Research Article

Panorama of natural fibers applied in Brazilian footwear: materials and market

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Abstract
Footwear material is of great importance mainly considering the user's health. There are many components in contact with upper and mainly lower part of foot, being the sole essential part to weight distribution, muscle activity and vertebral column. This study aimed to verify how the natural fibers are applied at Brazilian market footwear, demonstrating the types of raw materials utilized, textile constructions and other variables. As well as comparing the information at natural fibers applications data from economics sources and material employment at the footwear international market. The methodology was based in literature research and interviews with Brazilian companies. The employment of natural fibers in footwear corresponds to a small part in comparison of synthetic fibers. Cellulosic fibers have been researched to reinforce rubbers and they are applied to sole as snow footwear. In addition, these fibers are being researched as biodegradable materials, showing innovations for instance, the use of leather waste, coconut fiber and latex, multilayers fabrics and finishing process adding bactericide properties to cotton. Brazilian footwear industry is finding solutions to reduce production costs in order to compete in the international market. One of the strategies is the gradual replacement of leather by fabrics, synthetic polymers and rubbers. The interviews identified the employment of cotton, raffia and jute fabrics especially in footwear summer collections. Thus, the increasing of researches about recycling footwear components and the development of biodegradable materials points a sustainability trend in this sector.

Keywords Natural fibers · Brazilian footwear · Cellulosic fabrics · Biobased materials · Sustainability · Footwear components

1 Introduction

The footwear production in the world exceeded more than 20 billion/pairs in 2016 [1]. The largest producer (11.1 billion/year) and exporter (8 billion/year) is China, manufacturing a wide variety of models and having the United States as its main purchaser.

At the same time, Brazilian footwear production was of 908 million/pairs in 2017, which was the fourth largest production in the world. While Brazilian footwear is mainly focused on national market (around 88% of the production), the first three largest manufacture countries (China, Vietnam and Indonesia) aim at exporting their products to European and North American brands. These producer countries were chosen because they offer competitive prices and business benefits [1], such as a integrated industrial chain (R&D, design, material development, production and processing), proficiency and relatively manufacturing efficiency [2].

In the beginning of the 90ths, many footwear brands transferred their factories to the northeast of Brazil, looking for tax benefits and cheaper workforce [3]. These challenges affected the clusters productions, therefore, most

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brands decided to keep the development sector at original city foundation and transferring the manufacture [4] .

The raw material for footwear is important mainly because of the user's health. There are many parts of shoes in direct contact with upper and mainly lower part of foot, being the sole important factor related to weight distribution, the muscle activity and vertebral column [5]. The material sole must resist for the impact attenuation and forces received by the musculoskeletal [6], because it must be flexible, resistant and have adequate design [7]. In addition to these qualities, others properties are required to select the materials, like the venting capacity, heat dissipation, impact absorption, water resistance, etc. [5].

The study aimed to verify how the natural fibers are applied at Brazilian market footwear, demonstrating the types of raw materials, textile constructions and other variables. As well as comparing the information at natural fibers applications data from economics sources and the material employment at footwear international market.

2 Methodology

In this study, systematic scientific literature review was carried out and in order to identify the lasts trends, exploratory interviews were performed with sector enterprises' commercial managers at Inspiramais fair 2019 (Latin American fair of footwear components, organized by Assintecal an Abit, Brazilian associations of footwear and textile sector). It is the mainly materials design and innovation showroom fair in Latin America, launching over 750 materials each season, developed by fashion materials [8].

The selected interviewed companies were classified according with its size and the number of employees established by IBGE (Brazilian Institute of Geography and Statistics) [9]. They are classified as: micro company (up to 19 employees), small company (from 20 to 99 employees), medium company (from 100 to 499 employees) and; large company (more than 500 employees).

3 Results and discussion

3.1 World footwear production

The world market footwear has been through changes since 1990, due to the development of the global value chain, which influenced a shorter product life cycle, new methods of production, relationship between suppliers and geographic settings [10, 11]. Before this period, the vertical industries were common, for example, the footwear industry was developing all the production process: designing, cutting, sewing, joining parts and finishing. This demanded the intensive use of specialized labor force and slow manufacturing [10].

