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Review

A Review on Thermoplastic or Thermosetting Polymeric Matrices Used in Polymeric Composites Manufactured with Banana Fibers from the Pseudostem

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Abstract: Recent manufacturing advancements have led to the fabrication of polymeric composites (PC) reinforced with fibers. However, to reduce the impact on the environment, efforts have been made to replace synthetic fibers (SF) by natural fibers (NF) in many applications. NF, e.g., as banana fibers (BF) possess higher cellulose content, a higher degree of polymerization of cellulose, and a lower microfibrillar angle (MFA), which are crucial factors for the mechanical properties (MP), namely tensile modulus (TM) and tensile strength (TS), and many other properties that make them suitable for the reinforcement of PC. This review paper presents an attempt to highlight some recent findings on the MP of PC reinforced with unmodified or modified BF (UBF, MBF), which were incorporated into unmodified or modified (synthetic (SPM) or a bio (BPM)) polymeric matrices (UPM, MPM). The experimental results from previous studies are presented in terms of the variation in the percentage of the MP and show that BF can improve the MP of PC. The results of such studies suggest the possibility to extend the application of PC reinforced with BF (PCBF) in a wide range, namely from automotive to biomedical fields. The meanings of all the acronyms are listed in the abbreviations section.

Keywords: banana fibers; thermoplastic; thermosetting; polymers; reinforcement; mechanical properties

1. Introduction

The use of natural fibers (NF) as a renewable material, which can be extracted from renewable resources (e.g., leaves, peels, and trunks of plants), were discovered in the early 1900s [1]. Natural fibers act as biodegradable reinforcing materials and as an alternative for the man-made synthetic fibers (SF) due to their inherent properties. For instance, they are eco-friendly, unlike SF, because they are biodegradable and non-abrasive. On the other hand, NF enhances the mechanical properties of the polymers, i.e., tensile strength, flexural, and impact strengths properties of natural fiber-reinforced polymer composites with different fiber loadings, as presented in the following sections [2,3].

The most commonly used extract methods to obtain NF have been the mechanical method, chemical method, enzymatic (EM), biological, and combined procedures. The mechanical method has been the most common fiber–matrix procedure because it is fast and can be performed by a machine (e.g., mechanical decorticator), which acts by disintegration [4–7].

Chemical methods use strong acids (e.g., sulfuric acid or hydrochloric acid) to promote the hydrolysis (in some cases the bleaching [8,9] and sulfite process [9,10], which is more suitable for obtaining pulp), which removes the amorphous components of natural fibers and also to separate the cellulose fibrils from the cell wall [11]. After the acid reaction, the parts of the plants need to go through separation steps, namely: centrifugation or filtration and washing (using water or distilled water, acetate buffer, methanol (CH_3OH), benzoyl chloride (C_6H_5COCl), running tap water, etc. [6,9,12]). Chemical methods induce a rapid decrease in the degree of polymerization and consequently leads to the production of nano natural fibers through a reduction in the cellulose chain's size. The resulting natural nanofibers are also called whiskers or cellulose nanocrystals.

The enzymatic method is currently presented as a more sustainable alternative to chemical methods because it is an environmentally friendly process (e.g., it do not use strong acids or other chemical solvents), which acts by cellulases enzymes (e.g., xylanases), which have very specific catalyzed reactions with high reactivity and selectivity, causing focused results. Usually, enzymatic method can use pectinase, hemicellulase, and poligalacturonase, which modifies the amorphous components of the NF, maintaining the crystalline regions [9,13–15]. The enzymatic method can potentially reduce operational costs, energy, and water, and improve the product quality and potential process integration when is compared with the chemical method [6,16–19]. However, EM needs detailed knowledge, namely: surface chemistry, available forms of cellulose, specific interactions between the cellulases enzymes, and NF. EM also needs to be fast to avoid complete cellulose degradation [6,9,20]. The biological method consists of soaking a vegetable source (e.g., wood, algae, microcrystalline cellulose) for some days in water or distilled water containing several microorganisms. Thus, natural fibers are obtained by the biological action (in anaerobic or aerobic ways), which generates soluble components and gases such as methane [5,9,11,21,22].

All these extraction methods have been used to originate a complex NF in structure which constitutes composite materials. These materials can be divided into two major groups as far as the surface properties are concerned: a physical group (e.g., morphology, smoothness, roughness, permeability, and specific surface area) and chemical group (e.g., elemental, molecular, composition, and functional). The combination of these two groups determines the thermodynamics of the surface (e.g., free energy, acid–base acceptor, and donor numbers) and gives rise to PC consisting of three basic polymers: cellulose (the main component of plant cell walls), hemicelluloses, and lignin [6,19,23–25]. The presence of cellulose in the cell walls generally makes NF hydrophilic in nature, with moisture content (MC) of 8%–13(%) [26]. The MC influences the degree of crystallinity, crystallite orientation, tensile strength (TS), swelling behavior, porosity, and surface characteristics, which are crucial factors in NF classification [26–29].

Hemicellulose is located between cellulose and lignin, and it is a mixture of sugars (e.g., glucose, galactose, xylose, mannose, and arabinose) [28]. Both the hemicellulose and cellulose chains are components of the cementing mechanism of the NF [19]. Lignin is located between individual cells and between the cellulose fibrils forming the cell walls of the NF. It is composed of nine carbon units derived from substituted cinnamyl alcohol (i.e., coumaryl, coniferyl, and syringyl alcohols) and acts as a glue. It is associated with the hemicellulose and can range from water-soluble (lignosulfonates) to insoluble (kraft lignin), even in general organic solvents (e.g., acetone). Lignin plays a vital role in the physical properties of NF and influences their structure, rate of hydrolysis, the natural decay resistance, flexibility, and morphology. The impregnation state of the lignin will predict the hardness and stiffness of NF [19,28,30].

Other components need to be considered, such as for example the average viscosity of the degree of polymerization of cellulose and its molecular weight. This component can be about 10 to 100 times higher than that of hemicellulose [20,26,28,31,32], and it is useful to check the influence of the cellulose on the surface treatments, and also to check the significant shortening of the NF lengths induced by the hydrolysis process [9,33]. In general, NF are hypoallergenic and present the following properties: large surface area, high strength, and stiffness (due to the cellulose content [9,34]), low density, abundant availability, relatively low price, renewability, ease of processing, excellent MP, higher deformity, biodegradability, richness in cellulose, no environmental health concerns (reduced pollution level during production, CO_2 neutral, no emission of any toxic component, environment-friendly). It can also reduce tool wear (less abrasiveness to molds and mixing equipment) and is completely degradable by a composting process (with less garbage disposal problems).

NF by itself can be used in a conventional manner for the production of yarns, ropes, strings, cords, cables, clothes, and matting, as well as for making handicraft products (e.g., fancy articles, baskets, mats, etc.) and furniture. NF are also used in the paper industry (e.g., tea and coffee bags, sausage casing, electrolytic papers, currency notes, cigarette filters, medical and disposal papers) and are the main materials used for marine ropes due to its strength, lightness, and water resistance [19,26,35].

Since the 1980s [1,3], NF indeed received the research community attention as a potential reinforcement component in PC due to their light weight when compared to the SF-reinforced PC. The potential applications of these PC are growing rapidly in many engineering fields, particularly as non-structural building materials (e.g., wallpapers, laminated panels), construction materials (e.g., thermoacoustic insulation boards), packaging industries/products, electronics, cosmetics, biomaterials (e.g., biomedical and pharmaceutical applications such as dental and bone cements), aerospace, sports, automotive components (e.g., underfloor protection for passenger cars) and as nanomaterial [2,3,6,9,36–42]. NF such as banana, coir, date, wood, sun hemp, hemp, husk, jute, bamboo, roselle, sisal, pineapple, cotton, rice husk, abaca, kenaf, sugarcane (and bagasse), and flax fibers are increasingly used as reinforcing agents and filler for the reinforcement of PC with different fiber/particle geometries and properties, including the length, diameter, type, content, shape, thermal stability, structure (e.g., the proportion of crystalline fibrils and non-crystalline regions, spiral angle of fibrils), surface treatments, supramolecular structure, degree of crystallinity, degree of polymerization, crystal structure (e.g., type of cellulose, defects, the orientation of the chains of non-crystalline and crystalline cellulose), void structure (e.g., pore volume, specific interface, size of pores), whether the NF were taken from the original plant and the corresponding growing conditions [2,15,19,25,43,44].

In this review study, the authors focused their investigation on the utilization of BF from the pseudostem without other particulate fillers as the reinforcement of PC. Table 1 shows some suppliers for commercial products made with BF.

Table 1. -Some suppliers for commercial products made with banana fibers.

Company/Location/Website	Product Name/Characteristics/Commercial Products
Beleaf/Monaco/(http://www.beleaf.mc/en/home.php)	Veneered panels, flooring and tiles for dashboards, furniture, lamps, loudspeakers, etc.*
Champs Agro Unit/Maharashtra, India (http://www.champsecosignunit.in)	Eco-friendly materials from BF for BF paper, BF gift boxes, BF diary covers, BF drawing paper, etc.*
FIBandCO/Martinique, French West Indies (http://www.fibandco.com)	Green blade: exotic veneer in sheets. Veneers, panels, acoustic panels for furniture, building, construction and other industries, etc.*
Papyrus Australia Ltd./Mile End, South Australia (http://www.papyrusaustralia.com.au)	Papyrus veneers and panels. Veneers and panels for paper, packaging, furniture, building, construction and other industries*.
Tamoios technology/Itariri, São Paulo, Brazil (http://tamoiostecnologia.com.br)	IVAT: “Iací”; “Piramaia”, “Tipotí”, “Amandy” and “Puçá”. Wallpapers, packaging, reforestation materials, shims, thermoacoustic insulation boards, book covers, etc.*

Table 1. *Cont.*

Company/Location/Website	Product Name/Characteristics/Commercial Products
Rattan Furniture Indonesia/ Central Java, Indonesia (http://www.naturalrattan.com) Banana Furniture/Central Java, Indonesia (http://banana-furniture.com) Houzz/Online shop (http://www.houzz.com)	Handicraft and furniture

* These products are made with BF of different textures (coarse or fine and smooth or rough) and different colors.

In general, all the mentioned companies in Table 1 do not buy the banana fibers firstly to a supplier. These companies are involved throughout all the processes, since the harvest of the banana bunches until the manufacturing of the commercial products and its sale (e.g., panels, paper, handicraft, furniture, etc.). In the next sections, more information about the properties and the surface chemical treatments (SCT) that have been done on BF, before their incorporation into polymeric matrices (PM), are presented and discussed.

2. Banana Fibers

2.1. General Aspects

Banana is an Arabic word that means 'finger, toe' [26]. Banana plants have been cultivated since 5000 B.C. They are one of the oldest cultivated plants in the world and well-known fruit crops, of which the most common genus is called Musa Sapientum L.(Musaceae family) with lots of varieties of species (e.g., Musa acuminate Colla, balbisiana Colla, nana sensu Parham, xparadisiaca L., textilis Née, troglodytarum L., velutina H., etc.). However, only 20 varieties are used for common consumption [19].

The trees generally produce 30 large leaves and a banana pseudostem (BPS, it "looks like a trunk"). The leaves and the BPS are left to rot in the banana plantation after harvest bunches [45,46]. This generates a high amount of vegetable wastes of banana cultivation, which can be viewed as an environmental and health problem. To avoid that, the banana fibers' extraction needs to take place as soon as possible. The BF extraction can be done manually, semi-manually, or mechanically (e.g., by decorticating technique) from the BPS, from which a hard BF with five to eight different textures can be obtained: coarse or fine and smooth or rough [47]. The extraction of BF can be viewed as an additional step of the banana cultivation process, which can reduce the waste and benefits the environment by reducing methane gas (which contributes to climate change), which is a final product of the decomposition of the banana trees [5,19,48,49]. In addition, this additional step will also prevent the proliferation and spread of the major pest of banana: Cosmopolites sordidus (Germar, which is an insect popularly known as the banana root borer). This reutilization will provide additional income to the cultivators and help the improvement of the rural economy of the tropical and subtropical regions/countries of the world (e.g., Brazil, Colombia, India, Macaronesia, Malaysia, and China) where the banana plants are usually cultivated [5,26,37,45,50–53].

Among all the general mentioned properties of NF, banana fibers (BF) appear promising as an active reinforcing constituent due to its relatively good mechanical properties (MP), excellent compatibility, and bonding with PM [49,54–56]. The obtained polymeric composites reinforced with BF (PCBF) show to have toughness and wood texture. In addition, less energy is required for the manufacturing of PCBF [49]. For industrial purposes, BF can be obtained without any additional cost since manufacturing processes already exist. For instance, it is worth mentioning the patented manufacturing process by Daimler Chrysler's researchers (Rieter Automotive), which combines polypropylene (PP) with BF for the underfloor protection for passenger cars. Such a component is applied to the exterior of road vehicles and needs to have good properties regarding the resistance to the stone strike, the exposure to the elements, and dampness [19,40,49,57–60]. Many other existent applications can be found for banana fibers, such as the ones mentioned in Table 1. Figure 1 illustrates some of these applications.


(a) (b) (c)

Figure 1. Examples of banana fiber products: (**a**) Pressed banana fiber composite; (**b**) Final banana fiber composite, and (**c**) some products manufactured with banana fibers. These images were kindly provided by Edward Byrt, Chairman of Papyrus Australia Ltd.

Table 2 shows some of the typical properties of BF found by some authors.

Table 2. Typical properties of BF.

Property	Value	References
Density (g/cm^3)	1.3 ± 10 (%)	[3,12,26,35,38,61–82]
Cellulose content (%)	63 ± 10 (%)	[28,37,38,49,56,57,62–65,67,71,74,77,80–83]
Hemi cellulose (%)	19 ± 10 (%)	[38,57,62–65,67,74,77,80–82]
Lignin content (%)	5 ± 10 (%)	[28,38,57,62–65,67,71,74,80–82]
Moisture (%)	10 ± 10 (%)	[3,26,28,35,38,67,74,80,81]
Microfibrillar angle (°)	11	[12,26,37,38,49,56,57,67,71,72,80,81]
Lumen size (µm)	5	[12,57,67,81]
Diameter (µm)	80–250	[12,26,67,71,72,74,77,79,81]

BF possesses higher cellulose content, a higher degree of polymerization of cellulose, and lower microfibrillar angle (MFA), which are crucial factors for MP (namely tensile modulus (TM) and TS). In general, the addition of BF into PM tends to decrease the strength (relative to the pristine PM) as the wt % of BF increases until it reaches an optimum wt %, from which the strength starts to increase. This happens because when the amount of BF is high, the PM medium is insufficient to wet the BF completely. However, if the wt % of BF is optimum, there is no overlapping between flat surfaces of the BF, and all fibers are thoroughly wetted, causing an increase of the adhesion on the interfacial region (IR, the region located between NF and PM). This causes the improvement on the MP (e.g., tensile, flexural, impact, and yield strength), tribological, and many others properties that make BF suitable for the reinforcement of PC [2,28–30,37,78,84,85].

2.2. Mechanical Properties

The tensile properties (TP) of BF can be determined following ASTM standard test procedure D3379 and D3822 [35,86,87].

Table 3 shows some typical range values of MP found by some authors, namely: TM, TS, flexural modulus (FM), and ultimate strain (elongation at break) of BF.

Table 3. Some mechanical properties of banana fibers (BF).

Property	Value	References
Elongation at break (%)	3.5 ± 15 (%)	[12,26,28,32,61–65,67,71,73–82,88–90]
Tensile (elastic) modulus (GPa)	12–45 ± 15 (%)	[12,26,32,57,61–72,74,77–82,88–91]
Tensile strength (MPa)	430–650 ± 15 (%)	[12,26,32,35,38,61–65,67,71,74,77,78,80–82,88–91]
Flexural modulus (GPa)	2–5	[2,3,67]

The prediction of the MP of BF, namely TM, TS, and ultimate strain, can also be presented as a function of the diameter (μm) of the BF. Table 4 shows some examples found by some authors.

Table 4. Tensile properties and ultimate strain of banana fibers as a function of the diameter (μm) [26,92–94].

Property	Diameter (μm)	Value
Tensile (elastic) modulus (GPa)	50	32.703 ± 8.190
	100	30.463 ± 4.689
	150	29.748 ± 8.561
	200	27.698 ± 7.083
	250	29.904 ± 4.059
Tensile strength (MPa)	50	779.078 ± 209.300
	100	711.661 ± 239.614
	150	773.002 ± 297.104
	200	789.289 ± 128.588
	250	766.605 ± 165.515
Elongation at break (%)	50	2.750 ± 0.957
	100	2.469 ± 0.798
	150	3.583 ± 1.114
	200	3.340 ± 0.688
	250	3.244 ± 1.284

All the results presented in Tables 2–4 shows the excellent properties of banana fibers. The mentioned advantages in the introduction section, the MP (TM, TS, FM, flexural strength (FS), ultimate strain (elongation at break), rotting resistance, the specific FS similar to that of glass fibers(GF)), the variability of petroleum prices, the environmental sustainability, their light weight, the fact that BF are stiffer and stronger than sisal fibers [26], and the results of others comparative studies prove the potential and the effectiveness of BF to replace SF (e.g., GF) as a reinforcement of PC, by using various chemical treatments on the banana fibers, and to produce hybrid materials with synthetic fibers or with others natural fibers (e.g., sisal, kenaf, etc.) [1,4,6,9,19,26,30,32,34,37,39,45,47,57,66,81,89–118].

2.3. Direct and Indirect Surface Treatments on the Natural Fibers

The rapid moisture absorption tendency (MAT) or water absorption tendency of the lignocelluloses natural fibers is a common problem that can cause dimensional instability [12]. This situation is observed because the cell's wall contains hydroxyl and other oxygen-containing groups which attract moisture through hydrogen bonding. In addition, the moisture absorption tendency can cause rotting and an increase in MC (which decreases the electrical resistivity) and the swelling of the NF (causing weakness on the IR), which can induce an incomplete wetting (poor wettability) of the NF by the PM. This allows the formation of microgaps (e.g., voids and cracks) and flaws, which induces a weak interfacial bonding and contributes to more moisture absorption tendency on the IR [12,97].

The water molecules act as a plasticizer, and when they are absorbed by dry cellulose, they form cellulose hydrate, which influences the three phases of the PC simultaneously: NF, PM, and IR. This hydrate drift forms an exothermic reaction, providing the driving force for further moisture absorption.

The first layer of water bounds directly to the –CH_2OH group and forms a relatively strong hydrogen bond, attracting other water molecules by weaker hydrogen bonding. This weaker bound layer may be thickened by several molecular layers and aims the IR debonding to initiate the development of osmotic pressure pockets at the surface of NF (due to the leaching of water-soluble substances from the NF surface). They can be converted into other substances which are capable of acting as osmotic solutes, disturbing the mechanical integrity of the PCNF system [19,32,119–121]. The moisture absorption tendency in PC reinforced with natural fibers (PCNF) depends on conditions such as temperature and relative humidity. It increases with NF content and levels off at longer periods, which is an indication of saturation. The leveling off period increases with increasing NF concentration [32]. These facts associated with the composition, structure, number of defects in NF, and the fact that surface chemical composition of fibers has an impact on wetting and, thus, on the impregnation dynamic of the final PC [122], constitutes a disadvantage for the industrial use or for their application into PC in the biomedical field and leads to poor compatibility and dispersibility.

