibers may have been formed, generating small voids and/or defined stress points. Another hypothesis is that fillers stiffer than the matrix may increase the composite's elastic modulus.

Taken together, the analysis in Figure 2 shows a greater impact resistance for the compound with 30% (FR30) than for the one with 40% (FR40), corroborating the idea that in FR40 there was no good promotion of the interaction between the fiber and the matrix, in addition to the development of several tension points that reduce the capacity to absorb energy before failure, thus compromising the mechanical performance of the assembly.

Figure 2. Impact resistance test.



Considering these circumstances, carnauba wax may be an option for improving the interaction between the materials in the composite blend, given its chemical properties, good compatibility, and low molecular polarity. Therefore, when the wax was applied, the FC40 formulation showed a 3.2% reduction in maximum tension.

This behavior can be explained by a possible plasticizing effect of the wax, which enhances cohesion between the polymer blend and the vegetable fiber, thereby increasing the material's flexibility, as evidenced by the slight variation in deformation capacity of this formulation.

However, the modulus of elasticity of FC40 did not show any significant variation, remaining within the margin of error (Table 2). This can be inferred from the fact that the wax improved the cohesion between the fibers and the polymeric matrix, and from the uniform distribution of loads, reducing stress concentrations and delamination.

However, because the material has a high fiber content and a PLA matrix with a high modulus of elasticity, this performance was not demonstrated. For FC30, since it already has a more acceptable level of vegetable fillers in the blend, we observe that the addition of wax did not influence the mechanical properties of the material in such a way that in FC40, this followed a trend already expected for composites with vegetable fillers and the values of stress, modulus of elasticity and specific deformation remained within the margin of error of the data. Thus, in this material, the wax in question facilitated particle mobility during the extrusion process, reduced the tendency of the material to adhere to surfaces, and improved the surface quality of the products.

In terms of impact resistance, Figure 2 shows that, when comparing the FC40 and FC30 formulations with their FR40 and FR30 counterparts, respectively, the presence of PLA and carnauba wax increased impact resistance slightly. This is due to the wax, which improves the cohesion between the polymer blend and the vegetable fiber through its potential for plasticizing and compatibilizing. At the same time, the PLA contributes to the material's rigidity.

However, impact resistance is still limited by the high fiber content. Thus, it is noted that FC30 exhibits the highest impact resistance among the samples, due to the optimized amount of vegetable fiber, which allows good distribution and interaction with the PBS matrix, resulting in a material that effectively balances stiffness and impact resistance.

The contact angle analysis, in turn, aims to evaluate the wettability and surface adhesion properties of materials, providing crucial information on surface energy, interfacial interactions, and potential applications across coatings, adhesives, and biomaterials.

Figure 3 shows that the FC40 and FC30 formulations improved the contact angle, indicating that the use of wax may have enhanced the composite surfaces, increasing their hydrophobicity. However, only the increase in FC40 was sufficient to reach an angle greater than 90°, characteristic of hydrophobic specimens, in which there is no wettability, which reaffirms the theory of the plasticizing action of wax when 40% of vegetable fiber is present.

Conclusion

Therefore, it is concluded that the formulations developed with wax, FC40, and FC30 demonstrated improvements in hydrophobicity properties and impact resistance, with variable performance depending on the fiber content. These formulations are promising for applications that require moisture-barrier properties, due to their low wettability, and can enable greater process speed in automatic packaging machines. The information obtained is relevant for the optimization of polymeric materials to meet specific demands in various industrial applications and to strengthen the circular economy.

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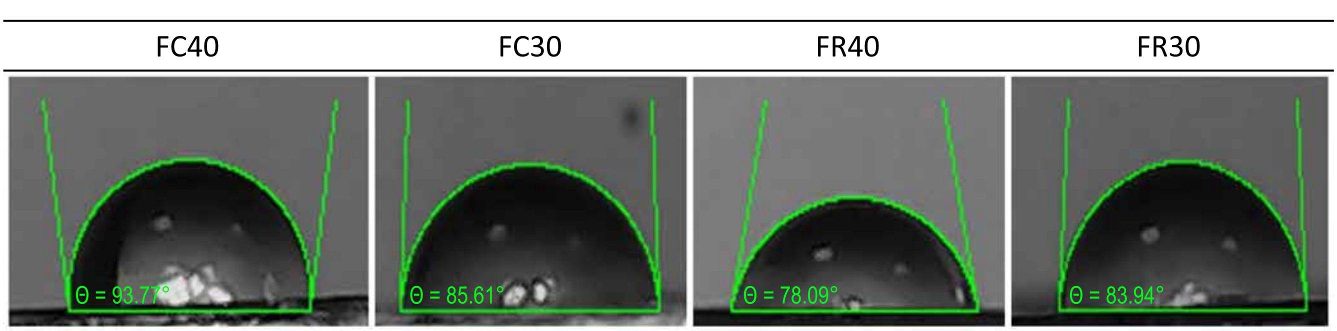
Figure 3. Contact angle test.



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