In the world ranking of footwear production, China leads the market (Table 1), producing more than 11 billion of pairs/year, which correspond to 54% of the world production. 72% of China´s production is destined to export, which corresponds to 8 billion/pairs [1]. The second largest footwear market, Vietnam, competes directly with China concerning production and exportation (Table 1). Compared to China, Vietnam pays cheaper salaries to its employees, as its industry focuses on low price and low quality [12].

Table 1 also indicates some Europeans countries exportation figures, such as Germany, Belgium, Netherlands and France. As these countries have their business model based on intermediating the production and sales process [13].

Between 2006 and 2016, anti-dumping actions were implemented in Europe to obstruct China and Vietnam´s footwear importation. The interest in tariff barriers were concentrated in Italy, Spain and Portugal and, after, Poland, Slovakia and Romania. However countries such as Holland, Belgium, Scandinavia and England were against it, because of their footwear production in China and Vietnam [11, 14]. The tariff barriers focused on leather material, due to the Italian production, which represented 46% in the European market. This excluded the model of sportive tennis [11].

Finally, these protective actions favored the Indonesian market, the fourth shoes producer in the world, which has been strengthened by offering high valued product. The country has been investing to assure workers' rights and consistent relation supplier practices [15].

Table 1 Ranking of the world's largest shoe exporters between 2014 and 2016, (millions/pairs) [1]

Country	2014	2015	2016	Range 2015–2016 (%)
China	8780	8341	8049	−3.5
Vietnam	569	617	654	6.0
Indonesia	354	366	387	5.5
Germany	228	237	252	6.5
Belgium	228	239	236	−1.0
United Kingdom	155	191	213	11.3
Italy	215	208	206	−0.8
India	165	177	181	2.2
Spain	158	158	160	1.1
Netherlands	163	142	146	3.0
Brazil	130	124	126	1.2
Others	1179	1252	1276	1.9
Total	12,322	12,053	11,886	−1.4

The international brands have demanded these actions, therefore, turning the country into a reference of quality and variety. The country produces from sportive footwear to military boots [16].

3.2 Brazilian footwear market

Brazilian footwear production was of 908 million/pairs in 2017, which was the fourth largest production in the world. Even not being the main goal, the Brazilian footwear market is mainly exporting to the United States, Argentina and Paraguay, with the numbers as follow in Table 2 [1]. Despite the positive data, the decrease in footwear export to United States presented as consequence the reduction in profits, due to the high added value of the products. Moreover, the Brazilian products were taxed by Ecuador in US$ 6.00/pair [1].

The Brazilian footwear industrial park is organized in clusters. This setting permits that suppliers get closer to industries and it allows rapid communication and materials delivery [3, 17, 18]. Depending on the footwear industry's target market, these clusters have a prevalence of product categories summarized in Table 3 [1].

Between the 80ths and 90ths, the South and Northeast regions of Brazil were the main footwear producers, controlling around 68% of the Brazilian production. Back then, the footwear employees in the northeast were only 3.3% of the effective labor force in the sector, whereas in 2001, this figure increased and reached 20% of the total workforce in the country [19].

The continuous increase of the number of employees in the northeastern footwear industry occurred due to the fact that many footwear brands were transferred to that region in the end of the 1990s, in order to reduce the production cost, gain tax benefits and find a cheaper workforce. This was a solution to reduce the production price and to compete in the world market [3]. Another strategy to reduce the production cost was the replacement of the shoes' raw material. The main material was leather and it has been gradually replaced by plastic [20]. Bellow follows Fig. 1, which shows the raw materials of exported footwear of 2003 and 2011, changing most of the models from leather to synthetics [21].

According to recent data about raw materials segments in Brazilian footwear, there is a tendency of employment of plastic and rubber materials. In 2017, the amount of material was: 49.8% plastic/rubber; 25.2% synthetic laminate; and fabrics—only 4.5%. [1].