Besides, the hydrophilic nature of the NF combined with the hydrophobic nature of the PM and the polar and dispersive components of the fibers' surface energy, causing the hydrophilic or hydrophobic behavior of the reinforcement, have an effect on the interface formation during manufacturing and also on the toughness of the composite under service conditions [122]. This will lead to poor MP, which limits their use as reinforcement in PCNF [19,27–29,32,37,49,89,97,123,124].

However, in the literature, controversy still exists about the effective nature of surface energy and wetting behavior of PM on NF. These drawbacks also attracted the attention of the research community, and a considerable amount of research has been carried out in order to optimize the IR quality and to promote the adhesion between PM and NF. Several solutions have been proposed, namely: the production of different NF (as a consequence of the cellulose source and the methods used to extract the NF), different SCT (during processing) of NF, and starch treatments. This last one involves the modification of the surface chemistry in order to change the thermodynamic properties and to create beneficial microtopographical features without deliberately coating the surface. As a consequence, the interfacial compatibility/adhesion into the IR will improve and also reduce the moisture absorption tendency [19,49,125]. SCT can be achieved directly or indirectly. The direct SCT uses chemical coupling agents (CCA) and also adds compatibilizers. CCA are molecules that have two functions: (a) the monomer reacts with hydroxyl groups (–OH) of cellulose and (b) it also reacts with the functional groups of the matrix [12,126]. They not only remove native surface material and leave behind a more active functional group to promote wetting, but they also can affect the morphology (e.g., by roughening the surface to some degree) and the functionalities of the NF surface (by reducing the hydrophilic nature of the NF). CCA can also reduce the moisture absorption tendency (the polymer fills the voids existing in the treated NF), replace some of the hydroxyl groups on the cell wall polymers, which create hydrogen bonding with the molecules/chemical groups (the hygroscopicity of the lignocellulosic material is reduced) and, as mentioned before, optimize the IR adhesion and the thermomechanical interlocking (e.g., storage modulus, thermal diffusivity and conductivity, and glass transition temperature (T_g)), in terms of PC processing and in comparison with untreated PCNF [12,19,26,34,37,48,49,61,127,128].

The moisture absorption tendency of PC can be conducted according to ASTM D570 standards [129] and is usually calculated from the weight difference. Researchers have reported various surface treatments that can be used either in single or in mixture [48,130,131], namely: chemical, mechanical, thermal, biological, and physiological (on carbohydrates and on the breakage along the amorphous zones) [85]. Physical treatments include heat treatment, stretching, 'calendering', solvent extraction, physical–chemical treatments (e.g., corona plasma discharges), laser and UV bombardment or steam explosion treatments, further chemical modifications both by direct and indirect grafting by monomer or by free radical or ionic polymerization [15,19,48]. These physical treatments improve MP and reduce the water uptake tendency [49,132,133]. Examples of used SCT are:

- Alkalization or mercerization (using sodium hydroxide (NaOH)) [77,85,134];

- Silanization by using silanes (e.g., 3-aminopropyltriethoxysilane (APS), bis-(3-triethoxy silyl propyl) tetrasulfane (Si69), methacryloxypropyl trimethoxy silane, and vinyl triethoxy silane) [32,34,48,77,93,94,103,135];
- Potassium permanganate ($KMnO_4$) treatment oracrylation [77,136], potassium metabisulfite ($K_2S_2O_5$) [6], potassium hydroxide (KOH) [6], sodium lauryl, sodium hypochlorite (NaClO), sodium chlorite ($NaClO_2$) [6], and acetic acid (CH3COOH) [6,32,34,48,93,94,103];
- Oxalic acid ($C_2H_2O_4$) acetylation, methylation, cyanoethylation, benzoylation (with benzoyl chloride) [15,19,77,137];
- Acrylation and the direct removal of amorphous materials/adsorbed components (which makes the NF incompatible with PM) such as lignin, fats, olefinic waxes, proteins, non-crystalline parts, and extractives by bleaching or steaming, etc. This step increases the decomposition temperature of treated NF due to the removal of amorphous and smaller molecules (and thus an increase in molecular weight) from the NF surface [19,127,138,139].

In general, the alkalization and acetylation (with acrylic acid ($C_3H_4O_2$)) are the most effective and economical techniques for SCT [37,38,59,85,140]. The alkalization of the NF can be done according to ASTM D1965-87 standard [141]. The alkalization of the NF removes the noncellulosic and amorphous components (e.g., hemicellulose, lignin, pectins, oil, waxes, and impurities from the wall surface of BF), the smelly odors, moistures, and weak structure. It also changes the color of the NF, the network structures of hydrogen bond due to the reaction with alkaline-based solution (NaOH), and the interfibrillar region of NF, which becomes less dense, less rigid, less hydrophilic, and rougher. As a result, the adhesion of the NF to PM and the surface wettability are improved, which consequently improves the mechanical interlocking/behavior (e.g., tensile and yield strength) into the IR [3,48,85]. The acetylation of the natural fibers reduces their tensile strength and hygroscopicity when compared with alkaline surface chemical treatments. This is due to the loss of hemicelluloses from the NF surface and also due to the generation of an ester bond when the carboxylic group of the $C_3H_4O_2$ reacts with the cellulosic hydroxyl group of the NF, respectively [37,48,142].

An indirect method to treat the NF is the addition of a compatibilizer into the PM. Compatibilizers are generally graft, block copolymers, or graft copolymers (GC) obtained by the modification of PM. The graft can be done by monomers such as stearic acid ($C_{18}H_{36}O_2$), acetic anhydride ($C_4H_6O_3$), maleic anhydride (MA), methylacrylate (MTA), acrylic monomers [37,60,143,144], etc. The GC can be added into the PM with initiators, namely benzoyl peroxide ($C_{14}H_{10}O_4$), dicumyl peroxide ($C_{18}H_{22}O_2$) [12,96,97], etc. The use of compatibilizers not only treats the PM, but also the NF, and significantly improves the IR interfacial adhesion by the formation of covalent linkages between the anhydride and hydroxyl groups of the cellulose of the NF [37,60,145,146]. Appendix A (Table A1) presents the various methods that have been used by some authors to extract, wash, and modify the BF before their incorporation into UPM or MPM.

3. Preparation of Polymeric Composites Reinforced with Banana Fibers

PC can have a PM of three types if classed according to the degree of reticulation and depending on their internal structure between polymer chains (cross-linked networks): thermoplastic, thermosetting, and rubbers [147].

Thermoplastic polymeric matrices (TPPM) cure reversibly and soften on heating when heated above the glass transition temperature (Tg) or melting point (lower than their decomposition temperatures). They also become hard after cooling, can be reshaped, have a linear or branched molecular structure and little or no reticulation, are often solvent-soluble, and present high strength and toughness, chemical resistance, good durability, self-lubrication, transparency, and waterproofing [147–149]. In the composite industries, the most applicable and important thermoplastic polymeric matrices are acrylonitrile, butadiene styrene, polycarbonates, polyethylene, polypropylene (PP), polystyrene, low density polyethylene (LDPE), polyether ether ketone, and polyvinyl chloride (PVC) [64,149].

Thermosetting polymeric matrices (TSPM) cures irreversibly become permanently hard and rigid after curing and have a three-dimensional network of covalent intermolecular bonds commonly called cross-linked networks and located between the polymer chains [150]. Unlike TPPM, cured TSPM cannot be remelted or/and flow soften when heated and, once formed, they cannot be reshaped. The continuous heating for a long time leads to degradation and decomposition. TSPM are stiff, tough, and durable (due to the large molecular structure), have good electrical and thermal insulation, and are chemically resistant [147,149,151]. In the composite industry, the most applicable and important TSPM are alkyds, bakelite, epoxy resins (EP), and amino resins (e.g., melamine–formaldehyde and urea–formaldehyde), phenolic resoles resins (including phenol–formaldehyde (PF)), polyester, polyurethane, unsaturated isophthalic polyester resin (UP–resin) and unsaturated polyesters (UP) [147,149,151].

As for the fibers, the growing demands for environmental sustainability and economic benefits have encouraged the research community to establish slowly the replacement of synthetic PM (SPM) by eco-friendly biodegradable biopolymeric matrices (BPM) [34,152]. The development of green PC with BPM is only defined based on the nature of their constituents. A huge changeover was reported on the usage of NF all over the world for the production of PC [90]. Examples of BPM are chitin–chitosan, alginate, starch and its derivatives, e.g., polylactic acid (PLA), cyclodextrins, lignin based PM, cellulose nitrate, polyhydroxyalkanoates, polybutylene succinate, soy protein isolate natural matrix (SPINM), etc. [6,30,31,34,37,48,65,96,97,153–157].

The development of biocomposites (BPC) reinforced with NF has been the subject of great interest for the materials science research community (academic and industry) for both an ecological and biomedical perspective. BPC have recently been proposed as having a great potential for several applications in the biomedical field (e.g., medical delivery systems, device market, and industrial packaging field) as they are totally biodegradable, biocompatible, and inexpensive [158–161]. BPC with starch matrices (SMBPC) are one of the strategies that have been used to reinforce BPC, because the SMBPC have shown to have a great potential in the bone-related with therapy applications [162–164], ranging from bone tissue engineering scaffolds [165] to bone cements [166].

Starch is the major polysaccharide produced and stored by many organ plants (e.g., corn, wheat, tapioca, potato, and rice). It commonly exists in a granular structure with about 15–45% crystallinity [161,167], is abundant, and a relatively inexpensive natural semicrystalline polymer and an easily available renewable resource composed of glucose monomers joined by 2-(1-4) linkages [49]. Starch consists in a mixture of amylose (a linear polysaccharide) and amylopectin (a highly branched polysaccharide) [168], and it can be processed as a thermoplastic polymer and converted into thermoplastic starch (TPS) by the addition of water and/or specific plasticizers combined with the application of high temperature and shear forces [161,169]. In addition, their moisture absorption tendency can be improved with the addition of polycaprolactone [65]. However, very recently, plasticized starch matrices–biopolymeric matrices (SMBPM) have been pointed out as a good matrix for the manufacturing of BPC for the biomedical field.

At this moment, very few studies still exist in the literature that used BF from BPS as reinforcement for plasticized SM (e.g., [123,153]). Guimarães et al. [153] prepared and characterized SMBPC containing both commercial and crude glycerin as plasticizer. Darwish et al. [123] prepared glycerol plasticized SMBPC with different weight fractions of BF for the fabrication of maxillofacial bone plates. Plasticizers can provide stability and compatibility with hydrophilic packaging chains in starches (due to the formation of hydrogen bonds with the starch), and they can reduce brittleness, making starch more flexible and avoiding the cracking of starch-based materials during handling and storage [153,161,170]. Some examples of plasticizers are glycerol and other polyols, sorbitol, formamide, ethanolamine, and sugars [153,171]. Glycerol or glycerin can be obtained through chemical and fermentation methods in pure form and, in general, they need to pass through a purification process, after which they can be called "crude glycerin" [153].

However, the community research has proved that even after the processing of the starch, the TPS still presents some disadvantages (e.g., MAT, retrogradation, water solubility, poor mechanical and thermal properties, and others) in comparison with SPM [153,161,170]. An approach to solve the mentioned disadvantages is the incorporation of NF as a reinforcement for TPS. Unlike biodegradable polyester, when NF are mixed into TPS, their MP are obviously improved, the chemical similarities of starch with the NF providing good compatibility and seeming to be the logical alternative in order to increase their MP and to preserve the environmental-friendly character of the final SMBPC [161,172]. BF are one of the NF that have been used recently as reinforcement of starches. As mentioned before, BF have specific properties that have been modified to extend its application from automotive to biomedical applications [41,173,174]. However, the processing techniques used to obtain the PC are of great importance in determining the final properties of these materials.

In Appendix B, Table A2 summarizes the techniques and methodologies used by some authors to prepare TPPM and TSPM with UBF or MBF. From Appendices A and B (Tables A1 and A2), it is possible to conclude that the NF can be used in different forms, such as randomly oriented, continuous, and as woven fabric mat [90]. It can also be stated that several processing techniques exist for the manufacturing of PC reinforced with BF (PCBF), namely: hand lay-up with or without a woven pattern, injection molding, melt blending technique employing a batch mixer, compression molding, mini injection jet molding, resin transfer molding, pultrusion, bumping process, and PC lamination.

Lamination is the technique of producing PC in multiple layers. This technique will ensure that the distribution and the orientation of the fibers can be controlled precisely in the PC laminates reinforced with banana fibers (PCLBF). Fiber orientation plays an important role in PCLBF because the properties measured along the fiber orientation are usually higher than the properties measured in the perpendicular direction [45]. Laminates can achieve improved MP, stability, sound insulation, and appearance properties by crossing the fiber orientation/distribution in the different positioning of layers of the laminates. A laminate is usually permanently assembled by heat, pressure, welding, or adhesives [1,38,45]. Investigations on the reinforcement of laminates have shown different arrangements of two or more types of NF. The final PC are designated as hybrid composites (e.g., jute and GF or BF and coconut fibers [38]). The variation of the mechanical properties (TM, TS, FM, FS, and IS) of some polymeric composite laminates reinforced with banana fibers studies [1,38,45,153] are presented in Appendix C (Table A3).

Finally, Figure 2 presents a scheme with the principal steps for PCNF manufacturing with unmodified and modified NF incorporated into an unmodified and modified PM. Figure 2 summarizes the information mentioned in the previous sections.

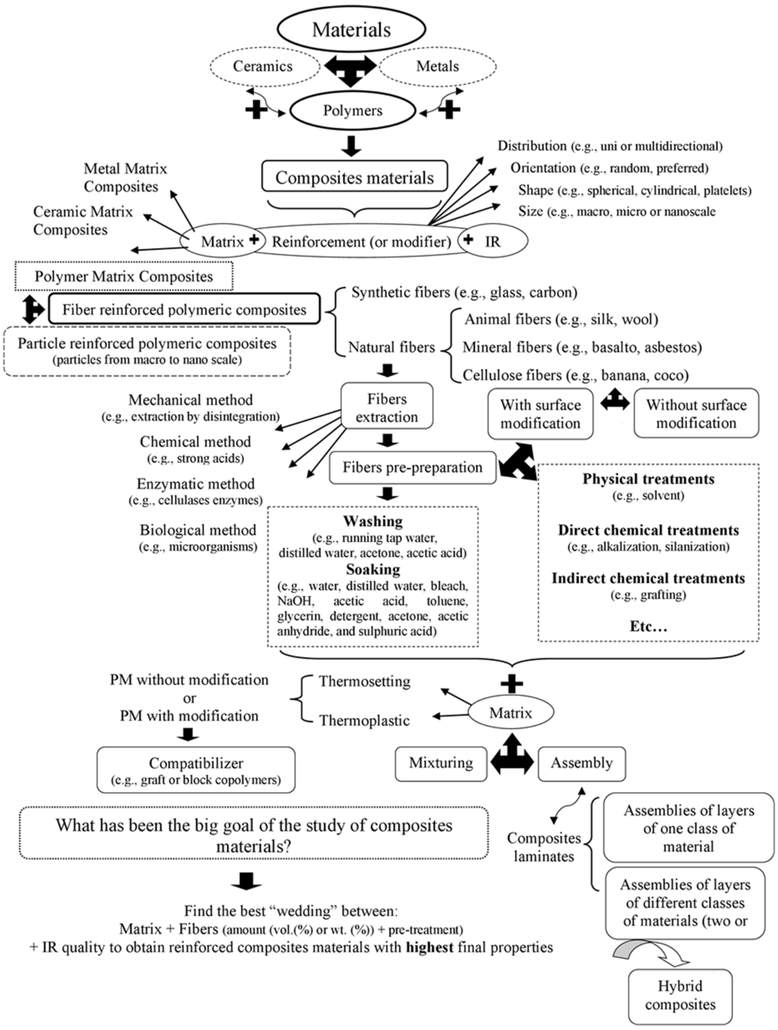

Figure 2. Scheme with the principal steps for polymeric composites reinforced with natural fibers, manufacturing with or without surface chemical treatment of the natural fibers, and for treated or untreated polymeric matrices.

4. Mechanical Properties of Polymeric Composites Reinforced with Banana Fibers

This section presents and compares the highest and lowest obtained results from selected authors with respect to some important MP of PC reinforced with UBF or MBF, namely tensile properties (TP), flexural properties (FP), and impact properties (IP).

MP are important to know in PC to check their capability to withstand load and to estimate their lifetime [1]. TP, namely TM–Young's Modulus or Modulus of Elasticity (ME) and TS are usually measured from the stress–strain curve or force–displacement curve from tensile tests. The TM is measured at the elastic stage and represents the stiffness of the material. On the other hand, the ability of composite material to resist breaking under tensile load is the TS, which is the maximum value recorded in the stress–strain curve in the plastic regime [90]. Both these parameters characterize the rigidity of the PC [175,176] and can be determined following ASTM standard test procedure D638 [177], which specifies dog-bone tensile test samples and is recommended for randomly oriented, discontinuous, moldable composites with TM less than 20.7 GPa (≈3 MSI). For highly oriented and for high TM fiber-reinforced PC, it is recommended that the determination of TP follows the ASTM D3039 [175,176,178]. For the PC laminates case, it is recommended that the determination of TP follow the ASTM D882 [179]. For the determination of the TP of thermosetting reinforced plastics using test specimens of uniform nominal width, it is recommended to follow the ASTM D5083 standard [123].

FP, namely FM and FS, also known as the bending modulus and bending strength, respectively, are the stiffness and the ability to resist deformation under flexural loading, respectively. The FP are measured from static flexural tests usually carried out under a three-point bend configuration and performed according to ASTM D790 [180]. For the case of PC laminates, it is recommended that the determination of FP should follow the ASTM D1037 [181].

The IP of PC, namely the impact strength (IS), can be measured as a function of the impact energy (or the energy absorbed before fracture) divided by the notched cross-sectional area. The energy needed to break the PC can be used to measure the toughness of the PC and the yield strength. The effect of strain rate on fracture and ductility of the PC can be analyzed by using an Izod impact machine and following ASTM standard test procedure D256 [182].

After mechanical tests, Scanning Electron Microscope (SEM) or by Field Emission Scanning Electron Microscope (FESEM) can be performed on the fractured surface (FSF) of the specimens to understand the failure mechanisms.

SEM studies can also be carried out on the tensile FSF of the specimens to understand the effect of different modification techniques on the fiber/matrix interfacial bonding and also to observe the morphology of the FSF on the PC (with or without unmodified or modified BF (UBF or MBF) into UPMs or MPMs) at the location near the crack tip and to assess the different modes of failure.

It is important to mention that the PC needs to be conditioned (before mechanical testing), according to ASTM E41-92 [183]. In Appendices A and B (Tables A1 and A2), more information about the used methods for the extraction and preparation of BF related PC are presented. In Appendices C–F (Tables A3–A6), more information can be found about the variations in percentage (average values) of the TM, TS, FM, FS, and IS in the obtained results from selected authors, which investigated PC manufactured with BF randomly oriented (RO), as a function of the fiber loading (FL) at a fixed FL and into plasticized SM for specific banana fiber length (BFLg). In the mentioned appendices, information about the MP of PCLBF and PC with woven pattern reinforced with BF (PCWBF) can also be found.

