Materials Research Express

TOPICAL REVIEW • OPEN ACCESS

Key advances in development of straw fibre bio-composite boards: An overview

To cite this article: John Tosin Aladejana *et al* 2020 *Mater. Res. Express* **7** 012005

IOP Publishing *Mater. Res. Express* **7** (2020) 012005 https://doi.org/10.1088/2053-1591/ab66ec

Materials Research Express

CrossMark

OPEN ACCESS

RECEIVED
22 October 2019

REVISED
17 December 2019

ACCEPTED FOR PUBLICATION
2 January 2020

PUBLISHED
20 January 2020

TOPICAL REVIEW

Key advances in development of straw fibre bio-composite boards: An overview

John Tosin Aladejana[1], **Zhenzeng Wu**[1], **Mizi Fan**[1,2,3] **and Yongqun Xie**[1,3]

[1] College of Material Engineering, Fujian Agriculture and Forestry University, Fuzhou, Fujian, People's Republic of China
[2] College of Engineering, Design and Physical Sciences, Brunel University, London, United Kingdom
[3] Authors to whom any correspondence should be addressed.

E-mail: mizi.fan@brunel.ac.uk and fjxieyg@hotmail.com

Keywords: development, strength properties, straw fibres, agricultural wastes, composite boards research

Abstract

In recent years, considerable attention have been given to the development and utilization of biodegradable fibres for bio-composite boards. This is due to the increase in the environmental consciousness and the need for sustainable development which enable establishment of new materials majorly for packaging, aircraft, furniture, and automobile. Straw fibres (wheat, rice, and corn fibre) are the most available natural agricultural wastes products, which has been utilized for the production of these new materials. This paper hence reviews the enhancement in production methodology and properties of the straw fibres bio-composite boards to add further scientific knowledge to the potentiality of using agricultural fibres as value added products. The future replacement of conventional wood fibres for the production of bio-composite panels, especially with agricultural wastes, could be centered on straw fibres. The introduction of straw fibres in polymer matrices were presented based on various research outcomes. Biodegradable fibres could be regarded as a good fibrous composite material. Although, more efforts are still needed in developing facile straw fibre composite production methods and materials with robust industrial and domestic applications. Industrial adoption of these fibres would gear effort towards achieving a clean, and pollution free environment.

1. Introduction

The technologies development that facilitates ease of human existence have been intimately associated with the accessibility of suitable materials [1]. Research advancement in the understanding of a material type and production processes are usually the backbone to the stepwise progression of a technology [2]. Straw fibre is an agricultural natural polymer materials used to manufacture bio-composite boards (BCB) product. It is a generic name for various types of agricultural wastes like wheat, rice and corn [3] and one of the most available wastes resources. Straw fibre BCB is the combination of two or more biological/natural materials to form a new product with certain unique properties which are usually more superior in functionality and usage. It usually has features that are not exhibited by any of its components in isolation [4]. Example includes; particleboard, medium density fiberboard (MDF), and plastic bonded board etc.

In recent time, there has been continuous renew interest in the use of materials whose production components are made from natural or biodegradable sources. Unlike synthetic fibre based polymers composites, BCB can easily be disposed or decomposed after usage. As a result, many researchers are finding the needs to produce new materials using different experimental procedures. One of the major drivers of the renewed research interest in BCB is the concerns about sustainability and environmental issues that the world has faced in recent times. Green materials are also targeted or expected to create a friendly environment by preventing natural disasters [5]. The recent survey by nova-Institute stated that demand for BCB materials would increase in an upward progression till year 2020 [6]. It was also projected in another review that the production of composites from renewable sources will increase from 12% in 2010, 18% in 2020 and/to 25% in

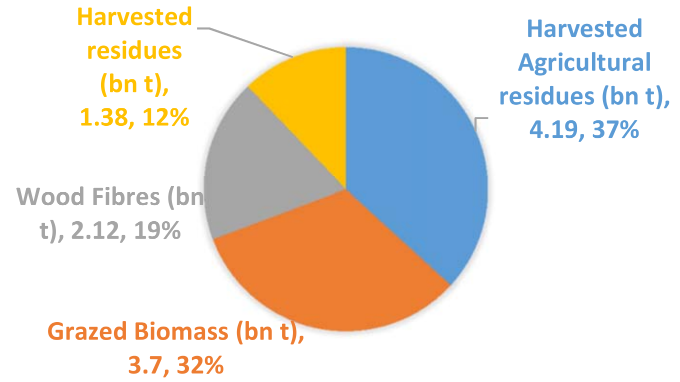

Figure 1. Global Biomass Supply.

2030 [7]. This shows continuous needs for more research and understanding of the basic principles that guides the use of the fibrous materials in the field of polymer science.