Table 2 Brazilian footwear exportation—amount (million/pair), value (US$ million) and growth rate between 2016 and 2017[1]

Country	Amount (million/pair)	Value (US$ million)	Range 2015–16 (amount) (%)	Range 2015–16 (value) (%)
United States	9.99	US$ 170.18	− 13.3	− 12.7
Argentina	10.83	US$ 70.26	+ 18.4	+ 30.2
Paraguay	12.85	US$ 12.85	− 6.5	+ 60.0

Table 3 Brazilian production footwear (millions/pairs and percentage), states and main clusters 2017 [1]

State	Amount (%)	Amount (mil/pair)	Main cluster	Sector	Cluster production (%)
Ceara (CE)	28.1	255.7	Sobral	Woman	61.3
Rio Grande do Sul (RS)	20.6	186.9	Vale dos Sinos	Woman	40.1
Paraiba (PB)	17.7	160.7	Campina Grande	Flip-Flop	94.5
Minas Gerais (MG)	14.9	135.1	Nova Serrana	Sportive	56.1
São Paulo (SP)	7.9	71.7	Birigui	Children	44.8
Bahia (BA)	5.3	48.4			
Santa Catarina (SC)	1.9	17.7	São João Batista	Woman	73.6
Paraná (PR)	1.2	11.0			
Sergipe (SE)	0.9	8.6			
Mato Grosso do Sul (MS)	0.9	8.0			
Outros	0.6	5.1			
Total	100	908.9			

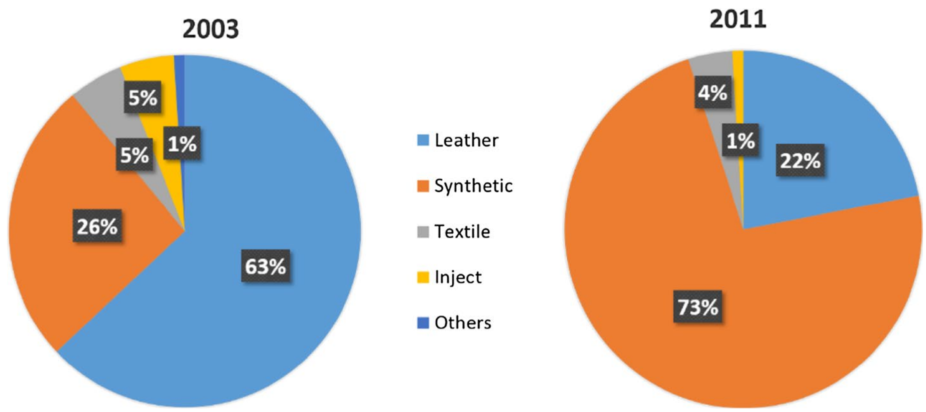


Fig. 1 Exportation of Brazilian footwear by type of raw material in the years of 2003 and 2011 [21]

3.3 Footwear structure and required properties

The functions of footwear are the protection from weather, warming the feet and the support to perform the daily activities. The decision of purchasing a footwear depends on the attractive design concerning the size of high heel for women's shoes, footwear shape, striking materials and style [22, 23].

Apart from design, there is the importance of footwear on human's health. The first contact of the human body with the external environmental is performed by feet. They send out signals to central nervous system during the static and dynamic activities [24]. Static and dynamic movements affect the stability and it can influence the posture. Therefore, as footwear is the intermediation between the foot and the ground, it can interfere in the pressure points on the foot, the muscles, the joint movement and vertebral column [5, 25].

The upper shoes (1–5) and sole (6–12) are the major parts of the footwear, being the sole composed by three parts: insole (6 and 9), inner sole (7 and 8), and external sole (10–12) (Fig. 2) [26].

Fig. 2 Footwear components, model of sandal [26]

The construction of footwear must be controlled by the choice of upper shoes material, sole curvature, weight and design. Researches show that these are not independent variants [25], as the incorrect fitting of footwear can result in disease or pain and the most responsible for it is the width of the shoe, being the most affected users elderly people and adults [27–29]. Another problem involving footwear is the use of high heels, which can cause forefoot pressure, imbalance, knee alterations, muscle changes and foot pathologies [23].

Regarding the materials applied inside of footwear, the insole normally retains moisture and heat, which can cause the proliferation of bacteria or fungus [30, 31]. Consequently, lining footwear is generally made of textiles, which must have the capacity of draining the moisture and evaporate the water to the upper part of shoes. This capacity depends on the kind of fiber and structure fabric applied in the lining [31].

When it comes to designing orthopedic footwear, the shoe soles' hardness is important to support the foot correction. The increase in the soles' hardness is more effective to correct the problem, however, it is necessary to cover this hard material in order to offer comfort. Either way, in some cases soft materials like polyethylene foam or latex are used to alleviate the pain [5]. Apart from hardness, other properties are required to produce orthopedic footwear, such as air permeability, heat dissipation, impact absorption, waterproof, etc. [5].