As mentioned before, the PCLBF and the PCWBF can be hybridized with other NF or also with particles. In some published examples, the following hybridizations were used: BF and abaca fibers PC (look similar as BF and also are a member of the Musaceae plant family) [19], BF–hemp fibers–GF PC [3], short BF and sisal fibers PC [67,69], GF–hemp fibers–BF PC [3,184], BF–wheat gluten PC [185], BF and cotton fibers in yarn textile production and PC [15], BF and GF [89], BF and nanoclay particles [186], PCWBF with sisal fibers [68], PCWBF with kenaf fibers [90], Nylon6/high-density polyethylene (HDPE) PCBF [66], etc. However, it is important to note that in this review work, some hybrid cases were considered with respect to the maximum variation (MV) of the studied MP, but only for 100% BF (e.g., 0% GF and 100% BF, see Appendix F (Table A6). No studies were found using Liquid Composite Molding processes, which are considered as promising and effective to manufacture structural composite parts reinforced with natural fibres [187]—for this case, using BF as reinforcement.

Table 5 summarizes the MP (only the highest and lowest obtained results) of the studies found in the literature that used BF as reinforcement in different situations.

From Table 5, some important conclusions can be drawn. The highest variation in MP is positive in almost all cases, in comparison with the respective control sample, except for TM and FM in the HPCBF case. The highest variation in terms of TM, TS, FM, FS, and IS were obtained for PCBF with SM, PCLBF, and PCWBF respectively.

As mentioned before, until today, there exists only a few numbers of studies in the literature that used BF as reinforcement for plasticized SM. Plasticized starch matrices have recently shown that they are good matrices for the manufacturing of BPC. In fact, as the PM is reinforced by the starch and then by the BF, this material is a hybrid composite. This hybrid showed the biggest improvements in the variation of TM and TS, for example, and the MP of the BPC increased because the starch worked as a good stiffening agent. On the other hand, this hybrid is more environmentally friendly than all the mentioned PCBF and can be used in the biomedical field.

Table 5. Variation of the mechanical properties (only highest and lowest obtained results) for polymeric composites reinforced with banana fibers (different BF loadings, fixed BF loadings, BF into starch matrices, laminates, woven and hybrid cases (only with BF)) in comparison with the respective control sample of each mentioned study. PCBF: polymeric composites reinforced with BF, PCWBF: PC with woven pattern reinforced with BF.

Cases/References (Respectively)/Mechanical Properties			**Variation in Tensile Modulus (%)**	**Variation in Tensile Strength (%)**	**Variation in Flexural Modulus (%)**	**Variation in Flexural Strength (%)**	**Variation in Impact Strength (%)**
PCBF (different loadings)	Highest	[74,81,96, 187,188]	870	400	164	280	247
	Lowest	[30,34,37, 48,81]	7	−80	−71	−36	−69
PCBF (fixed loadings)	Highest	[81,97]	218	271	83	400	180
	Lowest	[30,34,48, 97,103]	−39	−33	−10	1	−50
PCBF (starch matrices)	Highest	[123,156], N/A*	2619	1400	317	400	N/A*
	Lowest	[123,153], N/A*	140	−57	44	63	N/A*
PCLBF (laminates)	Highest	[1,12,45]	262	400	500	500	464
	Lowest	[1,32,38, 45]	−91	−50	−30	−43	4
PCWBF (woven)	Highest	[79,117, 118,137, 189,190]	36	138	300	515	1105
	Lowest	[79,117, 118,137, 189,190]	−14	−9	17	38	40
HPCBF (hybrid)	Highest	[58,190, 191]	−6	17	−2	4.3	35.5
	Lowest	[58,191]	−8	−14	−2	−4	−26

* N/A = not applicable.

However, some specific drawbacks (e.g., MAT) need to be solved. In the case of PCLBF, they have the arrangement of the BF made alternately; then, the crack propagation becomes more difficult, and the PCBF failure is found to be due to excessive bending deformations, leading to a mode with bending stiffness mismatch and reinforcement orientation differences between the adjacent plies [190].

The hybridization of PC by BF with another NF does not yield superior MP to that of hybridization by GF and carbon fiber, but this kind of hybrid composite is suitable for low-cost applications. The mechanical strength of PCWBF depends on the weave style, fiber orientation, and the bonding between the BF and PM. PCWBF have a high IS compared to those made out of nonwoven BF. The impact energy can overall be dissociated into three pools of energy: the stored energy, the absorbed energy, and the dissipated energy. The interlacing of yarns in the case of the PCWBF provides higher out-of-plane stiffness and can take up the loads due to load–path eccentricities [190]. The immediate response to a low-velocity impact is bending or local compression and shear with dominant damage mechanisms, being matrix cracking, fiber fracture, and delamination [190].

In general, BF introduces plasticizing effects on the PM. The PCBF have higher toughness, and the quality of the fiber-reinforced composite depends considerably on the fiber–matrix interface, because a well-formed interface allows better stress transfer from matrix to the fiber. BF have high extensibility and can withstand the applied stress, which will prevent catastrophic failure of the final composite. Therefore, good interfacial adhesion between the PM and BF is essential to improve the mechanical strength in the PCBF. The incorporation of BF at variable FL from 10 to 40 wt % resulted in a consistent increase in the modulus of PCBF. However, higher FL also results in the formation of voids in the PCBF because of BF/BF agglomeration due to H-bonding between the BF leading to non-uniform distribution of BF within PM, which results in the deterioration in MP.

The IS of a PCBF depends on many factors, such as the toughness properties of the reinforcement, the nature of the interfacial region, and frictional work involved in pulling out of the BF from the PM. The nature of the IR is of extreme importance in determining the toughness of the PCBF. If the interfacial bonding of the PCBF is weak, the crack will be propagated along the BF/PM, causing debonding. As a result of debonding, new surfaces will be produced, which leads to a significant increase in the energy-absorbing capacity of the PCBF. Therefore, it can be expected that the IS of the untreated polymeric composites reinforced with untreated banana fibers (UPCUBF) would be higher when compared to MPCMBF. However, in Appendix F (Table A6), the variation in percentage (average values) of the IS reached a value of 1105 for PCWBF with different BF FL (5, 10, 15, and 20 vol %) + SCT (1%, 3%, and 5% of NaOH and $C_3H_4O_2$).

5. Moisture Absorption Studies of Polymeric Composites Reinforced with Banana Fibers–Some Obtained Results

As mentioned before, BF has a hydrophilic nature and high cellulose content and also has the presence of lignin and hemicellulose components that can absorb the water molecule and swell. For this reason, BF can present some incompatibility within the PM which increased the microvoids, thus resulting in microcracks on the IR of the PCBF, which enhances the moisture absorption tendency. However, the hydrophilicity of BF can be reduced with different SCT.

Appendix G (Table A7) summarizes the moisture absorption tendency of PC reinforced with UBF or with MBF from selected authors in different situations. From Appendix G (Table A7), some important conclusions can be drawn. The variation in moisture absorption tendency is positive in all cases. However, the highest variation in moisture absorption tendency was found for PCWUBF (20 vol % of UBF into a polyester PM) in comparison with the pristine PC, which reached a moisture absorption tendency of +2431(%) [137] for a saturation time of 143 h. The authors decreased this moisture absorption tendency with SCT of BF. The lowest mean values in moisture absorption tendency were found for PC with UPC (PP matrix; +1.35(%) of MAT), and MPC (with MA; +0.30(%) of MAT) reinforced with UBF (20 mm in length) at a FL of 10 vol % in comparison with the pristine PC. MAT decreased with the addition of PP_MA in comparison with the PC without MA. The MAT for the PP + PP_MA + UBF mixture was the lowest. The authors justified this result with the presence of hydroxyl groups on the hydrophilic nature of the BF and their interaction with the anhydride groups of the treated PM (PP_MA). In this case, the sequence of the mixture also influenced the MAT results.

In another study, the authors decreased the moisture absorption tendency with the addition of MA into the PP in comparison with the PC without MA [100]. This was achieved due to the replacement of hydroxyl groups with hydrophobic ester groups by SCT treatments and by the incorporation of MA into the PM, which generates a chemical linkage between BF and PM and which reduces the microvoids' formation [37,100]. On the other hand, the presence of BF reduces the hydrophilicity of the starch-based PC, because starch is more hydrophilic than cellulose [123].

Concluding, in all cases, the poor wettability and adhesion into the IR was attributed to the hydrophilic nature of BF, as expected. Section 2.3 of this paper focused on the direct and indirect surface treatments on the natural fibers and their influence on MAT. Considering the obtained results by selected authors and the information in Section 2.3, it can be stated that MBF and MPM get masked into the PCBF with stronger adhesion, resulting in greater hydrophobicity and less MAT.

6. Final remarks and Outlook

This review summarized the most used methods to extract and to treat banana fibers before their incorporation into the polymeric matrices (thermoplastic polymeric matrices or thermosetting polymeric matrices). Using the different information available, which was sometimes difficult to correlate, an attempt was made to understand the effect of the addition of unmodified or modified banana fibers as a function of the fiber loading, or at fixed fiber loading, into synthetic or biopolymeric matrices, or into plasticized starch matrices. Such an effect can improve the mechanical properties, namely the tensile modulus and strength, flexural modulus and strength, and impact strength of untreated polymeric composites reinforced with untreated banana fibers, untreated polymeric composites reinforced with treated banana fibers, treated polymeric composites reinforced with untreated or treated banana fibers (with maleic anhydride), etc. Various studies were analyzed, and some important conclusions can be drawn.

The number of suppliers is still very limited for commercial banana fibers. In fact, the majority of the used banana fibers in the mentioned studies were extracted by local farmers, and after that, they were treated.

Banana fibers are most commonly available in tropical regions of developing countries (e.g., Brazil, Colombia, India, Malaysia, and China). This is why they constitute the best buying locations for the acquisition of commercial products made with banana fibers. In Europe, there are fewer material sources, which are mainly located in the Macaronesian region (e.g., Canary Islands and Madeira Island, respectively a Spanish autonomous community and Portuguese autonomous regions) and geographically located near Africa, where there is a need to make all processes (extraction and manufacturing) more efficient and economical when compared to the previously referred regions of the world.

The utilization of the banana plants reduces the resulting waste of banana cultivation and allows the extraction of hard banana fibers with five to eight different textures (from coarse to fine and from smooth to rough), which after appropriated treatment can be incorporated into usefully biopolymeric matrices to fabricate green polymeric composites.

Similar to natural fibers, banana fibers also are hydrophilic with a moisture absorption tendency, making banana fibers incompatible with the hydrophobic nature of the polymeric composites, causing weak interfacial bonding on the interfacial region (reduction of interactions) and causing failure by intercellular and/or intracellular modes. This is one of the reasons which led, in some cases, to the decrease of the mechanical properties of polymeric composites reinforced with banana fibers, with the addition of banana fibers. To solve this drawback, the research community has developed different surface chemical treatments, which cause morphological changes to the banana fibers and lead to a closer packing of banana fibers. This improves the compatibility between natural fibers (in this case, banana fibers) with the polymeric matrix and induces better mechanical bonding into the interfacial region.

Examples of surface chemical treatments are alkalization or mercerization, silanization, acetylation, cyanoethylation, potassium (e.g., permanganate, metabisulfite, hydroxide) treatments, sodium (e.g., lauryl, hypochlorite, chlorite) treatments, acid (e.g., acetic, oxalic) treatments, benzoylation, etc. On the modified banana fibers studied in this review work, the most used surface chemical treatments were alkalization and silanization.

An indirect method to treat the natural fibers, namely banana fibers, is by the addition of a compatibilizer into the polymeric matrix. Examples of compatibilizers are graft, block copolymers, or graft copolymers by the modification of polymeric matrices. In general, grafting can be done by monomers (e.g., $C_{18}H_{36}O_2$, $C_4H_6O_3$, maleic anhydride, and methylacrylate) and acrylic monomers (e.g., 2-EHA), etc. With this method, it is possible to obtain interactions between the monomers and the hydroxyl group (–OH) of banana fibers, which causes better adhesion into the IR and, consequently, some increases in the mechanical properties (e.g., toughness) of polymeric composites reinforced with banana fibers. In addition, it also causes a reduction in the moisture absorption tendency. In some of the consulted works, the Scanning Electron Microscope images revealed the good quality of the interfacial region (reduction of the crack propagation) and the higher adhesion between the modified polymeric matrices and the modified banana fibers, which were caused by the maleate groups. However, some improvement was also obtained for the modified polymeric matrices with unmodified banana fibers. In these cases, the authors speculated that the selected polymeric matrices were not the best choice. However, from the comparative studies of the mechanical properties of polymeric composites reinforced with unmodified banana fibers and mechanical properties of polymeric composites reinforced with modified banana fibers, it was found that the mechanical properties of polymeric composites reinforced with modified banana fibers are higher than that of polymeric composites reinforced with unmodified banana fibers.

Various techniques and methodologies exist to fabricate polymeric composites reinforced with banana fibers. For the polymeric composites reinforced with banana fibers studied in this review work, the most used was compression molding.

Polymeric composites reinforced with banana fibers with satisfactory behavior on the modulus and strength could be successfully manufactured using unmodified banana fibers as the reinforcing agent. However, some mechanical improvements can be a consequence of the reduction of the banana fiber length. In fact, the highest improvements were observed for the longest unmodified banana fibers at the highest fiber loading. This proves that it is necessary to add a large amount of unmodified banana fibers to make the polymeric composites reinforced with unmodified banana fibers more ductile. However, the shortest unmodified banana fibers improve the mechanical properties of the polymeric composites reinforced with banana fibers, even at a low fiber loading content. It would be interesting to compare the results with the shortest modified banana fibers instead with the shortest unmodified banana fibers.

Modified banana fibers with starch solution caused an increase of mechanical properties because starch was working as a good stiffening agent. It is well known that starch is widely used as a stiffening agent for fibers.

7. Future Trends

Banana cultivation is important to Madeira Island from an economic point of view, as well as a landscape standpoint. That is why, in the near future, the authors of this review paper will intend to extend PCBF application from the automotive to the biomedical field. At this time, a very small number of researchers are working on it, so there is a need to carry out more experimental and theoretical studies on PCBF in order to confirm the previous findings from several authors and to check the influence of several variable studies (BFLg, FL, SCT of BF, compatibilization of the PM) in order to propose reliable forecasting models and to make PCBF more economical by using efficient processes in the PC preparation and BF separation. The systematic and persistent research in the future will increase the scope and better future for polymeric composites reinforced with banana fibers.

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Highlights

- ► Banana fibers have shown their potential and effectiveness to replace synthetic fibers (e.g., glass fibers);
- ► Polymeric composites reinforced with banana fibers with satisfactory behavior on modulus and strength can be manufactured with unmodified banana fibers;
- ► Unmodified or modified banana fibers can be incorporated into compatibilized polymeric matrices;
- ► Unmodified banana fibers improve the mechanical properties of the polymeric composites reinforced with banana fibers even at a low fiber loading content;
- ► Highest improvements in mechanical properties were found for biopolymeric composite manufactured with banana fibers and plasticized starch matrix.

Abbreviations

Abbreviations	**Description**
APS	3-aminopro-pyltriethoxysilane
ASTM	American Society for Testing and Materials
BF	Banana fibers
BFLg	Banana fiber length
BLT	Banana leaves tapes
BPC	Biopolymeric composite;
BPM	Biopolymeric matrices
BPS	Banana pseudostem
CCA	Chemical coupling agents
CG	Crude glycerin
DW	Distilled water
EP	Epoxy resin
FESEM	Field emission scanning electron microscope
FL	Fiber loading
FLg	Fiber length
FM	Flexural modulus
FP	Flexural properties
FS	Flexural strength
FSF	Fractured surface
GC	Graft copolymer
GF	Glass fibers
GMA	Graft-glycidyl methacrylate
GTA	Glycerol triacetate ester
HDPE	High-density polyethylene
HDPE_MA	Modified high-density maleic anhydride grafted polyethylene
HPCBF	Hybrid polymeric composites reinforced with banana fibers and another type of fiber
IP	Impact properties
IR	Interfacial region
IS	Impact strength
LDPE	Low-density polyethylene
LDPE_MA	Low-density polyethylene modified with maleic anhydride
LDPE_MTA	Low-density polyethylene modified with methylacrylate and with starch
LHPE_MA_UBF	High-density polyethylene modified with maleic anhydride and unmodified banana fibers
LP	Layering pattern
MA ,	Maleic anhydride
MAPP	Maleic anhydride grafted polypropylene
MAT	Moisture absorption tendency
MBF	Modified banana fibers

Abbreviations	**Description**
MC	Moisture content
ME	Modulus of elasticity
MFA	Microfibrillar angle
MLDPE	Maleated low-density polyethylene
MP	Mechanical properties
MPCMBF	Modified polymeric composite matrix with modified banana fibers
MPCUBF	modified polymeric composite matrix with unmodified banana fibers
MPCUBF_MA	Maleic anhydride modified polymeric composite matrix with unmodified banana fibers
MPCLMBF_MTA	Modified methylacrylate polymeric composite laminates reinforced with modified banana fibers
MPM	Modified polymeric matrix
MTA	Methylacrylate
MTA/S	Methylacrylate with starch
MV	Maximum variation
NF	Natural fibers
NFLg	Natural fibers lengths
PC	Polymeric composites
PCBF	Polymeric composites reinforced with banana fibers
PCBF_SCT_GC	Graft copolymeric composites reinforced reinforced with treated BF
PCLBF	Polymeric composites laminates reinforced with banana fibers
PCLMBF	Polymeric composites laminates reinforced with modified banana fibers
PCLUBF	Polymeric composites laminates reinforced with unmodified banana fibers
PCLNF	Polymeric composites laminates reinforced with natural fibers
PCMBF_GC	Graft copolymeric composites reinforced with modified banana fibers
PCNF	Polymeric composites reinforced with natural fibers
PCUBF_MA	Polymeric composites reinforced with unmodified banana fibers into a modified matrix with maleic anhydride
PCWBF	Polymeric composites with a woven pattern reinforced with banana fibers
PF	Phenol formaldehyde
PLA	Polylactic acid
PLA_GMA	Modified polylactic acid with graft glycidyl methacrylate
PM	Polymeric matrices
PP	Polypropylene
PP_MA	Maleic anhydride grafted polypropylene
PVC	Polyvinyl chloride
RO	Randomly oriented
RT	Room temperature
RTW	Running tap water
SA	Surface area
SCT	Surface chemical treatments
SF	Synthetic fibers
SEM	Scanning electron microscope
Si69	bis-(3-triethoxy silyl propyl) tetrasulfane
SM	Starch matrix
SMBPC	Starch matrix biopolymer composites
SMBPM	Starch matrix biopolymeric matrices
SPI	Soy protein isolate
SPINM	Soy protein isolate natural matrix
SPM	Synthetic polymeric matrices
Tg	Glass transition temperature
TM	Tensile (elastic) modulus
TP	Tensile properties

Abbreviations	**Description**
TPPM	Thermoplastic polymeric matrices
TPS	Thermoplastic starch;
TS	Tensile strength
TSPM	Thermosetting polymeric matrices
UBF	Unmodified banana fibers
UHDPE	Unmodified high-density polyethylene
UHDPE_UBF	Unmodified high-density polyethylene with unmodified banana fibers
ULDPE	Unmodified low-density polyethylene
ULDPE_UBF	Unmodified low-density polyethylene with unmodified banana fibers
UP	Unsaturated polyesters
UP-resin	Unsaturated isophthalic polyester resin
UPCBF	Unmodified polymeric composites with banana fibers
UPCMBF	Unmodified polymeric composites with modified banana fibers
UPCUBF	Unmodified polymeric composites with unmodified banana fibers
UPF	Unmodified phenol formaldehyde
UPF_UBF	Unmodified phenol formaldehyde with unmodified banana fibers
UPLA	Unmodified polylactic acid
UPLAMBF	Unmodified polylactic acid reinforced with modified banana fibers
UPM	Unmodified polymeric matrix
UP_UBF	Unsaturated polyesters with unmodified banana fibers
UR	Unsaturated rubbers
VF	Volume fraction
WA	Water absorption
WAR	Weaving architecture
WF	Weight fraction
2-EHA	2-ethylhexyl acrylate

Appendix A

Table A1. Used methods for the extraction and preparation of BF. For a list of all abbreviations, please see the list directly above.