Natural fibre reinforced bio-composites have already been used for many applications, such as packaging, building, aerospace and automobiles industries where high load bearing capacities are not required [8]. There have also been huge opportunity to manufacture superior BCB for recreational applications, aerospace and automotive [9]. The utilization of BCB in automobile industries increased remarkably in the last few years, 10% growth from 2011 to 2016 [10]. A paradigm shift in the global biomass supply has recently been seen, about 37% of harvested agricultural biomass and 32% of grazed biomass, while wood and harvested wood residues shared the lowest percentage (figure 1) [11]. The total supplies of global biomass dated back to 2011 were estimated to be around 11.4 billions tones of dry matter.

The most selling point of natural fibres includes relatively low weight, high specific strength, ease of formability and substantial resistance to fatigue and Corrosion [12]. However, biodegradable fibre is not a problem-free alternative to synthetic fibres, because they exhibit some shortcomings characteristics, which may include high anisotropic nature, and moisture absorption [13]. However, the numerous benefits that natural fibre provides make it the best material for the present and future generation. In order to fully explore the potential benefits of these fibres for our daily constructional material needs, and also to further develop economic and ecological bio-based composite boards, a thorough understanding of the individual fibres is needed. Also, the knowledge of different developmental progresses regarding the use of each fibre in BCB structure could promote industrial adoption of the product, and give an informed direction for further development. This review article addressed the state-of-the-art development in the use of straw fibres for production of environmentally friendly composites boards with various adhesives serving as the matrix materials. Moreover some recommendations are raised for further scientific research.

2. Challenges of using Straw fibres for bio-composites board production

Straw fibre-reinforced BCB have great potential to replace the synthetic composites, which could lead to less expensive, stronger and environmentally-friendly materials [14]. However, the production of straw fibre based BCB have numerous shortcomings. The compatibility of recycled/virgin adhesive and straw fibre materials with other components in BCB system for better interface and improved mechanical properties pose major challenges [15]. For instance, Straw fibres contain extraneous substance, which could inhibit the bind-ability of the polymer matrix. Researchers usually employed different pre-treatment methods of extracting the inhibiting materials from the fibre components.

The cheapest and most commonly used treatment is hydrothermal, which has the ability to remove a substantial amount of the inhibiting substances. In a more broaden categorization, fibre treatment includes chemical (acetylation, silane and mercerization treatment etc), physicochemical (hydrothermal extraction), physical (Rays or plasma, steam explosion) and mechanical (rolling and swaging) treatments [16]. Most of the substances removed during fibre treatment are usually referred to as extraneous materials, although the constituent may vary depending on the type of biomass extracted. In a recent research conducted in the Technical University of Denmark, it was discovered that not only extraneous materials could contribute to poor formability of BCB, some of the cell wall components was also found to affect certain properties of the BCB produced from natural fibres, depending on the cell-wall component isolation processes [17].

Manufacturing of BCB is also a concerned where high production volumes is required. The lack of suitable and generally acceptable manufacturing processes posed a great challenge for its mass production, although, numerous production procedures have been used since the idea of using straw fibre for BCB was conceptualized. A full adoption of the fibre in automobile industries becomes limited even though, a typical truck application might have a volume ranging between 5,000 and 20,000 parts per year, and car application between 80,000–500,000 parts per year [1].

2.1. Advances through fibre surface modifications

Straw fibre surface modification is a method of permanent restructuring of the fibre cell walls by grafting polymers on the fibre surface. The fibre cell wall can also be cross-linked with various chemicals. This process improves the dimensional stability, increases hydrophobicity, enhances fibre/matrix interfacial adhesion, and restricts the activities of the bio-deteriorating agent [18]. Fibre surface treatment mainly includes acetylation, silane and mercerization [19], hydrothermal extraction, rays or plasma [20], enzymatic [21, 22], and steam explosion treatment [23]. Various types of chemicals have been used for the treatment of natural fibres. Alkali is one of the most commonly employed chemical treatment for modifying the cellulosic molecular structure of straw fibres. Its application enhanced the interlocking of fibres with its polymer matrix by removing the lignin, wax, and oil covering part of the fibres [24]. Also, it disrupts fibre clusters and forms amorphous at the expense of highly packed crystalline cellulose. Similarly, coupling agents are also adopted for blocking the hydroxyl groups on the fibre surface, thereby changing the hydrophilic nature of the fibre [25]. Numerous studies have been carried out to improve the adhesion between the straw fibre and matrix by modification of the fibre through physical, mechanical, and chemical methods.