Normally, the sole materials are made of synthetic polymers, which are processed by the injection of rubber and thermoplastics. They are adequate materials for having the properties of adherence and resistance to friction with the soil. Furthermore, they can absorb impacts, they are resilient and easily moldable [32].

Leather is applied mainly on the upper part of shoes, because of its capacity to evaporate the water to environment [7]. When in contact with the skin, it is softer, can adapt to the foot and has a lower tendency to proliferate fungus. Despite these properties, the employment of leather is decreasing at the market, due to its high price [3, 7].

The common use of synthetic fabrics in sportive footwear occurs due to specific materials properties such as flexibility, air permeability, lower water absorption, quick dry, low weight and low cost [33]. Nevertheless, fabrics of polyester are normally not so comfortable to users, because they cannot absorb the sweat properly and it can be improvement by blends with cellulosic fibers for instance, polyester-bamboo fabric [34], cotton-spandex fabric [33], etc.

3.4 Natural fibers applied in footwear

The literature pointed some important attributes influencing the materials choice for comfort. As mentioned previously these attributes are heat and moisture transference, absorption, air permeability, added tension strength, weight, thickness and shape [35, 36]. According to these properties, natural fibers can provide improvement in the footwear components. For example, the research about multilayer fabrics (cotton and hemp fabric, calf and pig leather) had positive results on the thermal comfort and they became more resistant and absorbents when cellulosic fabrics were added [37].

Another research compared lining shoes materials made of cotton (ring and open-end), and cotton with other fibers: bamboo, rayon viscose and Lyocel®. All blends were made of different construction fabrics and they were knitting by weft knit technology (interlock pattern) or warp knit (spacer fabric) [36]. Especially, weft and warp knit are the most important fabric technologies applied in footwear, due to superior strength, durability [38], compression elasticity and cushioning, and air permeability properties [36]. Concerning friction resistance, the results showed that best blends were made of cotton/rayon and cotton/bamboo warp knit. Moreover, Cotton/Lyocel® and cotton/bamboo weft knit demonstrate comfort under hot weather (high vapor permeability, heat conductivity). Finally aiming at cold weather, the best blends were of cotton/bamboo warp knit (high heat resistance, vapor permeability and low absorption) [36].

Besides textile constructions, finishing in cotton fabric are coated with Ag/TiO_2 is a possibility to avoid bacteria and fungus, which cause uncomfortable smell in shoes. The addition of SiO_2 acts as a sealant and assists the footwear cleanness [39].

Composite is another material that applies natural fibers, being cellulosic the most used fibers [40]. They present good possibilities to be applied at composites and also can be originated from different raw materials, such as agricultural wastes. Cellulosic fibers have important properties, for instance, lightweight and non-abrasiveness. In addition, they can improve chemical and mechanical properties, their employment can reduce virgin raw material use and energy consumption [40, 41], however require precautions to treat and process [41–43].

In researches about footwear composites with natural fibers, rubber is normally the main polymer (matrix). Natural rubber utilized cane bagasse (10–40 phr) reinforcement to possible application at flip-flops sandals [44], being that phr represents parts in wt of filler (cana bagasse) per 100 parts in wt of matrix (natural rubber). Some mechanical properties had higher findings, such as the Young´s module and the hardness (increased rates with higher fiber concentrations), and other mechanical properties decreased, like abrasion strength (28% of loss); strain and the stress slightly decreased as well. The best results was with 10 phr cane/natural rubber, even the mechanical properties decreased, the developed material achieved the minimum standard in according to "Testing and Research Institute for Footwear Production" (PFI) [44].

Accidents caused by slippage can be avoid by increasing the coefficient of friction of the materials. For instance, it can be applied to shoes and car tires and intermediate the human activities on ice [45]. Composite soles can improve and solve the coefficient of friction, rubber and bamboo fiber were treated with phenolic; after the friction test, the mechanical properties (hardness and Young´s module) were maintained [45]. In the same application in shoes on ice, a recent study has pointed the use of natural rubber with nanocellulose and silicon dioxide extracted from the process of burning rice husks. The best result of friction's coefficient was to dry ice (0.61), wet ice (0.19) and melted ice (0.16), respectively. These values showed the material is suitable to be applied in the sole [46].