References	Fibers Extraction/Fibers Preparation
[74]	BF + steam explosion process. BF (macro): cutting + drying (in air and vacuum oven). BF (micro): soaking (in NaOH) + autoclave + distillation (in water) + autoclave + distillation (in water + NaClO + acetate buffer + mechanical stirring + filtration + drying. BF (nano): soak (in NaOH) + autoclave + distillation (in water + NaClO) + acetate buffer + distillation (in water) + drying + soaking (in $C_2H_2O_4$) + autoclave + wash (with $KMnO_4$) + mechanical stirring + drying.
[79,116,117,188]	BF (from BPS) + MM (extracting machine) + drying (under sunlight (2 weeks) + soaking (in water) + and drying (under sunlight) + woven roving.
[99]	BF (from BPS) + MM (extracting machine and by hand) + soaking (in bleach aqueous solution (10%)) + drying (in oven (60 °C)) + cutting.
[32,93,94]	BF (from BPS) + MM (by hand) + SCT. Modification with silane: soaking (in METHACRYLOXYPROPYL TRIMETHOXY SILANE + VINYL TRIETHOXY SILANE solution (0.6%) + ethanol + water (6:4)) + allowing to stand ((1 h) until pH=4) + soaking in the same solution (1 h 30 min (until reach $4< pH< 7$, by adding $C_3H_4O_2$)) + drainage + drying (in air 30 min) + drying (in oven at 70 °C). Alkaline SCT: soaking (in NaOH solutions (0.25% and 0.5%) for 30 min) + wash (with very dilute acid) + dying (in oven at 70 °C for 3 h). Acetylation SCT: soaking (in $\approx$10 mL solution (CH_3COOH + $C_4H_6O_3$ + H_2SO_4) + wash (with DW) + drying (in oven at 70 °C for 30 min) [93]. In [32,94], BF were neatly separated by hand and arranged into a mold in the form of mats.
[64]	BF (from local Egyptian farmers) + milling (for a few minutes in a mechanical grinder (3000 rpm)) + sieving (mesh sizes (18, 35, and 60 mesh)).
[188]	BF (from local supplier) + wash (pyroligneous solution) + drying (at RT) + defibrillation + milling + drying (at 60 °C for 12 h) + storage.
[102]	BF ((0.18 mm) from BPS) + autoclave (electrically heated rotatory) + pulping (with 10% (w/w) of NaOH + liquor to BF (10:1)) + cooking (from RT to 170 °C for 1 h and 170 °C for 2 h). BF ((0.04 mm) by SET) + batch reactor (at 220 °C for 240 s) + wash (with water) + storage + modification (with xylene) + stirring (at 100 °C) + mixing (67–70 g of MA + 3 g of BF + 1 g of sodium hypophosphite monohydrate) + reaction (for 2 h at 100 °C) + filtration (soxhlet extraction with xylene for 24 h) + drying (in oven at 70 °C for 24 h).
[103]	BF (from local supplier) + drying (in air oven at 70 °C for 3 h) + SCT. Alkali SCT: soaking (in NaOH (10%) for 1 h) + wash (with water + CH_3COOH) + drying (in oven at 70 °C). Silane SCT: soaking (in alcohol/water (6:4) + VINYL TRIETHOXY SILANE) + pH control (by adding CH_3COOH for 1 h 30 min) + drying (in oven at 70 °C) + soaking (in 1% $C_{18}H_{36}O_2$ in alcohol for 1 h) + drying (in oven at 60 °C for 1 h). C_6H_5COCL SCT: soaking (in NaOH (2%) for 30 min) + wash (with C_6H_5COCL for 30 min) + wash (with water) + drying (in oven at 70 °C). $KMnO_4$ SCT: soaking (in $KMnO_4$ (0.5%) + acetone for 30 min) + decantation + drying (in air).
[100]	BF (from local supplier) + soaking (in bleach aqueous solution) + drying (in oven) + PM modification (with MA).
[12]	Monomer SCT of BF: wash (with acetone for 30 min at RT) + drying (at 50 °C for 24 h in vacuum oven) + cutting + mixing (MTA+2% $C_{14}H_{10}O_4$+ CH_3OH) + soaking + curing (at 50–90 °C for 10–50 min (different stages)) + wash (acetone for 5 min) + drying (in oven at 50 °C for 20 h). For SM SCT: soaking (in SM solutions (2–5 wt % for 2–8 min)) + drying (at 80 °C for 24 h).
[49]	BF (from local supplier) + cleaning + cutting (150 mm) + wash (with acetone) + soaking (in acetone for 30 min at RT) + drying (in air during a week) + drying (at 80 °C for 24 h in a vacuum oven). Monomer SCT: mixing (2-EHA (10%–30% (different EHA solutions)) + 2% photoinitiator + CH_3OH) + wash + drying + soaking (during 2–8 min) + irradiation (with UV radiation at wavelengths of 254–313 nm and 2 kW power at 50 amps current for 24 h). Starch SCT: soaking (in SM solutions prepared using hot water (90 °C), 3–7 wt %) + drying (at 105 °C for 24 h) + storage (in a sealed container).
[38]	BF (from local supplier) + chased and then, mercerize (with NaOH (1 N) for 1 h) + wash + drying (in oven at 60 °C for 6 h).

Table A1. *Cont.*

References	Fibers Extraction/Fibers Preparation
[1,45]	BF (from the leafs (as sheets)) + soaking (in tap water) + brushing + soaking (in G solution + DW (1:3) at 80 °C for 24 h) + cleaning (with RTW) + drying (at RT for 24 h) + pressing (at 70 °C, 100 kg/cm^2). For BF (from BPS) + cutting (using a machete) + wash (in the RTW) + drying (at 100 °C in convection oven for 24 h) + sieving (150 µm) + mixing (110.25 g of BF + 35.0 mL of water (at RT)) + pressing (100 kg/cm^2 at 180 °C for 5 min) + cooling (to RT under the same pressure for 30 min).
[37]	BF (from BPS) + SCT. Alkali SCT: wash (with water) + soaking (in NaOH ((1%)1:15) for 30 min at RT) + wash (with RTW) + wash (with DW until reach pH = 7) + drying (in oven at 70 °C for 48 h). $C_3H_4O_2$ SCT: soaking (in $C_3H_4O_2$ ((1%) 1:15) for 20 min) + wash + drying (in oven at 70 °C for 48 h).
[156]	BF + modification (in a regional laboratory) + soaking (in toluene for 24 h) + wash (with petroleum ether) + drying (at 80 °C for 24 h) + immersion (in NaOH (5%–10%) at RT) + wash (with DW) + drying (in oven at 80 °C for 24 h).
[153]	BF (from BPS) + shredding + drying (in air for 1 week) + drying (in oven at 65 °C) + milling (for 1–3 h in a vibratory ball mill to get 3–5 mm in length) + storage.
[81]	BF were purchase and added directly into the PF without SCT.
[79,116,117,188]	BF (from BPS) + drying (in sunlight for 12 h) + weaving (by hand lay-up).
[123]	BF (from BPS by mechanical separation) + and chopping (manually) + SCT (with NaOH (0.5%) at 90 °C for 30 min) + wash (in RTW until the PH value reached 7) + drying (in oven).
[97]	BF (from local supplier) + arrangement (into small bundles) + immersion (in detergent (2%) at RT for 2 h) + wash (in DW) + drying (in air (1 day) and in vacuum oven at 80 °C for 12 h) + SCT ((silane (APS 60%) + ethanol (40%) + stirring (for 15 min) + immersion (in the initial solution for 1 h) + wash (in DW) + drying (as before)) + chopping.
[96]	BF (from BPS and supplied by Taiwan Banana Research Institute) + immersion (in detergent (2%) at 60 °C for 1 h) + wash (in RTW and DW) + drying (in vacuum oven at 80 °C) + alkaline SCT ((with 4% NaOH solution for 45 min) + wash (in RTW and DW until the pH value reached 7.0) + drying + chopping). For silane SCT: immersion (in acetone solution of silane (5 g of BF for 0.5 g of silane)) + agitation (for 30 min) + stabilization (for 12 h at RT) + wash (with acetone) + drying (at 80 °C in oven).
[30,34,48]	Wash (in water for 4 h) + drying (at RT for 24 h). For SCT BF: immersion (in NaOH (5%) for 2h at RT) + wash (in CH_3COOH (1%)) + rinse (in DW) + drying (at RT for 24 h) + storage or BF (from supplier) + cutting + immersion (in detergent at 60 °C for 2 h) + wash (in DW) + drying (in air for 2 days) + SCT. Alkaline SCT: immersion (in NaOH (1N) for 1 h at RT) + wash (with DW + few drops of CH3COOH) + drying (at RT for 24 h) + drying (in vacuum oven at 80 °C for 12 h). Silane SCT: APS or Si69 (5 wt %) + water–ethanol (40:60 w/w)) + CH3COOH (until the pH value reached 4.0) + stirring (for 1 h) + soaking (for 3 h) + wash (with DW) + drying (in air for 2 days) + drying (in vacuum oven for 12 h at 80 °C) + cutting. Acetylation SCT: immersion (in CH_3COOH and $C_4H_6O_3$ (1.1) solution with H_2SO_4) + separation + wash (with DW) + drying (at RT for 24 h) + drying (in vacuum oven for 12 h at 80 °C).
[85]	BF (from BPS and obtained from local agricultural waste) + cutting (1–10 mm]) + rinse (with DW) + drying (in an oven at 60 °C for 48 h). For SCT BF: immersion (in NaOH (5%) for 24 h at RT) + wash (with DW) + drying (in an oven at 60 °C for 48 h).
[57]	BF (obtained from local agricultural waste) + cutting (in mats with uniform thickness) + drying (under sunlight for 24 h) + wash (with acetone thinner) + hand lay-up process.

Table A1. *Cont.*

References	Fibers Extraction/Fibers Preparation
[2]	BF (obtained from local agricultural waste) + drying (under sunlight) + cutting + sieving (in the size ranges 1–10 µm and 10–100 µm).
[191]	Cross-plied BF (from supplier)
[60]	BF (from BPS) + cutting (6 (mm)) + immersion (in detergent solution) + drying (in vacuum).
[137]	Cutting (banana trunks were cut horizontally in order to get the average width of 10–15 (mm)) + soaking (in water for a week) + drying at 808 °C + different BF FL (5, 10, 15, and 20 vol %) + SCT (1%, 3%, and 5% of NaOH and $C_3H_4O_2$) + drying at 258 °C for 20 min + washing with DW + drying at 708 °C for 3 h (before PCBF preparation)

Appendix B

Table A2. Techniques and methodologies used to prepare TPPM and TSPM with BF.

References	Composites-Compound Materials and Manufacturing	Matrices Type
[99]	PC with PVC matrix reinforced with UBF (0.04 (mm) in thickness and with FL of 5, 10, and 20 vol %: extrusion (at 130–160 °C, 60 bar) + cooling (20 s (TP samples) and 15 s (IP samples)) + chopping.	TPPM (PVC)
[64]	PM (ULDPE and LDPE_MA) reinforced with UBF (380 µm of length, 38.5 µm of diameter and with FL of 10, 20, 30, 40, and 50 wt %) + $C_{18}H_{36}O_2$ (2 wt %) + MA (0.8%) + extrusion (at 130 °C for 10 min, 75 rpm) + melting (10 min) + chopping + compression molding (at 130 °C, 200 bar up to 0.5 (mm)).	TPPM (LDPE and LDPE_MA)
[188]	PC with HDPE matrix reinforced with UBF (0.42–1.19 (mm) in length with FL of 10, 20, 30 and 40 wt %): extrusion (at 150 °C and 170 °C, 300 rpm) + injection molding (at 150–180 °C, 30 cm^3/s, 1000 bar for 4 s) + cooling (30 s).	TPPM (HDPE)
[102]	PC with UHDPE or HDPE_MA matrices reinforced with BFLg of 0.04 (mm) and 0.18 (mm) with FL of 20, 40, and 60 wt %: Mixing (BF + HDPE + MA, at high temperature, in xylene (10%)) + stirring (until homogeneity) + cooling (at RT) + compression molding (at 130 °C for 5 min up to approximately 0.6(mm)).	TPPM (HDPE and HDPE_MA)
[103]	PC (PP fibers as matrix) with BF (6 (mm) in length at a fixed FL of 50 wt %: mixing (PP fibers + BF) + arrangement (in a tray) + pressing (into a mat) + compression molding (at 170 °C ± 3 °C, 8 kg/cm^2 for 3 min) + cooling (at RT).	TPPM (PP fibers)
[100]	PC with PP matrix reinforced with UBF (20 (mm) in length) at a fixed FL of 10 vol % obtained by extrusion (at 190–200 °C, 50 rpm) + chopping + heating (at 60 °C for 4 h in oven) + injection molding (at 170–210 °C, 300 bar) + cooling (30 s at RT) + mixing (different sequences ((PP + PP-MA + BF), (PP/PP-MA), ((PP/PP–MA) + BF) and PP (PP + (PP-MA + BF))).	TPPM (PP and PP_MA)
[37]	ULDPE matrix reinforced with UBF and MBF (NaOH), with 10 (mm) in length with FL of 10, 15, 20, 25, 30 wt % and for ULDPE and LDPE_MA matrices: drying (BF and PM, in oven) + compression molding (at 180 °C, 20 MPa for 10 min) + mixing (using mechanical stirrer) + cooling (at RT).	TPPM (LDPE)
[1,45]	Various layers of BLT (acrylic adhesive in the form of a double-sided tape) with different BLT fiber orientations: aligned in the same direction (parallel orientation) and layers aligned in the cross-direction (criss-cross orientation) + compression molding (100 kg/cm^2 at 180 °C for 5 min).	TPPM (adhesive tape)

Table A2. *Cont.*

References	Composites-Compound Materials and Manufacturing	Matrices Type
[12,49]	Assembly composites for 3 cases: PCLUBF, MPCLMBF (MTA), and MPCLMBF (MTA/S (4% of starch)). MBF were also treated with 2-EHA monomer (mixed with methanol (CH3OH) under UV radiation) and also with aqueous starch solutions (3–7(%) wt %): 4 layers of BF and 5 layers of PM + pressing (at 180 °C, 7 MPa for 5 min) + compression molding (at 190 °C, 10 MPa for 5 min).	TPPM (LDPE)
[153]	SMBPC reinforced with BF and sugarcane bagasse fibers were fabricated. These NF were incorporated into an SM ((Amidex-3001 (with about 28% amylose)) + glycerin–as plasticizer (of two types: “Synth PA”–glycerol and “crude glycerin” (CG) (mixture of glycerol (81.7%), water (4.4%), traces of methanol and ethanol (0.01% and 0.03%, respectively)). The cases that the authors used BF were B-4 (SM 50%, glycerol 30%, 20 wt % BF), B-3 (SM 45%, glycerol 30%, 25 wt % BF), B-1 (SM 35%, glycerol 30%, 35 wt % BF), and B-6 (SM 40%, CG 30%, 30 wt % BF). TPS laminates: mixing + thermal molding (3 to 7 ton at 110 °C and 170 °C) as patented method. For PCLBF: hydraulic pressing (4 to 9 ton at 150–190 °C).	TPPM (TPS)
[156]	SPINM reinforced with BF with different amounts of glycerol (25-50 wt % as plasticizer): mixing (1.5 g glycerol + 3.0 g of SPI in 30 mL of water for about 1 h) + mixing (BF + SPI/ glycerol) + casting + pressing (10 tons at 155 °C for 7 min) + cooling.	TPPM (SPINM)
[123]	SMBPC with BF into a SM (native cornstarch (28% amylose) with 11% moisture and reagent grade glycerin (99.7% purity)), plasticized by 30 wt % glycerin and 20 wt % of DW. BF into the SM by FL contents of 40, 50 and 60 wt % at a fixed FLg of 30 (mm): Emulsification (with DW) + reinforcement (alkali-treated BF) + hot pressing (5 MPa at 160 °C for 30 min).	TPPM (TPS)
[97]	PCBF with UBF and MBF (2–3 (mm) and silane SCT) into a UPLA and PLA_GMA matrix (PLA-graft-glycidyl methacrylate (GMA)) + $C_{14}H_{10}O_4$ + $C_{18}H_{22}O_2$) at a fixed FL of 30wt %, GC was added to the PLA_GMA (5, 10, 15 and 20 wt %: drying (at 60 °C for 4 h in a vacuum oven) + mixing (at 180 °C, 60 rpm for 15 min) + cooling (to RT) + pelletizing + storage (at 60 °C for 2 h) + injection molding (at 175–180 °C, 60 rpm). For GC: mixing (PLA + GMA, at 165 °C, 80 rpm for 12 min) + crushing + separation (by precipitation) + wash (with methanol) + drying (in vacuum oven at 65 °C for 24 h).	TPPM (PLA)
[96]	PCBF of UPLA with UBF (fixed FL of 20 wt %) and MBF ((NaOH) FL contents of 20, 40, and 60 wt % with 10 (mm) in length: drying (PM + BF (with and without SCT) in oven at 100 °C for 4 h) + mixing (PM + BF + $C_{18}H_{22}O_2$) at 170 °C, 60 rpm for 15 min) + compression molding (at 185 °C up to 0.5 (mm)) + cooling + annealing (at 130 °C for 1 h 30 min).	TPPM (PLA)
[30,34,48]	In [34,48] were reported the manufacturing of PCBF with UBF and MBF). SCT of the BF were made with NaOH, C4H6O3, APS, and Si69. MBF were incorporated into UPLA matrix. UPM with UBF and MBF (2–5 (mm) or (2–3 (mm) and NaOH SCT. UBF were incorporated into UPLA matrix with BF (10, 20, 30, and 40 wt %). MBF (NaOH) were incorporated (10, 20, and 30 wt %) or studied at a fixed FL of 30 wt % for PLA_MA(1 to 5 wt % matrix and GTA (5 to 12 wt %): drying (PM + BF at 80 °C under vacuum for 12 h) + mixing (at 180–190 °C, 40 rpm for 10 min) + cooling + storage (at 80 °C for 2 h) + compression molding (at 190 °C, 80 kg/cm^2 for 15 min).	TPPM (PLA)
[74]	UPF matrix composites reinforced with UBF (macro (BFLg of 30 (mm) with FL of 10 and 20 wt %), micro (microfibrils with FL of 4, 8, 10, 15, and 20 wt %) and nano (nanofibers with FL of 4, 6, 8, 10 and 12 wt %): arrangement (BF in the mold) + hot compression (at 80 °C, 10–15 MPa for 20 min) + post curing (at 70 °C for 1 h) + cooling (to RT).	TSPM (PF)
[79,116,117,189]	PC (LP and WA) as a function of the effect of fiber VF: Hand-woven lay-up + mixing (PM and hardener) + stirring + casting (to the mold with 4 layers of the sample) + pre-curing (for 2h) + curing and pressing (for 24 h, 1 bar, at RT).	TSPM (EP resin)