Straw fibre was treated with alkali (NaOH) and subsequently hydrolyzed with H_2SO_4. The alkali treatment was found to be efficient in removing hemicelluloses and lignin, but the lignin was only fully removed after acid hydrolysis treatment [26]. It was found that the treatment induced a cellulose increase from 31 to 96% [26]. This indicated that apart from the main purpose of fibre treatment (Fibre/matrix adhesion), the treatment could also provide an opportunity of sustainable extraction of cellulose from the straw fibre. And another development has found that, 43% cellulose could be extracted by a dilute sulfuric acid/steam explosion of wheat fibre [27], due to slower hydrolysis of cellulose at low combined severity factors [28]. By using Alkaline solutions at three concentrations (2, 5 and 10%), to specifically treat both rice and wheat fibres with the aim of improving the fibre surface interface, it was reported that the alkaline treatment dissolved some fraction of hemicelluloses, waxes and lignin, such that the polarity of its surface increased. Furthermore, the treatments showed more influence on wheat straw than on rice straw fibres, as revealed by the Fourier Transform Infrared (FTIR) spectra and environmental scanning electron microscopy (ESEM) observations [29]. When the two fibres were further treated with silane, without or with alkaline treatment, it was observed that the silane treated fibres had a lower moisture sensitivity but higher surface energy of the fibres. The BCB reinforced with fibres treated by combined treatment of alkaline solution and silane had higher bending strength than those reinforced by unmodified fibres or by only silane treatment alone [29]. It has also been reported that the combination of hydrothermal and NaOH-delignification could remove up to 86% of lignin in wheat straw [30]. Therefore, the fibre surface treatment by alkali and subsequent modification with silane or in the presence of hydrothermal reaction should be encourage for more effective result.

Straw fibre can also be modified by acetic anhydride. Acetylation can be done by introducing an acetyl functional group ($CH_3COO–$) into the organic compound. Esterification is the best method for acetylation of straw fibres due to its ability to plasticize cellulosic fibres. Fibre modification with acetic anhydride replaced the polymer hydroxyl groups of the cell wall with acetyl groups, thereby altering the properties of these polymers. Acetylation can reduce the hydrophilic nature of natural fibres [31]. It is a simple procedure for developing inexpensive and biodegradable thermoplastic BCB from straw. It was reported that when the acetylated rice straw was casted to form transparent films, all the cell surface of the fibre could be altered due to its irregular structure. The attachment of the acetyl group could be further confirmed by the x-ray diffraction (XRD) [32]. The compatibility of acetic acid with diethyl phthalate (plasticizer) strengthen the elongating capacity of the acetylated fibre [32] (Zhang, *et al*, 2013). In addition, the phosphotungstic acid ($H_3PW_{12}O_{40}{\cdot}6H_2O$) could be an effective catalyst for the acetylation of the straw based cellulose [33]. Similarly, Benzoylation of straw fibres could also take place by introducing benzoyl functional groups ($C_6H_5C = O$) at the fibre surface with the aid of benzoyl chloride. This method enhanced the hydrophobic nature of the fibres by increasing the hydrophobic linkages on the polymer matrix, thereby increasing the water resistance of the BCB [34, 35]. Also, higher thermal stability and thermplasticity were observed [36]. It should be noted that prior to carrying out the reaction between the fibre and benzoyl groups, the fibre should be pretreated with NaOH aqueous solution in order to activate and expose the hydroxyl groups on the fibre surface [37]. Benzoyl functional groups are also required for the reaction between rice straw fibre and water glass ($Na_2(SiO_2)_nO$), which is another fibre surface treatment enhanced with Sodium silicofluoride, zinc polyphosphate and ammonium polyphosphate [38]. Poly(butyl acrylate) was also successfully coated on rice straw fibre by suspension polymerization of butyl acrylate (BA) monomer. It was reported that the procedures could increase the tensile strength by 7.98% (6 MPa) and lower its water absorption [39].

Linseed oil is known for its use as a chemical preservative for wood decking [40]. The linseed oil glyceride was synthesized by using a transesterification process with a glycerol/linseed oil molar ratio of 1.0, after which it was coated as a preservative on the wood surface [41]. Differently, the treatment was applied purposely for improving the fire performance of wheat straw fibre. The significant effect of the linseed oil treatment at the macroscopic level by flammability test and microscopic level by differential scanning calorimeter (DSC) was revealed, and it was found that, the linseed oil treatment retarded the flame spread and prevents BCB degradation [42]. Plasma treatment is another useful fibre surface modification technique for improving the polymeric materials by utilizing tools, such as electrons, high-energy photons, radicals and ions. The use of dielectric barrier-discharge plasma with water vapor as feeding gas led to the surface roughness of wheat straw fibre, and the generation of massive free radicals [43]. Also, the equilibrium contact angle and the surface total free energy were increased significantly after plasma modification [44]. Rice straw fibre treated with ultraviolet-ozonolysis (UV/O_3) also showed rougher surface and improved adhesion with the polymer matrix. The tensile strength of UV/O_3-treated BCB showed about 5% increase. In addition, it reduced processing time and raw material wastage during BCB manufacturing [45]. This could facilitate the commercial production of sustainable and environmentally friendly materials. Mechanical processing method can also be used for fibre surface treatment. Solid State Shear Milling process (SSSM) was adopted as fibre surface modification. The process gave wheat straw an ultra-fine particle size. Optical and electron microscopy showed that BCB produced by SSSM exhibited excellent dispersion of cellulose nanofibrils, hemicellulose, and lignin. The resultant polymer matrix and wheat straw BCB exhibited a fast crystallization rate (0.8 min crystallization half-time). This led to the enhancement in flexural modulus of the BCB [46].