Besides the issue of physical–chemical properties improvement, cellulose fibers are also researched due to the environmental concerning related to their recycle and biodegradable capabilities [47].

Concerning the recycling of leather, a new biobased material was proposed from natural fibers (coconut, banana and sugarcane bagasse), latex and waste leather. The best result was the coco/leather/latex (50:40:10 ratio) sample, in compliance with findings in mechanical tests—tension strength, break elongation, tear resistance, desorption and flexibility (Fig. 3) [47].

Another research on biomaterials, specifically with latex and Brazilian jute, showed improvements in the properties of elastic module (the elongation increased between 100

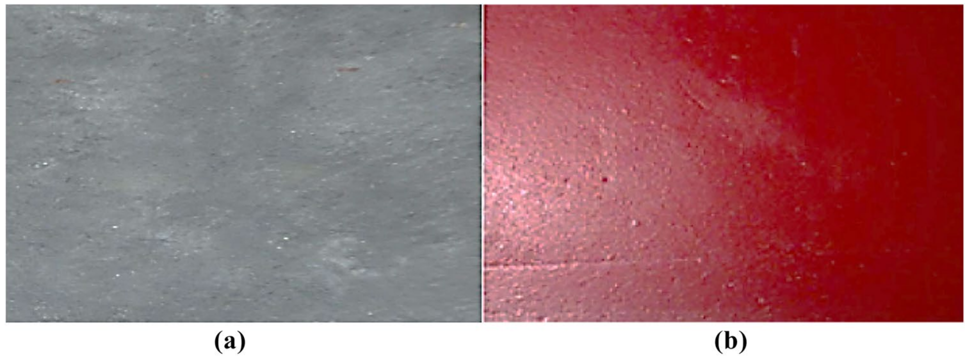


Fig. 3 Appearance of regenerated leather made by coco fiber, leather waste and latex: **a** raw material after experimental process; **b** finished material after coated with red pigment [47]

and 300%). Furthermore, it showed an increase in hardness and tensile, but had problems for dispersion, because the particles tend to agglomerate [48].

Cellulose was developed through *Komagataeibacte* (genre) bacteria, which digests the kombucha tea and produces cellulose film [49]. When this material is dried, it resembles soft bovine leather, and it could be used in diabetic orthopedic footwear, since they have sensitivity in their feet and this material provides the shoe with a soft surface [49].

In this way, it is evident that cellulosic fibers can be applied in fabrics to produce upper part of shoes or lining and composite sole, and they are also alternatives to replace leather.

3.5 Natural fibers in Brazilian footwear

As mentioned before, considering the total amount of materials applied in Brazilian footwear in 2017, only 4.5% was constituted by fabrics [1]. This value does not include linings and non-woven textiles that complement the footwear construction. The kinds of fabrics are not classified according their fibers (natural, artificial or synthetics), or constructions of weaving or knitting, being in this way difficult to identify the amount of natural fibers employment at sector. The two most produced natural fibers in the world are cotton and jute, which are also produced in Brazil. The production of Brazilian cotton lint has grown recently, from 1.5 to 2.6 million tons (2016–2019) [50]. On the other hand, jute production presented a reverse scenario, the production was 42 kt in 2017, it is decreasing since 2014, when the amount was 1172 kt [51]. Furthermore, between 2014 and 2017, the importation of jute grew 285%, being 67 kt in 2017 [52].

In order to verify how the natural fibers are applied at Brazilian market footwear, an exploratory research including four surveys about product development and market were carried out at the Inspiramais fair (January 2019).

The interviewed companies did not allow having the brand's name announced. In this way they were named as companies A, B, C and D; and classified by company's size, kind of product, application, description and an example of product (Table 4).

Company "A" (Table 4) sells around 100,000 m fabrics per month and the main products are made of cotton and its mixtures with polyester. This company reported using recycled polyester and other yarns, but affirmed "for synthetic fabrics production, there are many suppliers". Synthetic knitting fabric production is the only sector of company B, which manufactures for all footwear lining market. Company B (Table 4) is one of the three largest Brazilian textile industries focused in footwear; the other two companies also produce only synthetic fabrics, and only the fourth largest one employs cellulosic yarns.