Table A2. *Cont.*

References	Composites-Compound Materials and Manufacturing	Matrices Type
[32,93,94]	UP-resin matrix with BFLg of 10, 20, 30, and 40 (mm) with FL of 10, 20, 30, and 40 wt %: Hand lay-up + mixing (UP + hardener) + pressing and impregnation (into a mat) + removal of air bubbles (with a roller) + pressing (for 12 h) + curing (at RT for 12 h) + post-curing (for 2h at RT).	TSPM (UP)
[81]	PC with a fixed FL of 45 wt % of UBF with 30 (mm) in length: Hand lay-up + compression molding (at 100 °C) + impregnation (mats with PM) + curing (at RT).	TSPM (PF)
[38]	PCLBF (assembly) with UP-resin matrix and with BFLg of 4 (mm): PM first and then BF + pre-compression (10 kgf/cm2 for a day) + compression molding (50 kgf/cm^2, for 24 h at RT).	TSPM (UP-resin)
[85]	Mixing (PM (EP resin (bisphenol-A + polyoxypropyelene diamine + diethylenetriamine) + hardener (ratio 4:1)) + BF (5, 10, 15 and 20 wt %) + releasing agents + casting + compression molding (at RT, pressure of 7 MPa for 24 h) + storage (at RT with 65% in relative humidity, 101 kPa in pressure for 24 h).	TSPM (EP resin)
[57]	PCLBF with different VF of BF versus EP resin, namely: 40BF/EP60, 50BF/50EP, and 60BF/40EP vol %: mixing (EP resin + catalyst (MEKP($C_8H_{18}O_6$)) + Impregnation of the mats + drying (under sunlight for 48 h) + Hand lay-up of 3 layers of BF + forming with a roller + compression molding (at 32 °C, under the pressure of 6 MPa, and the average relative humidity of 65%).	TSPM (EP resin)
[2]	Three different PC (with short, micro, and macro BF) with three different BF contents (25, 30, and 35 wt %): Mixing (EP resin + hardener (ratio 10:1) + BF) + casting + curing in a compression molding machine (at 80 °C in the pressure of 103 bars for 45 min).	TSPM (EP resin)
[191]	Mixing (EP resin + hardener (ratio 10:1) + BF mats (cross-plied laminates) + Hand lay-up + compression molding (curing under a load of about 25 kg for 24 h) + post-curing (in the air for 24 h).	TSPM (EP resin)
[60]	Mixing (PP + MAPP (1%–3%) + BF) + extrusion (at 175 °C for 10 min at 30 rpm) + compression molding (sheets of 3 ± 0.1 (mm)) + drying (in vacuum at 80 °C) + storage (in sealed desiccators for 24 h).	TPPM (PP)
[137]	Dried BF were woven manually into an approximate mat size of 25 × 25 cm + impregnation (with polyester) + vacuum (bagging molding) + curing (at RT for 24 h). The PCBF studied with 4 different VF (5, 10, 15, 20%)).	

Appendix C

Table A3. Variation of the mechanical properties for polymeric composites reinforced with banana fibers as a function of different banana fibers loadings in comparison with the respective control sample of each mentioned study.

References	PC Type	Highest MV on MP of (. . .) in Comparison with (. . .)/ Lengths/Contents (wt %)			Studied Properties				
					TM	**TS**	**FM**	**FS**	**IS**
[64]	RO	UPCUBF pristine PC	380 μm	40	+57	−43	-	-	-
		MPCUBF(MA) UPCUBF			+28	+50			
Authors Findings	The variation in the TM increased for highest values of FL (i.e., 40 and 50 wt %) in both cases (ULDPE and LDPE_MA). However, the variation in the TM displays a continuous increase until an optimum FL of 40 wt %. In the presence of MA, the variation in the TM also displays the higher variation at the same FL. However, at low FL (10 and 20 wt %) and in the presence of MA, the variation in the TM decreased. It seems that these authors found the optimal content with respect to the TM at 40 wt % for the both cases (ULDPE and LDPE_MA). However, PCUBF_MA didn't reach a higher variation in TM in comparison with UPCBF. In fact, the presence of MA decreased the variation in TM (29% less) at the same FL (40 wt %). Concerning the variation in the TS, it clearly increased as the FL was increased for LDPE_MA. In contrast, TS tends to decrease for UPCUBF. According with the authors and with the observed SEM results (for UPCUBF), UBF pull-out as well as holes resulting from UBF delamination were observed. Pulled-out UBF and gaps were an indication of a weak/poor adhesion between UBF and the ULDPE into the IR. This observation is in agreement with the observed loss in the variation of TS for the UPCUBF. However, for LDPE_MA, the authors observed through SEM images that the UBF were found to be uniformly coated by the LDPE_MA and, also, the UBF were severely fractured after the mechanical tests, suggesting that the UBF didn't get strained up to their maximum stress values. According to the authors, these observations are indicative of good chemical compatibility (between the UBF and the LDPE_MA) caused by the maleate groups.								
[37]	RO	. . . UPCUBF . . . pristine PC . . .	10 (mm)	10	+82	−23	-	−36	−69
				15	+97	-	-	-	-
				20	+187	-	-	-	-
				25	+228	-	-	-	-
				30	+256	-	-	-	-
		. . . MPCUBF (MA) . . . pristine PC		25	-	+29	-	-	-
		. . . MPCMBF (MA; $C_3H_4O_2$) . . . MPCUBF . . .		25	+15	-	-	-	-
		. . . MPCMBF (MA; $C_3H_4O_2$) . . . MPCUBF . . .		25	-	-	-	+17	+12

Table A3. *Cont.*

References	PC Type	Highest MV on MP of (...) in Comparison with (...)/ Lengths/Contents (wt %)			Studied Properties	TM	TS	FM	FS	IS
AF	The variation in TM increased with the addition of UBF. The obtained increases may have been a consequence of the higher TM of UBF compared to that of the pure ULDPE matrix. The variation in TS, FS, and IS decreased considerably with the addition of UBF.									
[102]	RO	... UPCUBF ... pristine PC	0.18 (mm)	40		-	+86	-	-	-
				60		+77	-			
			0.04 (mm)	40		-	+186			
				60		+200	-			
		... MPCUBF(MA) ... UPCUBF ...	0.18 (mm)	20		+45	+89			
			0.04 (mm)			+42	+121			
Authors Findings	The variation in the TM for PCBF (BF = 0.04 (mm)) was found to be higher compared to PCBF (BF = 0.18 (mm)) at the same FL (60 wt %). The observed difference in the variation of TM may have been a consequence of the higher degree of crystallinity of shortest UBF in comparison with the longer UBF. For HDPE_MA matrix, MA modification didn´t improved the variation in TM in comparison with the unmodified case. That variation increased for a lowest value of FL (i.e, 20 wt %) in both cases due to the better adhesion of BF to the PM, but afterwards, it decreased because the PCBF lost its flexibility, which leads to poor adhesion of BF to the PM if more BF were added. In addition, it was observed that the higher crystallinity of the steam-exploded BF results in a higher modulus. Moreover, the higher lignin content facilitates BF dispersion in the PM. The variation in TS clearly increased as the FL increased for the two different studied BFLg and for UPCUBF, except for an FL of 60 wt %. Above an FL of 20 wt %, the variation in TS tends to decrease. It is important to note that a similar increase in the variation of TS was observed at different FL for MPCUBF(MA) and UPCUBF, respectively. In fact, the MA induced an improvement of more 3% at a lower FL content (20 wt %). According with the authors and through SEM images, the addition of 20 wt % of UBF into HDPE_MA induces a better adhesion of the BF to the PM compared to the UHDPE and, thus, a better stress transfer into the IR. In fact, for UPCUBF were observed rather smooth FSF, UBF pull-out as well as holes and delamination, especially for the largest UBF 0.18 (mm). Moreover, the shortening length of the added UBF (0.04 (mm)) facilitated the UBF dispersion into the UHDPE and the HDPE_MA, resulting in the highest TS and a higher degree of crystallinity to the final PCUBF. For additions of UBF with a FL up to 20 wt % and for HDPE_MA, as for TM, the authors have also observed a loss of flexibility, which reduced the TS property.									
[2]	RO	... PCUBF ... pristine PC for TP ... PCUBF ... PCUBF (25 wt %) for FP and IP ...	short	25		+17	−15	-	-	-
				30		+53	+14	−29	+2	+15
				35		+45	+20	−24	+37	+60

Table A3. *Cont.*

References	**PC Type**	**Highest MV on MP of (. . .) in Comparison with (. . .)/ Lengths/Contents (wt %)**			**Studied Properties**	**TM**	**TS**	**FM**	**FS**	**IS**
		. . . micro PCUBF . . . pristine PC for TP and with short PCUBF at 25 wt % for FP and IP . . .	micro	25		+32	−39	−36	−11	+30
				30		+40	−39	−13	+30	+15
				35		+77	−26	−44	+44	+5
		. . . macro PCUBF..pristine PC for TP and with short PCUBF at 25 wt % for FP and IP . . .	macro	25		+12	−33	−11	+9	+15
				30		+26	−28	−3.8	+31	+25
				35		+47	−18	−30	+69	+60
Authors Findings	Comparing the short UBF and macro UBF cases, it is possible to remark that the increase in TM needs less 5 wt % of short UBF than macro UBF for a higher increase. However, the short PCUBF with 35 wt % showed the highest MV on TS, whereas the macro PCUBF with 35 wt % showed the highest MV on FS. From the SEM images of the FSF of the PCUBF with 35 wt % of short BF, after the tensile tests, it was observed a better BF/PM interaction between the short BF and the PM. Furthermore, the BF breakage was observed in the FSF and it was the evidence of an effective stress transfer between the BF and the PM. However, the short PCUBF was unable to withstand a heavy flexural load, which led to the failure of the BF and resulted in a decrease in the FM. The increased FS in the macro PCBF was due to the better interfacial adhesion in the IR of the PCBF. In the case of the IS, both the short PCUBF and macro PCUBF showed the highest MV on IS. The micro PCUBF showed lowest value than the other two PCUBF, and the authors explained these results due to the characteristic of the NF, which presents lower IS and to the weak interfacial strength of the IR for micro UBF. Globally, the MP of the PCBF increased substantially with the increase of BF content (short, macro, and micro BF).									
[81]	RO	UPCUBF . . . pristine PC . . .	30 (mm)	16		+13	−14	−71	-	-
				27		+111	+129	−70	-	-
				32		+114	+186	−43	-	-
				41		+151	+271	-	-	-
				45		-	-	+25	-	-
				48		+320	+400	-	-	-
Authors Findings	TM and TS increase with the increase in FL. The highest MV on TM and TS were found for a FL of 48 wt % when compared with neat resin. At low loading of BF, the FM was found to be lower than that of the neat resin. However, on increasing the FL to 45 (wt %), the FM increased to about 25%. The FS also shows very good enhancement on increasing FL. PC with good strength could be successfully developed using BF as the reinforcing agent. The addition of fibers makes the matrix more ductile. The tensile, flexural, and impact properties of the PC are found to be dependent on FLg, and the optimum length of fiber required to obtain PCBF of maximum properties was found to be 30 (mm). The experimentally obtained TS values of PCBF were found to be comparable with Hirsh's theoretical predictions.									

Table A3. *Cont.*

References	PC Type	Highest MV on MP of (…) in Comparison with (…)/ Lengths/Contents (wt %)		Studied Properties	TM	TS	FM	FS	IS
[30]	RO	… UPLAUBF … pristine PC	2–5 (mm)	10	+7	−45	-	-	-
				20	+14	−39			−10
				30	+19	−29			−7
				40	+23	−35			−8
		UPLAMBF (mercerization) … pristine PC		10	+22	−42			−15
				20	+24	−34			−17
				30	+41	−17			−28
Authors Findings	It was evident that the addition of UBF at variable FL from 10 to 40 wt % resulted in a consistent increase in the variation of TM of the PCBF, increasing the toughness of the final material. UPCMBF achieve a highest variation in TM for a lowest FL. This observation was attributed to the increase in molecular orientation, to the better packing of cellulose chain, and to the good orientation of the MBF due to the alkalization, which makes them less dense and with a less fibrillar crimp region, making them more capable of rearranging themselves along the direction of TM deformation. The variation in TS decreased with the addition of UBF and MBF. The variation in TS was not significantly affected by the merceration of MBF. In fact, small increases at 30 wt % of FL were observed. These observed decreases were attributed to the effect of softening of the fibrillar crimp region and BF agglomeration, which may affect the overall uniform stress transfer into the IR under TS deformation. The variation of IP showed the same tendency as TS behavior. The addition of UBF and MBF (NaOH) decreased the variation in IS of UPCUBF and PCMBF. At an FL of 30 wt %, UPLA_MBF composites showed a higher descreased of 5% than UPLA_UBF. In this case, the alkaline SCT does not bring any significant improvement in IS variation.							
[34,48]	RO	… UPLAUBF … pristine UPLA …	2–3 (mm)	10	+12	−72	-	-	−41
				20	+19	−66			−39
				30	+31	−62			−23
				40	+33	−80	-	-	−45
Authors Findings	The incorporation of UBF into the UPLA increases the variation in TM. In this case, the variation in TM was 10% lower than UPCUBF from [30] at the same FL; this can be due to the used BFLg, which were 2–3 (mm) and 2–5 (mm), respectively. In fact, less than 2 (mm) on BFLg can make all the difference on TM behavior. The addition of UBF with different FLs reduces the variation in TS. The negative variation on TS was due to the poor adhesion in IR and to the agglomeration of UBF. The absence of SCT of the BF contribute to poor stress transfer across the IR. TS increased in comparison with the pristine PM at 30 wt % of BF, as compared with the UPCUBF prepared at 10 wt % of BF. However, beyond 30 wt % of BF, a significant decrease in TS was observed, as compared with the 10 wt % FL. This behavior was due to the fiber content for which the agglomeration of fibers takes place, resulting in poor stress transfer across the IR. The variation in IS decreased in all cases. IP follow the same trend as TS.							

Table A3. *Cont.*

References	**PC Type**	**Highest MV on MP of (. . .) in Comparison with (. . .)/ Lengths/Contents (wt %)**			**Studied Properties**	**TM**	**TS**	**FM**	**FS**	**IS**
[74]	RO	. . . UPCUBF . . . pristine PC	nano	4	-		+86	-	+150	+25
				6			+114		+180	+50
				8			+129		+230	+83
				10			+157		+260	+108
				12			+142		+280	+133
			micro	4			+29		+40	+8
				8			+71		+50	+13
				10			+100		+100	+17
				15			+114		+130	+33
				20			+157		-	+67
			macro	10			+86		+150	+8
				20			+129		-	+42
Authors Findings	PCBF (nano) have better MP (TS, FS, and IS) compared to PCBF (micro) and PCBF (macro) with very limited FL. The brittle nature of the PM decreased even with the addition of small quantities of nano BF. Significant increases in TS (142%), FS (280%), and IS (133%) at 12 wt % of nano FL were observed. This was due to the presence of cellulose nanocrystals in the PM, which contributes more effectively in enhancing the MP because there is an efficient stress transfer between the fiber cellulose nanocrystals and the PM. The MP of UPCUBF such as TS can be improved by the addition of a shorter FL (in this case, nano UBF), in comparison with longer UBF. The same increase of 157% was obtained for TS and for the longer and shortest UBF. For the shortest UBF (nano BF), such an increase was obtained at a lowest FL of 10 wt %. The highest values for the MV in FS and IS were obtained for nano UBF, even at a lower FL content (12 wt %).									
[85]	RO	. . . UPCMBF . . . pristine PC . . .	1–10 (mm)	5	-		+47	-	-	-
				20			+17			
Authors Findings	The increasing in the FL decreased the TS of PCBF until at certain FL. The optimum FL were found at 5, followed by 20, 10 and 15 wt %. After that, the variation in TS intends to recover the observed decreases. However, the optimum WT of UBF and MBF is in both cases at 5 wt %, followed by 20 wt %. The authors explained these increases due to the PM-BF interaction and, also, to the alkaline SCT which modifies the internal and external structure of the BF, making their surface rougher and with higher PM absorbance capacity. These observations were confirmed through SEM images which revealed that the alkaline SCT changed the structure of BF.									

Table A3. *Cont.*

References	**PC Type**	**Highest MV on MP of (. . .) in Comparison with (. . .)/ Lengths/Contents (wt %)**			**Studied Properties**				
					TM	**TS**	**FM**	**FS**	**IS**
[99]	RO	. . . UPCUBF . . . pristine PC . . . vol %	0.04 (mm)	5	-	−1	-	-	+28
				10		+8			+43
				20		+4			+6
AF	Tensile and impact results show that the addition of UBF into the PVC matrix increased the TS and IS properties. However, for TS, such an increase is less than 10% for all used FL. TS and IS obtained the highest increases at the same FL of 10 vol %. The incorporation of BF induces approximate increases of 28%, 43% and 6% on IS for the formulations with 5, 10 and 20 wt % of BF, respectively, in comparison to the pure PVC compound. These results suggest that the incorporation of BF into the PVC matrix changes the local stress concentration along the BF. Resistance may lead to a change in the mechanism of deformation of the PC. For the formulation with 20 wt % of BF, the increase in IS was not significant. This was due to the low affinity observed into the IR by SEM. A lack of adhesion and voids were observed (resulting from the BF pull-out), suggesting the need for an SCT of the BF or the addition of a compatibilizing agent, in order to increase interfacial adhesion.								
[188]	RO	. . . UPCUBF . . . pristine PC . . .	0.42 −1.19 (mm)	10	+326	-	-	-	+247
				20	+520		+62		+142
				30	+727		+147		+136
				40	+732		+164		−20
Authors Findings	TM results show that the addition of UBF into the HDPE matrix increased the variations in TM, FM, and IS properties. This was due to the decrease of the deformation capacity of the PC when submitted to the tension and flexion, affecting the properties in a way inverse to the elongation in the rupture of the PC. The variation in IS increased with the addition of UBF up to a FL of 30 wt %. However, a further addition of UBF causes a loss in IS of about 20% in comparison with the pure PM. This was due to the deterioration of the SMBPC due to the agglomeration of the UBF. These authors also concluded that the PCBF can replace PCGF for FP and IP with the addition of 20 wt %) of BF into the HDPE matrix.								
[96]	RO	. . . UPCUBF . . . pristine PC . . .	10 (mm)	20	+100	+37	-	+26	−23
				40	+515	+100		+66	−23
				60	+870	+67		+63	−34
		. . . UPCMBF . . . UPCUBF . . .		20	+467	+19	-	+18	−23

Table A3. *Cont.*

References	PC Type	Highest MV on MP of (. . .) in Comparison with (. . .)/ Lengths/Contents (wt %)	Studied Properties	TM	TS	FM	FS	IS
Authors Findings	The variations on TM and TS of PCBF are all higher than those of pristine PC (PLA matrix). However, the TS at 60 wt % is somewhat less than at 40 wt %; this was due to the adhesion of BF/PLA and to the deterioration of the UPCUBF at 60 wt %. This was the result of the particular morphology aggregation by the high content of BF, which influences the MP of the UPCUBF. Moreover, TS at 20 wt % of UBF was superior to that of 20 wt % of MBF. This indicated that grafting MBF onto a PLA chain can effectively improve the TS of PLA. However, the TM at 60 wt % of BF is the largest, and the TM at 20 wt % of MBF is larger than that at 20 wt % of UBF. This was due to the fact that the strain of UPCUBF at 60 wt % is the smallest (elongation at break: 0.08%), and the strain of UPCMBF at 20 wt % (elongation at break: 0.23%) is far smaller than the one of UPCUBF at 20 wt % (elongation at break: 1.29%). This indicated that the adhesion of BF/PLA is improved via grafting MBF onto a PLA chain, and the strain of PCBF is less decreased by the addition of MBF than the UBF. The comparison of the variation in TS at 20 wt % of UBF and MBF shows an increase of about 19%, which indicates the effectiveness of the modification. the MBF. The variation in IS decreased with the FL for both cases (UBF and MBF). This was due to the decreasing tendency of strain, which shows that the stiffness of the PM is improved by the FL of BF, but also induces their brittleness. These results are according with the SEM observations, which showed: the brittle nature of UPLA matrix, the poorest quality of the IR for UBF case (confirmed by the presence of voids and pull-out UBF on the FSF of the samples), the good quality of the IR for up to 40wt % MBF.							