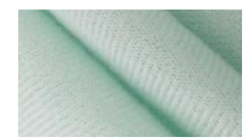
Company "C" (Table 4) is a small size group, which manufactures flat woven with rustic yarns of raffia, which is normally applied to cover high heels or produce women sandals' stripes. Company "D" (Table 4) produces the inner sole, a composite that is made from 50% of recycled materials (reinforcement) and matrix of virgin polymer (polypropylene and polyethylene) with different qualities, depending on type of footwear and properties demanded (tear resistance, hardness, flexion). In this company, the customers can bring their wastes of fabrics, laminate or polymers to receive a discount on new products.

Furthermore, in the conducted interviews, it was observed that the industries of footwear components see the need to introduce sustainable raw materials into the product portfolio much more due to business opportunities and in the expansion of new markets than environmental concerning.

4 Conclusions

The Brazilian footwear industry is the fourth largest in the world, is formed by clusters, and is spread in several regions of the country. Around two decades ago, there have been changes regarding the materials used to produce footwear. This happened so as to reduce the

Table 4 Summary of the surveys carried out in Inspiramais fair with Brazilian manufacturers of footwear components, in relation to size and location, type of product, application, description and a product example

Company	Size/Localization	Application	Description	Description	Product example
A	Small/Rio Grande do Sul (South)	Fabrics: 100% cotton or cotton/polyester (crude twill, canvas and denim)	Upper part of shoes	The company outsources the weaving and sells 100,000 m/month of fabrics; it provides for all clusters in Brazil	
B	Medium/Metropolitan region of Sao Paulo (Southeast)	Fabrics and ropes: 100% polyester; polyester/elastane	Shoe lining	The company is one of the three largest in Brazil in footwear sector. It has circular and warp knitting machines and produces mainly lining	
C	Small/Rio Grande do Sul (South)	Fabrics and strips: 100% raffia	Cover soles and sandal straps	Raffia flat fabrics and strips in various colors and patterns. The competing companies also employ jute in the same applications	
D	Small/Rio Grande do Sul (South)	Recycled inner sole	Upper part of shoes	It makes composites from polypropylene (PP) and polyethylene (PE) with textile and synthetic laminate wastes. Customers (footwear companies) can bring their waste. Daily production of 13,000 m^2	

production cost and allow the companies to be able to compete in the world market. In addition, the country changed the location of the companies, reduced labor cost and also replaced raw materials. Consequently, fabrics, polymers and rubbers were gradually replacing leather, which used to be the predominant material.

Materials for footwear must have good mechanical properties. Besides the appearance, shoes must support the body weight, static and active body, and the foot's reaction to the ground. Lacking these properties, the footwear can cause health problems related to muscles, knees, as well as diverse types of pain.

Physical–chemical material properties must be considered in the construction of footwear. There are researchers about the use of cellulosic fiber (bamboo, cotton or hemp) blended with polyester fabric when applied in lining. This can improve the footwear comfort, since cellulosic fabrics absorb the moisture. On other hands, polyester brings relevant attributes, such as air permeability, quick dry, low weight and low cost.

According to these properties, natural fibers can provide improvement in the footwear components. Cellulosic fibers have been researched to reinforce rubbers, in order to reuse cellulosic agricultural waste to development new products or add mechanical properties, such as material to avoid slippage at snow (when shoe sole must have increased coefficient of friction). Cellulose fibers are also researched due to the environmental concern and biodegradable materials are being investigated, as new leather made by leather waste, coconut fiber and latex, multilayer materials (cellulosic fabrics and leather), or finishing process to cotton fabrics to add new properties (anti bacteria coating).

Few references were found about specific market data on the natural fibers' employment in Brazilian footwear. The results of the surveys could be a reference about the employment of these raw materials in the sector. Cotton, raffia and jute fabrics are applied normally in summer footwear collections. For lining, researches point the best results on cellulosic fibers mixed with polyester, but this blend has not been usually employed in the Brazilian footwear industry. Nonetheless, one surveyed company reported the use of cotton/polyester blend in denim and canvas fabrics at the upper part of shoes, in order to reduce the product cost.

In this way, the increasing of researches about recycling footwear components or development of biobased materials point a new trend of sustainability in this sector and that could motivate the employment of cellulosic and other natural fibers.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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