Appendix D

Table A4. Variation of the mechanical properties for polymeric composites reinforced with banana fibers at fixed banana fibers loadings in comparison with the respective control sample of each mentioned study.

References	PC Type	Highest MV on MP of (. . .) in Comparison with (. . .)/Lengths/ Contents (wt %)			Studied Properties	TM	TS	FM	FS	IS
[103]	RO	. . . UPCUBF . . . pristine PC.	6 (mm)	50		-	-	-	-	-
		. . . UPCMBF (10%NaOH) . . . UPCUBF				+12	+19	+29	+26	−50
		. . . UPCMBF (benzoylated) . . . UPCUBF				+11	+14	+14	+14	−11
		. . . UPCMBF (stearic acid) . . . UPCUBF				+8	+13	+11	+2	−9
		. . . UPCMBF (vinyltrimethoxy silane) . . . UPCUBF				+9	+10	+15	+19	−33
		. . . UPCMBF ($KMnO_4$) . . . UPCUBF				+10	+7	+12	+5	−20

Table A4. *Cont.*

References	PC Type	Highest MV on MP of (...) in Comparison with (...)/Lengths/ Contents (wt %)			Studied Properties	TM	TS	FM	FS	IS
Authors Findings	The variations in TM, TS, FM, and FS were found to have a maximum for PCMBF (10% NaOH) in comparison with PCUBF. This was due to the increasing degree of molecular orientation. The removal of low cellulose fractions and cementing materials lead to better orientation and packing of molecules. Regarding the effect of alkalization on the PCBF properties, the process of fiber fibrillation in bast fibers is significant. Even at low NaOH concentrations, fibers can fibrillate, resulting in a reduced BF diameter. This was in agreement with SEM images that showed the BF aspect ratio as well as the effective surface area, which was in contact with the PM. As a result, there was an enhancement in BF/PM adhesion and thus improved PCMBF properties. From the SEM images of the tensile fracture surfaces of UPCUBF and UPMBF, it was possible to remark that BF/PP matrix interactions were dependent on the polarity parameters of MBF. BF with a lower polarity was more compatible with the non-polar PP matrix. For UPCUBF, the tensile rupture was accompanied by the debonding of the UBF leaving holes, which indicated a weak adhesion into the IR. However, for the UPCMBF, they observed significant improvement in the MBF/UPM adhesion by the absence of holes and debonding of the MBF. These observations can help us to understand the obtained results for the variation in TM, TS, FM, and FS. However, an opposite trend was observed for the variation in IS, which was found to be lowest for UPCMBF (10% NaOH). However, the variation in IS for UPCUBF was found to be higher in comparison with the UPCMBF. The observed that a decrease in IS was due to the separation of the UBF from the UPM (PP), which helped the creation of roughness on the surfaces during the fracture, thus consuming more energy during the tests. For the UPCMBF, the interfacial adhesion was more effective and consequently induced a low loss of energy during the fracture process of the samples. In general, the used SCT for BF improved the MP of PCMBF, but the PCMBF (10% NaOH) demonstrated the best MP (both tension and flexural).									
[100]	RO	... UPCUBF ... pristine PC vol %	20 (mm)	10		-	-	-	-	-
		... UPCUBF (PP+BF) ... pristine PC vol %				−17	−10			+9
		... MPCUBF((PP + PP-MA + BF)) ... pristine PC vol %				−8	−9			+24
		... MPCUBF((PP + PP-MA) + BF) ... pristine PC vol %				−4	−6			+13
		... MPCUBF (PP + (PP-MA + BF))) ... pristine PC vol %				−5	−6			−2
Authors Findings	Tensile and impact results show that the addition of UBF into the PP matrix decreased slightly the TP of the PC. The observed decreases were lowest for the sequence of mixture (PP+PP_MA)+UBF. The observed decreases in the variation of TM and TS were lower than 10%, except for the sequence of mixture PP+BF. It was possible to conclude that no significant changes were observed on TP by the addition of UBF into the studied matrix (PP). An increase in IS was observed for the sequence of mixture PP+PP_MA+UBF. Through SEM images, UBF showed higher adhesion for the PC with modified PM (MA).									

Table A4. *Cont.*

References	**PC Type**	**Highest MV on MP of (. . .) in Comparison with (. . .)/Lengths/ Contents (wt %)**			**Studied Properties**	**TM**	**TS**	**FM**	**FS**	**IS**
[37]	RO	. . . UPCUBF . . . pristine PC . . .	10 (mm)	25		+7	+29	-	+11	+2
		. . . MPCMBF (MA-NaOH) . . . UPCUBF . . .				+4	+11		+15	+11
		. . . MPCMBF (MAg -$C_3H_4O_2$) . . . UPCUBF . . .				+15	+17		+17	+12
Authors Findings		The incorporation of MA into PCUBF and PCMBF leads to improved interfacial bonding between BF and the LDPE matrix. The addition of MA showed some improvements in the variation of TS, TM, FS, and IS for UBF and MBF (alkali and acrylic acid) as compared to the same UPCMBF (without MA). This was due to the addition of MA, which generates strong covalent bonds between the maleic anhydride groups of MA and hydroxyl groups of BF surface, while the LDPE of MA-g-LDPE is compatible with LDPE matrix, resulting in the wetting and dispersion of the BF improved within the LDPE matrix and thereby enhancing the MP. In relation to the compatibilized composite containing UBF, compatibilized composites with surface-treated fibers showed better FS. The better FS indicates that the incorporation of compatibilizer provides better compatibility between the surface of MBF and LDPE matrix. The maximum FS variation was observed with compatibilized composites containing C3H4O2. However, the variation in TS of the MPCMBF showed lowers variations, which is paradoxical to the fact that good interfacial bonding improves the TS of the PC. It was due to the degradation of cellulose fibrils by SCT, which reduced the TS of PC. The degradation of MBF by SCT attack was observed by SEM.								
[81]	RO	. . . UPCUBF . . . pristine PC	30 (mm)	45		+218	+271	+25	+400	+180
AF		The FL and the BFLg were fixed at 45 wt % and 30 mm, respectively, and the variations on MP are shown. However, it seems that 48 wt % is the optimal FL for all the mechanical properties.								
[34,48]	RO	. . . UPCMBF (NaOH) . . . UPCUBF . . .	2–3 (mm)	30		−22	+9	-	-	+8
		UPCMBF ($C_4H_6O_3$) . . . UPCUBF . . .				−39	−15			+22
		UPCMBF (APS) . . . UPCUBF . . .				−20	+19			+24
		. . . UPCMBF (Si69) . . . UPCUBF . . .				−13	+136	-	-	+49

Table A4. *Cont.*

References	PC Type	Highest MV on MP of (. . .) in Comparison with (. . .)/Lengths/ Contents (wt %)			Studied Properties	TM	TS	FM	FS	IS
Authors Findings	The mercerization of BF results in an improvement in interfacial bonding into the IR, which is probably because of the formation of additional sites created for mechanical interlocking. This contributes to more fiber interpenetration at the IR, thereby increasing the strength in the PC. A marginal increase in TS of 9% was obtained for UPCMBF(NaOH) as compared with UPCUBF. Some authors reported the fact that NaOH treatment results in the removal of surface imperfection of the fibers, which helps efficient mechanical interlocking with the matrix. However, 19% improvement in TS was observed when BF was treated with APS. Some authors suggested that APS has the ability to interact with the polylactide chain, which plays a vital role in making it compatible with the BF. During the treatment, APS hydrolyzes to silanol, which can bond effectively with carboxylic groups of BF through ester linkage. Amino groups from APS can also form hydrogen bonds with C=O sites on the PLA backbone. This induces improvements in the compatibility of the BF with the PLA matrix, thereby increasing the strength. A significant improvement of 136% in TS was achieved with the incorporation of MBF (Si69) into the PLA. This was due to the ethoxy group of Si69, which reacts with the carbonyl group of the cellulosic fiber in ethanol media, which further interacts with PLA through hydrogen and covalent bonds. The sulfur atom presented in Si69 can also impart polarity in the system to enhance the interaction with the PLA matrix. Thus, it forms a bridge between BF and PLA, enhancing the interfacial interaction into the IR. In all the cases, the UPCMBF (except for Si69) showed a decrease in TM as compared with the UPCUBF. UPCMBF (treated with NaOH and APS) showed the smallest losses for TM as compared with the UPCUBF and the pristine PC. UPCMBF treated with (Si69) showed a marginal increase in TM because of increased interaction into IR. IP showed a similar trend. These obtained results confirm the improvement quality of the IR by the Si69 SCT of BF. In fact and as explained by the authors [48], the enhancing quality of the IR was the responsibility of the ethoxy group and the sulfur atom present in Si69. The first one reacts with the carbonyl group of the BF in ethanol media interacting with the UPLA through hydrogen and covalent bonds, and the second one changes the polarity of the system. These are the satisfactory conditions to hence the interpenetration of the MBF at the IR, increasing the strength in the final UPCMBF(Si69). However, an oposite trend was observed for MBF (acetylation) results, which showed a considerable decrease in the variation of the TP. The decrease was atributed to the cross-linking reactions and agglomeration of MBF during the manufacturing of the UPCMBF. This fact induces degradation on MBF and on the PM, and it results in poor stress transfer across the IR, which implies a reduction in MP. The SCT of BF enhance the IS of the UPCMBF as compared with UPCUBF. Nearly 8% improvement in IS was observed for UPCMBF(NaOH). Significant improvements of 24% and 49% in IS were observed for UPCMBF(APS and Si69), respectively. These results confirms an increasing in IR adhesion upon surface treatments. Finally, among all the UPCMBF, UPCMBF(Si69) showed optimum IS as compared with the virgin PM and other PC.									
[97]	RO	. . . UPCUBF . . . pristine PC . . .	2–3 (mm)	30		+85	+5	+40	+1	−41
		. . . UPCMBF (APS) . . . pristine PC . . .				+112	+19	+83	+9	−28
		. . . MPCMBF(APS-GC) . . . UPCMBF (APS) . . .		30(BF)+5CG		−5	+2	−4	+9	+24
				30(BF)+10CG		−7	+10	−7	+17	+29
				30(BF)+15CG		−8	+13	−7	+20	+54
				30(BF)+20 CG		−19	+6	−10	+7	+61

Table A4. *Cont.*

References	PC Type	Highest MV on MP of (. . .) in Comparison with (. . .)/Lengths/ Contents (wt %)		Studied Properties	TM	TS	FM	FS	IS
Authors Findings	The incorporation of UBF resulted in an improvement in the variation of TM and TS of PCBF. This behavior was explained by the stiffening effect of BF. The addition of MBF(APS) increased TM, TS, and FM. This was attributed to the better interfacial adhesion after APS treatment, which results in effective stress transfers into the IR. Moreover, the stiffening effect exerted by BF also ascribes for the high modulus of PCBF. During melt mixing, the carboxyl group of PLA reacts with one end of silanol, while the other end of silanol has already shared a bond with the hydroxyl group of BF. This multifunctionality of silanol resulted in good interfacial bonding. However, TM, TS, and FM reduced with the addition of GC. This behavior was due to the agglomeration of GC, which may have caused non-uniform stress transfer into IR. The addition of GC from 5 to 15 wt % improved the FS of PCMBF. This behavior was explained on the basis that the interaction of fiber and matrix with the epoxy as well as acrylic group of GC restricts the motion of PLA segments, thereby increasing the FS. Hence, the loading of 15 wt % of GC was considered as an optimum FL for obtaining better MP. On the contrary, with FL from 5 to 20 wt % of GC to PCMBF, a reduction in TM was observed. The FM of MPCMBF (APS-GC) with a varying amount of GC from 5 to 20 wt % also followed the same trend. Furthermore, it was observed that after the incorporation of GC, the IS of MPCMBF (APS-GC) improved significantly. This might be attributed to the plasticizing effect of GMA in GC.								
[30]	RO	. . . MPCUBF (MA) . . . pristine PC . . .	2–5 (mm)	30 (BF)+1MA	+62	−8	-	-	+24
				30 (BF)+3MA	+47	−12			+19
				30 (BF)+5MA	+44	−17			+11
		. . . MPCUBF (GTA) . . . pristine PC . . .		30 (BF)+5GTA	+45	−11			+13
				30 (BF)+10GTA	+35	−23			+127
				30 (BF)+12GTA	+26	−33			
Authors Findings	A high increase in the variation of TM was observed with the addition of MA and GTA. For the highest FL of GTA (12 wt %), the variation in TM decreased 13% compared with 5 wt % GTA. These effects were attributed to the formation of ester linkage into the IR due to a reaction between the anhydride group of MA with the acid group of the TPPM (PLA), which improves the interactions into the IR. The addition of more MA into the PM from 1 to 3 and 5 wt % induced a decrease in the variation of TM. This was an indication of a critical content of MA. In this case, MA additions higher than 1 wt % do not benefit the TM of the PCBF. The same trend was observed in the variation of TS. For the highest MA concentrations (3 and 5 wt %), the variation in TS decreased. Concerning the IP, the addition of MA increased the variation in IS. These results reveal that a low concentration of MA is enough as an effective PM compatibilizer. In fact, MA chemically modifies the IR, reducing the crack propagation. The addition of GTA also improves the IP of the PCBF. The comparison between both compatibilizers (MA and GTA) showed that MA improved more the MP of the PCBF with the PLA matrix. SEM observation showed clearly the satisfactory wetting of the BF within the PM.								

Table A4. *Cont.*

References	PC Type	Highest MV on MP of (. . .) in Comparison with (. . .)/Lengths/ Contents (wt %)			Studied Properties	TM	TS	FM	FS	IS
[60]	RO and H	. . . PCUBF . . . pristine PM (PP) . . .	6 (mm)	10		+9	+17	+7	+19	+19
				20		+39	+28	+22	+28	+29
				30		+68	+46	+33	+36	+42
				40		+78	+20	+39	+16	+12
		. . . MPCUBF (MAPP) . . . PCUBF . . .		30 (UBF) +1 (MAPP)		+20	+3	+10	+10	+11
				30 (UBF) +2 (MAPP)		+45	+11	+11	+26	+22
				30 (UBF) +3 (MAPP)		+32	+6	+3	+17	+10
Authors Findings	The presented results are concerning the 0% GF case and with WF variation of UBF. MP increases with increases in BF loading up to 30 wt %. It was also evident that there was an increase in TP (TS), FP, and IS with a maximum corresponding to the samples containing 30 wt % of BF, in comparision with the pristine PM (PP). This was due to the addition of BF bridges, which increases the resistance to the propagation of the cracks. On the other hand, the uniform cross-section and high aspect ratio of the BF were sufficient to restrain the PM, leading to uniform stress distribution and the capability of supporting effective stress transformation from the PM to the IR. At low BF FL, the verified improvements in MP were lower as compared with 30 wt % of BF. In fact, lower BF FL results in largest free space for BF movement, thereby reducing the effective stress transfer from BF to PM. In this case, a minimum of 30 wt % of BF FL was required to reinforce the PM. This BF FL was retained for MAPP studies. No significant differences in the MP of PC with or without MAPP were observed in comparison with the UPCUBF. On the other hand, at a higher BF FL of 40 wt %, the decrease in strength (TS and IS) was observed due to the reflection of poor adhesion between the BF and PM, which promoted microcrack formation into the IR as well as non-uniform stress transfer due to the BF agglomeration in the PM. This justified the obtained low value of IS at 40 wt % due to the poor BF alignment (which has an important role in the final performance of laminates or hybrid PC), the presence of too many BF ends within the PC, which could have resulted in crack initiation and hence the potential failure of PC (fiber agglomeration result in regions with stress concentrations that requires less energy to propagate a crack) and considerable less stress transfer from the PM to the BF due to incompatibilities between the different surface properties of the polar BF and non-polar PM [60,192], which results in the deterioration in MP.									

Appendix E

Table A5. Variation of the mechanical properties for polymeric composites reinforced with different banana fibers loadings into plasticized starch matrices in comparison with the respective control sample of each mentioned study.

References	PC Type	Highest MV on MP of (…) in Comparison with (…)/Lengths/ Contents (wt %)			TM	TS	FM	FS	IS
[153]	SM	… MPCUBF(B-6) … pristine PC (70 starch + 30 glycerol)	3–5 (mm)	30BF + 40starch + 30CG	+228	−57	-	-	-
		… MPCUBF(B-4) … pristine PC (70 starch + 30 glycerol)		20BF + 50starch + 30glycerol	+186	+2	-	-	-
		… MPCUBF(B-3) … pristine PC (70 starch + 30 glycerol)		25BF + 45starch + 30glycerol	+294	+1	-	-	-
		… MPCUBF(B-1) … pristine PC (70 starch + 30 glycerol)		25BF + 35starch + 30glycerol	+201	−11	-	-	-
		… MPCUBF(BN1) … pristine PC (70 starch + 30 glycerol)		25BF + 45starch + 30CG	+1861	+9	-	-	-
Authors Findings	Plasticized starch shows low TS. Even at the boiling point of G (209 °C), starch–glycerol matrices exhibit higher strength properties when glycerol is completely decomposed compared to what happens when it acts exclusively as a plasticizer. Hence, the TS of such matrices may not be very high. The incorporation of lignocellulosic fibers into the plasticized starch improved the Young's modulus and yield strength but without changing the TS over that of the matrix (starch + glycerol). This have been attributed to the compatibility (both chemical and structural) between the reinforcements (cellulose chains) and the starch–glycerol matrix. An improvement in Young's modulus in such systems is also attributed to the deplastification of starch caused by the partition of glycerol into the IR. The variation in TM increased over the PM for BF contents of 20, 25, and 35 wt %. TS remained relatively constant for B-1, B-3, and B-4). However, for B-6 at an FL of 30 wt %, the variation in TS had the maximum loss of about 57%. The TM and TS variations for 25 wt % of a BF with CG (BN1) were higher compared to those with all the PCBF with commercial glycerol, indicating the effect processing method. However, with controlled conditions, MPCMBF (BN1) showed higher variation in TM and TS over both the MPCMBF (B-3 and B-6). The results indicated that (i) comparatively good adhesion between the BF and the matrix is provided by both types of glycerol whereby the BF reinforces the matrix, enhancing its strength properties; (ii) CG gives better adhesion between the BF and the starch; and (iii) controlled processing conditions improve the adhesion irrespective of the type of glycerol used, thus increasing the TP and suggesting the positive effect of controlled processing conditions on the TP of corn starch composites. The applied pressure improved the TP for the same BF content, irrespective of the type of glycerol used. CG produced more homogeneous PCBF, which could have better properties than those produced with commercial glycerol. Here, we observed the effectiveness of the patented processing method and a strong correlation between the TP and the processing methods, which automatically controlled the temperature. The optimum FL content of BF for TM property seems to be 25 wt % of BF.								

Table A5. *Cont.*

References	PC Type	Highest MV on MP of (. . .) in Comparison with (. . .)/Lengths/ Contents (wt %)			TM	TS	FM	FS	IS
[123]	SM	. . . MPCMBF (NaOH) . . . pristine PC (TPS) . . .	30 (mm)	10	140	200	44	63	-
				20	270	400	100	125	
				30	400	625	156	200	
				40	540	850	222	275	
				50	820	1400	317	400	
				60	630	900	189	338	
Authors Findings	Both TM and TS increased linearly with the increasing of BF content up to 50 wt %. Besides, FM and FS followed the same behavior as TM and TS. In accordance with the SEM images, we observed good interfacial adhesion between the TPS matrix and MBF (NaOH). Such good adhesion was evident by the fracture of the BF at the surface, the decreased number of fibers pull-outs and holes, and the absence of a gap between the BF and the TPS matrix. This was due to the similarity in polarity between the BF and the TPS. However, the increasing of BF content from 50 to 60 wt % caused deterioration in the MP of the SMBPC and in the wettability of BF with emulsified TPS matrix. This was explained by the agglomeration of the BF, by the increased number of pulled-out BF and holes, and also by the surface cleanliness of the pulled-out BF.								
[156]	SPINM	. . . MPCUBF(0.2 vol %) . . . pristine PC (CBF-0) . . .	0.5 (cm)	50/50 wt %	CBF-2.0	+268	−41	-	-	-
		. . . MPCUBF(0.25 vol %) . . . CBF-0 . . .			CBF-2.5	+470	−19			
		. . . MPCUBF(0.3 vol %) . . . CBF-0 . . .			CBF-3.0	+548	−9			
		. . . MPCUBF(0.35 vol %) . . . CBF-0 . . .			CBF-3.5	+606	−13			
		. . . MPCMBF(0.2 vol %) . . . pristine PC (CBF-0) . . .	11 (cm)		CBF-2.0	+662	+38			
		. . . MPCMBF(0.25 vol %) . . . CBF-0 . . .			CBF-2.5	+799	+42			
		. . . MPCMBF(0.3 vol %) . . . CBF-0 . . .			CBF-3.0	+963	+82			
		. . . MPCMBF(0.35 vol %) . . . CBF-0 . . .			CBF-3.5	+994	+43			
		. . . MPCMBF (25 wt % glycerol and 0.3vol % of BF (10%NaOH) ..(CBF-0) . . .	0.5 (cm)	25/50 wt %	glycerol25CBF-3.0	+2351	+156			
		. . . MPCMBF (37.5 wt % of glycerol + 0.3 vol % of BF (10% NaOH) . . . (CBF-0) . . .			glycerol37.5CBF-3.0	+1242	+80			
		. . . MPCMBF (50 wt % of G + 0.3 vol % of BF (10% NaOH) . . . (CBF-0) . . .			glycerol50CBF-3.0	+963	+82			

Table A5. *Cont.*

References	PC Type	Highest MV on MP of (. . .) in Comparison with (. . .)/Lengths/ Contents (wt %)			TM	TS	FM	FS	IS
		. . . MPCMBF (25 wt % G and 0.3 vol % of BF (10% NaOH) . . . (CBF-0) . . .	11 (cm)	glycerol25CBF-3.0	+2619	+232			
		. . . MPCMBF (37.5 wt % of glycerol + 0.3 vol % of BF (10% NaOH) . . . (CBF-0) . . .		glycerol37.5CBF-3.0	+1779	+175			
		. . . MPCMBF (50 wt % of G + 0.3 vol % of BF (10% NaOH) . . . (CBF-0) . . .		glycerol50CBF-3.0	+1115	+108			
AF	The MP of the PCBF are found to be dependent on the VF of BF and on the nature of the matrix. The MP (TM and TS) of MPCMBF (SPI matrix and MBF (10% NaOH)) and MPCUBF were measured. Both cases (MPCMBF and MPCUBF) showed an increase in TM from 0.2 to 0.35 VF of BF (UBF or MBF). TS increased up to 0.3 VF of MBF, which was followed by a decrease. The addition of UBF showed a negative effect on the variation in TS. However, the smallest negative variation in TS was observed at 0.3 VF of UBF. In general, soy protein PCMBF showed higher TS and TM compared to MPCUBF. This was due to better interaction into the IR after modification by sodium hydroxide. This has been confirmed by the increase in roughness as observed in the SEM images of alkali-modified BF. TM and TS were highest with the SPI matrix having 25 wt % of glycerol. A further increase in the concentration of glycerol resulted in a decrease in the TM and TS of the MPCMBF. Composites having long fibers (11 cm) had higher MP (TM and TS) properties, regardless of the plasticizer content. The direction of the measurement of MP for MPCMBF was along the BF orientation. A longer BF will have less fiber ends, and there would be less flaws or low stress-bearing points, which is the reason for the increase of TM and TS for these PC. The results indicate that at 0.3 VF, the TS and TM of MPCMBF (MBF(10% NaOH) or 50 wt % of glycerol and MBF(10% NaOH)) increased to 82% and 963%, respectively, compared to soy protein film without BF.								

Appendix F

Table A6. Variation of the mechanical properties for polymeric composites reinforced with banana fibers: laminates, woven pattern, and hybrid (only BF case) in comparison with the respective control sample of each mentioned study.

References	PC type	Highest MV on MP of (. . .) in Comparison with (. . .) /Lengths/Contents (wt %)	TM	TS	FM	FS	IS
[49]	L	. . . MPCMBF (2-EHA) . . . UPCUBF . . .	+44	+53	+40	+36	+49
		. . . MPCUBF (starch) . . . UPCBUF . . .	+25	+67	+42	+51	+86
Authors Findings	The results show the remarkable improvements on MP of the PCLBF after monomer treatment. Through SEM images, some void spaces around the UBF were observed, and some of them were pulled out. These observations were due to the poor adhesion between UBF and PM. In the case of MBF (using 2-EHA), relatively fewer void spaces and a lower proportion of pulled-out MBF were observed, and the authors explained these results due to the good adhesion into the IR. In the case of MBF (using starch), the MP of the PC increased because the starch worked as a good stiffening agent. The alignments of MBF were almost unidirectional compared to UBF into the PC. As a result, starch (3–7 wt %) improved the MP (except for TM) of the PCBF more by improving the IR quality, in comparison with the 2-EHA. At higher starch concentrations (7 wt %), BF becomes too sticky, and as a result, the adhesion into the IR becomes worse.						
[191]	H	. . . PCLBF (0% jute) case . . . pristine PCL (0% jute and 0% BF) . . .	-	+17	-	+4.3	+35.5
		. . . PCLBF (0% jute) case . . . PCLBF (50% jute) . . .	−8	−12	−2	−4	−26
Authors Findings	The addition of BF in the pristine PCL resulted in the increase in strength (TS, FS, and IS). However, the decreasing of WF of BF (from 100% BF (0% jute) until 50% BF (50% jute)) increases MP up to a certain WF. Furthermore, the addition of BF causes them to decrease due to poor interfacial bonding between the fiber and matrix. The MP (TM, TS, FM, FS, and IS) were found to be maximum for 50/50 WF of jute and BF into PC. The variations of TM, TS, FM, and FS were not significant in comparison with the 50/50 case. However, IS decreased more for the 0/100 BF case. This was due to poor interfacial bonding between BF and PM, and this was evident from SEM analysis.						
[58]	H	. . . PCLBF (0% sisal) case . . . PCLBF (50% sisal) . . .	−6	−14	−2	4	−26
Authors Findings	The WF of BF was fixed at 16 wt % and FLg to 15 (mm). The addition of BF in the pristine PCL resulted in the increase in strength (TS, FS, and IS). However, the decreasing of WF of BF (from 100% BF (0% sisal) until 50% BF (50% sisal)) increases MP up to certain WF. Further, the addition of BF causes them to decrease due to poor interfacial bonding between the fiber and matrix. The MP (TM, TS, FM, FS, and IS) were found to be maximum for 50/50 WF of sisal and BF into PC. The variations among TM, TS, FM, and FS were not significant (<15%) in comparison with the 50/50 case. However, IS decreased more for the 0/100 BF case. This was due to poor interfacial bonding between the BF and PM, and this was evident from SEM analysis.						

Table A6. *Cont.*

References	PC type	Highest MV on MP of (. . .) in Comparison with (. . .) /Lengths/Contents (wt %)		TM	TS	FM	FS	IS
[1,45]	L	BLT of 4 layers . . . control . . .	parallel orientation	−74; −73	+400; +400	+500; +500	+500; -	-;+410
			criss-cross orientation	−90; −91	+280; +280	+300; +282	+300; -	-;+464
		BLT of 3 layers . . . control . . .	parallel orientation	−69; −66	+250; +390	+341; 341	+343; -	-;+400
			criss-cross orientation	−78; −78	+242; +290	+235; +212	+214; -	-;+428
		BLT of 2 layers . . . control . . .	parallel orientation	−55; −55	+183; +250	+165; +153	+257; -	-;+346
			criss-cross orientation	−57; −57	+17; +40	+153; +147	+129; -	-;+372
		BLT of 1 layer . . . control	parallel orientation	−8; −8	+167; +200	+19; +19	+200;-	-;+255
			criss-cross orientation	−36; −32	+8; +34	+16; +17	+86;-	-;+228
Authors Findings	For all the studied cases, the increasing of the number of layers of BLT (from 1 to 4 layers) decreased the TM. The observed decrease was due to the increase in the amount of acrylic adhesive used to laminate the BLT. This can cause the entrapment of air between the BLT layers, turning the resulting board less rigid. Another observation was the insignificant effect of fiber orientation. For parallel orientation, the leaf layers overlapped over each other by following the fiber grain or fiber direction. While for criss-cross orientation, the fiber alignment layers overlapped perpendicular to each other. TS increased for the parallel and criss-cross orientations with the addition of BLT layers. The addition of 4 BLT layers displayed the highest TS. The addition of more BLT layers requires more strength to break the banana stem particle board panel. They also observed that the TS is higher for parallel orientation in comparison with the criss-cross orientation for all studied cases. Moreover, this can occur because in criss-cross orientation, there is less BF that is able to support the force during tensile test as compared with the parallel orientation. The variation in FM increased with the increase in the number of BLT layers. The effect of BF orientation on FM was significant when the number of BLT layers was greater than 2. There is not much difference in FS in term of orientation (parallel or criss-cross). As in FM, the addition of 4 BLT layers also displayed the highest variation in FS, while 1 BLT layer with criss-cross orientation showed the lowest variation. For FS, fiber orientation had no significant effect. Further, IS increased with the increasing of the number of BLT layers and was dependent on the viscous component in the banana stem particle board panel. The achieved increment was similar for both orientations.							

Table A6. *Cont.*

References	PC type	Highest MV on MP of (…) in Comparison with (…) /Lengths/Contents (wt %)			TM	TS	FM	FS	IS
[38]	L	… UPCLMBF (NaOH) … UPCLUBF (0% coconut fibers) …			+213	+15	+100	+8	+4
AF	A low WF of BF decreases the strength of the hybrid PCLBF, but a higher WF value can significantly increase the TS of the hybrids. Moreover, the skin-eccentric type (BBC) composites exhibited higher TS, even higher than the pure BF composites. In all cases, TS was higher for treated fibers (NaOH). This was due to the interfacial adhesion, which has a greater effect than the layering pattern. Alkali STC can cause morphological changes in the fiber surface, which can lead to closer packing. The TP of a hybrid composite is also influenced by the specific strength of the fibers used. The TS of BF is higher than that of coconut sheath fiber. However, for the BF case (0% coconut fibers), the variation in TP and FP is higher when using MBF, justifying the SCT. All hybrid composites showed an enhancement in stiffness compared to the pure BF composites. From the SEM images, the tensile and flexural fracture surfaces showed delamination failure and double-sided delamination, respectively. Large gaps between fibers and fiber pull-out were noticed due to the poor IR adhesion. An uneven fiber distribution in the PM was apparent. These features suggested the failure of PCLBF at minimum WF. When BF are used as a skin layer and a coconut sheath is used as the core, a higher modulus was obtained for alkali-treated BCB. It was also seen that the skin-core and skin-eccentric patterns influenced the modulus of PCLBF. Impact damage causes fiber pull-out, fiber-matrix debonding, and matrix fracture, being the former mechanism dominant for IS. Coconut sheath fiber composites showed higher IS than pure BF, so debonding between coconut sheath fiber and the PM required more energy. IS increases when BF content increased from 30 to 70 wt % (BCB and BBC cases), decreasing after that (from 70% to 100 wt %). The IS of NaOH treated composites was generally higher than that of the untreated composite, because this treatment removes substances such as lignin, pectin and hemicelluloses from the fiber surface, making it rougher and better anchored to the PM. Finally, there was not much difference in the MP between pure coconut sheath and PCLBF, except for that of FS, which was higher for coconut sheath in untreated and alkali-treated conditions.								
[12]	L	… UPCUBF … pristine PM	150 (mm)	40	+262	+71	-	-	-
		… MPCUBF (25 wt % of MA) … UPCUBF …			+38	+45	-	-	+36
		… MPCMBF (MA+S (4%) … MPCUBF (MA) …			+41	+57	-	-	+59

Table A6. *Cont.*

References	PC type	Highest MV on MP of (. . .) in Comparison with (. . .) /Lengths/Contents (wt %)			TM	TS	FM	FS	IS
AF	It was found that BF reinforcement occurred and TS, TM, and IS were increased significantly. The IS of UPCUBF was not evaluated because the pristine PM (LDPE sheet) does not break during impact testing because of its high elongation and high plasticity. It was clearly found that BF suitably reinforced PM and caused a significant improvement of the MP, which indicated BF/PM adhesion. It was also evident that the TS, TM, and IS values increase with increasing monomer concentration and attain a maximum at 25 wt % of MA concentration. The decrease in properties at higher monomer concentration could be associated with the fact that at higher monomer concentration, the radical–radical recombination reaction among growing MA molecules i.e., the homopolymerization reaction between monomer + monomer radicals is dominant, and the reaction of monomer + BF is less prominent. The highest TS, TM, and IS values were found for the sample treated with 25 wt % of MA at 70 °C. This indicated that BF/PM adhesion is better for MPCUBF than that of UPCBF. MPCMBF (MA + 4% starch) showed higher TS, TM, and IS values than that of MPCUBF (MA) and even than that of UPCBF. MBF (starch solution) caused an increase of TS, TM, and IS. As a result, stress transfer from BF to PM is higher. At higher starch concentration (5 wt %), BF becomes too sticky and, as a result, the adhesion between the BF/PM may not be so good. The SEM of fractured surfaces of UPCUBF and MPCMBF(MA/S) showed some void spaces around the UBF pulled out for the first case and less void spaces and a lower proportion of pulled-out UBF for the second case. However, for MPCMBF(MA/S), BF were broken without complete pull-out during the fracture process, and there was a lot of PM still coating the UBF. The SEM observations corroborate with the obtained results and confirm the improvements of the MP by the SCT.								
[32]	L	. . . PCLBF . . . Pristine PLC . . .	20 (mm)	10	−53	−50	−30	−42	-
			20 (mm)	20	+245	−27	+53	−32	-
			20 (mm)	30	+175	+4	+ 62	−22	-
			20 (mm)	40	+145	+27	+49	−13	-
			40 (mm)	20	-	+20	-	-	+177
				30	-	-	-	-	+270
				40	-	-	-	-	+341
			10 (mm)	20 or 40	-	-	-;+3	−43;-	+189
			20 (mm)		-	+13	-;+50	−32; -	-
			30 (mm)		-	+20	-;+2	−41; -	+167
			40 (mm)		-	+8	-;+13	−39; -	+300

Table A6. *Cont.*

References	PC type	Highest MV on MP of (. . .) in Comparison with (. . .) /Lengths/Contents (wt %)		TM	TS	FM	FS	IS
Authors Findings	Maximum TS and TM values were observed for 40% and 20% FL, respectively. The effect of FLg on the TS and TM was also studied. TS was found to be maximum for 30 (mm) and showed a linear increase with FL. However, there was a decrease in TS at 40 (mm) FL. At higher FL dispersion, problems and BF interactions can occur, and the FL is not enough to impart high strength to the PCLBF. In fact, in this case, it was necessary to add a large amount of BF to make the PCLBF more ductile. Other scenarios were also analyzed, namely the MV in TS and IS at a fixed FL of 20 or 40 wt %. The MV in TS and IS at a fixed FL of 20 or 40 wt % were in agreement with the observation made by SEM, which showed a good adhesion into the IR for the mentioned BFLg and FL. At a fixed BFLg of 20 (mm), the addition of BF induces a low variation in FM at a FL of 10 wt % but increased for highest FL. A contradictory behavior was observed in FS variation, which decreased considerably. These authors also studied the effect of SCT (by silanes) on BF. The increase in TS was found to be 11% at 0.3% silane while TS was 28% at 0.6% silane concentration in comparison with the pristine PCL. At a higher concentration, the improvement was negligible. The SCT undergoes hydrolysis to form silanols, which serves to bridge the IR and improve stress transfer. FS was found to be a maximum for 40 wt % FL of BF. For every 10% increase in FL, there was approximately an increase of about 13% in FS. The FM is low for 10 wt %, but the variation in FM increases appreciably when the FL increased for 20 wt %. The FM does not showed increasing trend after 30 wt %. The FM was found to be maximum when the FL was 20 (mm) and 20 wt %. The effect of SCT on the FS and FM gives a high value at 1% silane concentration. For a fixed FL of 40 (mm), the IS increases linearly with increasing of FL. At a FL of 40 wt %, the IS was maximum when the FLg was 40 (mm). This was due to the extra energy dissipation mechanisms due to the plastic deformation. For shorter FLg, the fiber being pulled out of the PM is more likely than plastic deformation.							
[57]	L	. . . PCLBF (40 BF/60 PM) . . . PCLBF (60 BF/40 PM (EP)) . . .	-	+10	-	-	+8	-
		. . . PCLBF (50 BF/50 PM) . . . PCLBF (60 BF/40 PM (EP)) . . .	-	+15	-	-	+16	-
		. . . PCLBF (60 BF/40 PM) . . . PCLBF (40 BF/60 PM (EP)) . . .	-	-	-	-	-	+10
			-	-	-	-	-	+30
Authors Findings	The MV in TS and FS of the different combinations of the PCLBF clearly indicated that PCLBF(50BF/50PM) showed better mechanical performance in comparison with the other tested combinations. However, for the variation in IS, the PCLBF (60 BF/40 PM) combination was the best. SEM images from the fracture zone of the PCLBF showed that the flexural loading broke BF in the perpendicular direction of the BF reinforcement, and the good arrangement of the BF into EP was also observed. SEM micrographs from PCLBF subjected to impact loading revealed clearly the breakage of the BF layer. These results suggested that the 50 BF/50 EP combination can withstand higher loads when compared to the other studied combinations.							

Table A6. *Cont.*

References	PC type	Highest MV on MP of (. . .) in Comparison with (. . .) /Lengths/Contents (wt %)	TM	TS	FM	FS	IS
[190]	W	. . . PCWBF (2 layers, 0.5% (VF)) . . . PCWBF (1 layer) . . .	−7	−9	-	-	-
		. . . PCWBF (3 layers, 0.7% (VF)) . . . PCWBF (1 layer) . . .	−9	−1	-	-	-
		. . . PCWBF (4 layers, 0.9% (VF)) . . . PCWBF (1 layer) . . .	−14	+1	-	-	-
		. . . PCWBF(5 layers) . . . PCWBF (1 layer) . . .	−8	−2	-	-	-
		. . . PCWBF (3 layers, 0.7 VF, closed WAR) . . . PCWBF (3 layers, 0.7 VF, open WAR) . . .	-	+65	-	-	-
		. . . PCWBF (2 layers, 0.5 VF, open WAR) . . . PCWBF (3 layers, 0.7 VF, open WAR) . . .	-	+76	-	-	-
		. . . PCWBF (2 layers, 0.5 VF, closed WAR) . . . PCWBF (3 layers, 0.7 VF, open WAR) . . .	-	+117	+56	-	-
		. . . PCWBF (2 layers, warp direction) . . . PCWBF (3 layers, warp direction) . . .	-	+26	-	-	-
		. . . PCWBF (2 layers, weft direction) . . . PCWBF (3 layers, warp direction) . . .	-	+86	-	-	-
		. . . PCWBF (2 layers, weft direction) . . . PCWBF (3 layers, warp direction) . . .	-	+138	-	-	-
		. . . PCWBF (3 layers, weft direction) . . . PCWBF (3 layers, warp direction) . . .	-	+81	-	-	-
		. . . PCWBF (3 layers, warp and weft directions) . . . PCWBF (3 layers, warp direction) . . .	-	+79	-	-	-
		. . . PCWBF (4 layers, warp and weft directions) . . . PCWBF (3 layers, warp direction) . . .	-	+57	-	-	-
		. . . PCWBF (4 layers, warp and weft directions) . . . PCWBF (3 layers, warp direction) . . .	-	+105	+162	-	-
		. . . PCWBF (0.87 VF, warp/weft/weft/warp) . . . PCWBF (0.87 VF, weft/warp/weft/warp) . . .	-	-	-	-	+97
		. . . PCWBF (0.87 VF, weft/weft/weft/warp) . . . PCWBF (0.87 VF, weft/warp/weft/warp) . . .	-	-	-	-	+787

Table A6. *Cont.*

References	PC type	Highest MV on MP of (. . .) in Comparison with (. . .) /Lengths/Contents (wt %)	TM	TS	FM	FS	IS
Authors Findings	The MV of TS was found to be maximum for PCWBF with 2 layers and with a VF of 0.5 in comparison with the neat PM. The MV decreases slightly with a higher fiber VF (0.7 and 0.87); this was due to the inefficient wetting of the BF with the EP at higher VF. The inefficient wetting was evident in the fractured samples. Further increases of the VF after 0.5 gives more or less the same MV of the TS. When the number of layers were increased, there was more yielding on the part of the PCWBF. This was attributed to the effect of the BF bundles. Even after the failure of the EP, the woven BF resist the complete failure of the PCWBF leading to yielding, unlike in the case of short PCBF. Two unique positions exist in the PCWBF. One was the interstitial position, which is surrounded with four different yarns, and the other one was the undulated position, which was defined as the point of intersection of the warp and the fill yarns. Compared with the other regions, these positions become EP-rich regions in the PCWBF. The MV of TS made out of two-layer open WAR was found to be lower than that of PCWBF made out of the two-layer closed WAR. The increase in the gap size has a two-fold effect: first, it leads to straightening of the yarns and thereby increases the Young's moduli up to an optimum value and, second, it reduces the absolute quantity of the fiber available for taking the load. However, the reduction in the absolute quantity of the fiber brings about a lowering of the TS in the case of open WAR. The explanation for the higher TS, observed in the case of the two-layer composites with the closed-WAR pattern, is applicable in this case also. Moreover, this observation supports the fact that the PCWBF failure is determined by the crack initiation in the matrix-rich region of the PCWBF, namely the interstitial and the undulated regions. An increase of 23% was observed for the MV of two-layer PCWBF with closed WAR in comparison with the two-layer PCWBF with open WAR. When a three-layer fabric was used, again, the trend was the same, i.e., a higher value is obtained in the case of the closed-WAR fabric than the open-WAR fabric. PCWBF with 4 layers and with open WAR could not be manufactured due to the lack of the open WAR. Better MP were observed for PCWBF where the samples were tested in the direction of the weft BF, where a greater number of layers existed in the weft BF direction. This could be explained because the fabric was not balanced, and more BF was available in the weft direction than in the warp direction. In addition, this can be due to the difference in the crack propagation pattern. The number of layers as well as the layering pattern affects the IS. The MV for IS was obtained for PCWBF with 4 layers (VF=0.87). The PCWBF failure was due to excessive bending deformations, leading to a mode with bending stiffness mismatch and reinforcement orientation differences between the adjacent plies. The MV of FS was found to be maximum for PCWBF with 3 layers. The lower value for PCWBF with 4 layers was attributed to the inefficient wetting of the fabric. FM increases with the number of layers and was found to be maximum for the PCWBF made out of 4 layers with a closed-WAR and was the lowest for PCWBF with 3 layers. For 2 layers of PCWBF, bending-induced stresses are compensated to an extent by the reversible manner in which the interlacing yarns respond.						
Authors Findings (Continuation)	The MV of IS of the PCWBF showed a considerable improvement with the increase in the number of layers and VF of BF. The MV of IS was found to be for PCWBF with 4 layers (alternate arrangement of warp and weft BF) and with a closed WAR (VF=0.87%). The number of layers as well as the layering pattern affects the IS. The maximum IS has been observed for PCWBF with fabric alternately arranged in the transverse and longitudinal directions. In this type of arrangement, maximum energy dissipation occurs because the impact energy will be dissipated by the delamination between the layers as well. When the fabric is arranged in the same direction, crack propagation becomes easier because the resin-rich regions will be closer to each other. This can very well be interpreted as the reason for the higher IS for composites with the given arrangement. These results showed the important role of the VF and the studied arrangement on the PCWBF. When the VF increased, more energy will have to be used up to break the coupling between the interlaced BF bundles. For BF, the fibrillation also takes place with impact damage and an increase in the VF content uses up more energy for fibrillation.						

Table A6. *Cont.*

References	PC type	Highest MV on MP of (…) in Comparison with (…) /Lengths/Contents (wt %)		TM	TS	FM	FS	IS
[79,116,117,189]	W	… PCWBF(3 layers) … control sample …		+36	+90	+17	+38	+40
Authors Findings	The determination of TP and FP for PCWBF with different geometries evaluated the maximum stress value and Young's modulus along two directions. We found the maximum deflection under the maximum load conditions. TP, FP, and IP increased when compared to virgin epoxy. PCWBF exhibited a ductile appearance with minimum plastic deformation. It demonstrated a very stable average mechanical behavior in the x-direction and y-direction. Then, it was employed and we discussed the suitability of the design and fabrication of PCWBF impregnated with an EP matrix for different applications, namely the manufacture of household telephone stands and multipurpose tables.							
[137]	W	… PCWUBF … pristine PC …	5 vol %	-	-	+133	+339	+259
			10 vol %	-	-	+233	+346	+387
			15 vol %	-	-	+200	+339	+613
			20 vol %	-	-	+217	+323	+471
		… PCWMBF (1% NaOH) … PCWUBF …	5 vol %	-	-	+183	+376	+337
			10 vol %	-	-	+267	+369	+458
			15 vol %	-	-	+250	+346	+643
			20 vol %	-	-	+233	+339	+541
		… PCWMBF (1% $C_3H_4O_2$) … PCWUBF …	5 vol %	-	-	+217	+392	+453
			10 vol %	-	-	+300	+515	+737
			15 vol %	-	-	+283	+500	+1105
			20 vol %	-	-	+200	+431	+947

Table A6. *Cont.*

References	PC type	Highest MV on MP of (. . .) in Comparison with (. . .) /Lengths/Contents (wt %)	TM	TS	FM	FS	IS
Authors Findings	The effects of MBF (NaOH (1%) or $C_3H_4O_2$(1%)) on FM, FS, and IS were analyzed. Improvements were observed for PCWUBF and PCWMBF in comparison with the pristine PC. It was also observed that with the increase of BF content up to 10 wt %, the MV of FS of both MBF OR UBF increases, and thereafter with a further increase of BF content both properties tend to opt toward lower values. When the BF content increased to 15 wt % and above, BF were not well-bonded by PM, and thus poor PM adhesion occurred. SEM images indicated that there was a considerable difference in the fiber–matrix interaction between the PCWMBF and PCWUBF. It was observed that in the PCWUBF system, the phenomenon of pull-out occurred to a greater extent than in the PCWMBF. This was due to the existence of voids into the IR, which lead to weak interfacial interaction results. The PCWMBF showed better adhesion compared to the PCWUBF one. These observations would counteract the improvement of interfacial properties and increase in FP. The MV in IS was found to increase with the increment of the BF content and show the maximum values at 15 vol % of BF content. When the BF content exceeded 15 vol %, the wetting of the BF by the PM (polyester resin) was insufficient and many voids appeared, leading to poor BF/PM adhesion. IS showed a similar trend as MBF (1% C3H4O2), which indicates the highest trend in comparison with those of UBF and MBF (NaOH 1%)-treated systems. For the PCWUBF, we observed the presence of wax, oil, and surface impurities. It is known that waxes and oils provide a protective layer on the surface of the BF, but they also contribute to the ineffectiveness of the IR of the PC. On the other hand, the surface of the MBF appears to be roughened by the SCT. Besides, the individual ultimate BF showed a slight separation. This was due to the removal of the BF outer surface layer through dissolution in the SCT, promoting fibrillation and consequently a better mechanical interlocking.						

Appendix G

Table A7. Variation of moisture absorption tendency for polymeric composites reinforced with banana fibers in comparison with the respective control sample of some of the mentioned studies.

References	PC type	Highest MV on MAT (. . .) in Comparison with (. . .)/Lengths/Contents (wt %)	MAT (%)	Authors Findings
[97]	RO	. . . Control Sample . . .	0.878	We showed evidence of the positive effect of the SCT on MPCUBF (PLA/SiB), in comparison with the untreated case (UPCUBF). Moreover, GC can react with hydroxyl groups of BF and hence decrease the hydrophilicity. The maximum MAT of MPCUBF was 3.28%, which is 17.6% less than that of MPCUBF (PLA/SiB). It was clear that the GC achieved a good compatibility with the PM and its reinforcing BF. The MAT obtained was less.
		. . . UPCUBF . . .	5.27	
		. . . MPCUBF (PLA/SiB) . . .	3.98	
		. . . MPCUBF (GC) . . .	3.28	

Table A7. *Cont.*

References	PC type	Highest MV on MAT (. . .) in Comparison with (. . .)/Lengths/Contents (wt %)		MAT (%)	Authors Findings
[12,49]	L	. . . PCUBF . . . BFLg= 40 (mm) (saturation time = 30 days)		+12.6/ +12.8	The PCUBF samples continued to take up water throughout the period of monitoring. MAT values remained almost constant. The minimum amount of MAT was taken up for PCMBF_MTA/S (4% or 6% starch). The highest MAT was taken up for UPCUBF. It was also noted that MPCBF (25% of MTA) showed better resistance property toward water. These results were consistent with the obtained MP.
		. . . PCMBF_MTA/S(4% starch) . . . (saturation time = 30 days)		+7.9	
		. . . PCMBF_MTA/S(6% starch) . . . (saturation time = 30 days)		+5.6	
[37]	RO	. . . UPCUBF . . . at a fixed FL of 25 wt % (saturation time = 20 days)		+18	The MAT of the PCUBF increased with the increasing of BF loading from 10 to 30 wt %. This was because BF are hydrophilic in nature. Cellulose, which is the main constituent of BF, has free hydroxyl groups which create hydrogen bonding with the molecules. Another reason was the incompatibility between BF/PM, which increased microvoids' formation in the PCBF. It was also revealed that the MAT of PCMBF reduced considerably as compared to the PCUBF. The best result was obtained for the MPCMBF (MA;C3H4O2).
		. . . MPCMBF (MA-$C_3H_4O_2$) . . . at a fixed FL of 25 wt % (saturation time = 20 days)		+6	
[123]	SM	. . . PCBF (TPS matrix) . . . (saturation time = 7 days)	40BF	+59	The increasing of BF in wt % decreases the MAT of the final material. The obtained results were ascribed to the fact that starch is more hydrophilic than cellulose; thus, the presence of BF reduce the hydrophilicity of the starch-based PC.
			50BF	+47	
			60BF	+42	
[34,48]	RO	Pristine PM (PLA) (saturation time = 30 days)		0.64	Virgin PLA showed a high rate of hydrophobic nature. The incorporation of BF to the PLA matrix enhances the MAT in the PCBF significantly. The MAT of PCUBF increased as compared with the virgin PLA matrix. We also observed a water affinity character in PLA/Si69-BF and PLA/APS-BF PCBF and reported a considerable decrease in MAT, which was justified by the presence of bulky functional groups that restrict the entrapment of the water molecules inside the interstitial positions. On the other hand, PLA/Na-BF PCBF showed similar characteristics as those of PCUBF, wherein –OH functionalization to O–Na might have contributed to the MAT through hydrogen bonding. PCMBF (silane) showed lower MAT as compared with all other treated PCBF systems, thus revealing improved IR quality.
		. . . UPCUBF . . . pristine PM . . . (saturation time = 30 days)		30	

Table A7. *Cont.*

<table>
<tr><th>References</th><th>PC type</th><th colspan="2">Highest MV on MAT (...) in Comparison with (...)/Lengths/Contents (wt %)</th><th>MAT (%)</th><th>Authors Findings</th></tr>
<tr><td rowspan="2">[100]</td><td rowspan="2">RO</td><td colspan="2">... UPCUBF (PP+BF(10 vol % of BF)) ... pristine PC ...</td><td>+1.35</td><td rowspan="2">MAT decreased with the addition of PP_MA in comparison with the PC without MA. MAT for (PP + PP_MA) + UBF and (PP-MA + UBF) mixtures were similar. However, the MAT for PP + PP_MA + UBF mixture was the lowest. This result agrees with the verified increase on MP of the same PC and proved the efficiency of the selected sequence of steps for the mixing process.</td></tr>
<tr><td colspan="2">... MPCUBF((PP + ... MPCUBF (PP + (PP-MA + BF) 10 vol % of BF)) ... pristine PC</td><td>+0.3</td></tr>
<tr><td rowspan="2">[156]</td><td rowspan="2">SPINM</td><td colspan="2">SPINM with G 25-50 wt %, 50 wt % of BF and crosslinker of 0.8% (saturation time = 26 h)</td><td>72</td><td rowspan="2">After immersion in water, the disintegration of PC samples was observed. The BF were seen as totally separated from the SPINM matrix, and the MAT decreased as the concentration of the cross-linker increased from 0.8% to 2.6%. The highest observed MAT of the SPINM may be due to the hydrophilic nature of both the fibers (288% ± 5%) and matrix (78% ± 3%).</td></tr>
<tr><td colspan="2">SPINM with G 25–50 wt %, 50 wt % of BF and crosslinker of 2.4% (saturation time = 26 h).</td><td>62</td></tr>
<tr><td rowspan="2">[32]</td><td rowspan="2">L</td><td>... Pristine PLC ...</td><td rowspan="2">30 wt %
(35 days)</td><td>0.8</td><td rowspan="2">The MAT for neat polyester matrix was negligibly small after a period of 35 days. However, the MAT for samples with 10, 20 and 30 wt % were found to increase regularly and leveled off at longer periods, which was an indication of saturation. The maximum MAT was found for PCBF with 30 wt % of BF.</td></tr>
<tr><td>... PCLBF ... Pristine PLC ...</td><td>29</td></tr>
</table>

Table A7. *Cont.*

References	PC type	Highest MV on MAT (…) in Comparison with (…)/Lengths/Contents (wt %)		MAT (%)	Authors Findings
[137]	W	… PCWUBF … pristine PC … (saturation time = 143 h)	10 vol %	+1394	PCWBF absorbed water very rapidly at the initial stage, and later, a saturation level (after 143 h) was attained without any further increase in WA. PCWBF have higher WA than PM (polyester) itself because of the hydrophilic nature of the BF, and the WA trend increased as the BF content increased from 10 to 20 vol %. WA decreases considerably with the SCT of BF. PCWMBF ($C_3H_4O_2$) showed a considerable reduction in WA, which confirmed a better adhesion between MBF($C_3H_4O_2$) with polyester resin. The variation in WA of PCWMBF (NaOH) were are also considerably less than those of the PCWUBF. In this case, the poor wettability and adhesion between UBF and polyester resin was attributed to the hydrophilic nature of BF. The hydrophilicity is responsible for the higher percentage of WU in PCWUBF due to the presence of lignin and hemicellulose component. In the case of PCWMBF, the BF get masked with the polyester resin in the laminate with a stronger adhesion, resulting in greater hydrophobicity and less WA. PCWUBF for both 10 and 20 vol % showed higher values, which indirectly indicate higher void content in the system, and hence, water can easily diffuse into the composites through this void. The PCWMBF (10 vol % $C_3H_4O_2$) indicate the lowest diffusion coefficient value as compared with other composites. Besides, the good adhesion of PCWMBF ($C_3H_4O_2$) also reduces the saturation level value.
			20 vol %	+2431	
		… PCWMBF (1% NaOH) … PCWUBF … (saturation time = 143 h)	10 vol %	+1281	
			20 vol %	+1859	
		… PCWMBF (1% $C_3H_4O_2$) … PCWUBF … (saturation time = 143 h)	10 vol %	+1125	
			20 vol %	+1684	

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