Regardless of the fibre surface modification method adopted for BCB production, there are other factors that could influence the properties of the final products. Factors such as the fillers content, particle sizes, fibre processing methods, fibers characteristics, and the structure of the BCB. A detailed comparison of the surface modification techniques with regards to the aforementioned factors would enable accurate selection on the most suitable fibre treatment methods. Dilute sodium hydroxide (NaOH), dilute sulfuric acid (H_2SO_4), hydrothermal (LHW), calcium hydroxide (CaOH) and other organic solvents such as methyl isobutyl ketone (MIBK) and aqueous ethanol (EtOH) surface treatment, were examined on properties of wheat straw fibre BCB by a number of researchers (table 1). The chemical composition was successfully altered as revealed by the different polar functional groups (O–H, C–H, CO, N–H, CH_2, and C–OH) incorporated into the wheat fibre surfaces from the FTIR spectra of each treatment (figure 2). NaOH and H_2SO_4 increased cellulose content by 29.6 and 35.1%, respectively. The surface cleaning of the treated fibres occurred in all the treatment but sufficient surface roughness was observed in the H_2SO_4, NaOH, and MIBK treated fibres. In addition, H_2SO_4. NaOH and H_2SO_4 treated fibres achieved the most prominent surface modification [47]. Contrarily, it was found out that the steam cooking and steam explosion fibre treatment methods which were not considered in the previous work performed better than the other fibre treatments [48]

3. Development of straw fibre based bio-composite boards

The synergy between polymer matrix and straw fibre depends largely on the fibre properties [19]. However, the production method employed in board formation could determine the final properties of the fabricated BCB.

3.1. Wheat fibre bio-composite boards

Wheat straw contains 33.4–41.93, 25.2–30.2, and 14.55%–18.0% of cellulose, hemicelluloses and lignin respectively [50–52] . The length of elongated fibre, linear density of the fibre bundles, tenacity of the fibre bundles and elongation of the fibre bundles were found ranging from 800–1300 μm, 37–45 dtex, 9–17 cN tex^{-1} and 1%–5% respectively [53]. The mechanical properties of wheat fibre bundles are inferior to the properties of conventional textile bast fibres. Due to the very low bending tenacity, the use of wheat fibre is only reasonable in form of whole stem for some technical applications [53], although, the fibre could be reconstituted to enhance the quality/properties of its product. In a comparative experiment conducted on straw fibres, the mechanical properties of wheat straw fibre composites showed better features compared to corncob and cornstalk fibre based composites, which may be due to a good compatibility between the more non-polar surface of wheat straw fibres and high density polyethylene (HDPE) [54]. In a similar research with different approach for investigating the potential inclusion of treated wheat fibre in a polymer matrix. The stems of wheat straw were reinforced with injection of the animal glue to improve the crushing force and strength of the straw fibre itself. This approach

Table 1. Straw fibres surface modification treatments.

Name of treatment	Chemical (s) used	Molecular formula	Concentration	References
Mercerization	Sodium Hydroxide	NaOH	4 wt%; 2, 5 and 10 wt %	[26, 29]
Acid hydrolysis	Sulphuric acid	H_2SO_4	10.0 mol L^{-1}; 1.13% w/w	[26, 27]
Silane	γ-aminopropyltriethoxysilane; γ-glycidoxypropytrimethoxysilane	$C_9H_{23}NO_3Si$; $C_9H_{20}O_5Si$	1 wt%	[29]
Acetylation	Glacial acetic acid	$C_2H_4O_2$	25 wt %; 90 wt %	[32, 33]
Benzoylation	Benzylchloride	C_7H_7Cl	20 wt %	[36]
Butyl acrylate modification	Poly(butyl acrylate)	$C_7H_{12}O_2$	15, 20, 25, 30, 40, 80 and 100 wt %	[39]
Linseed oil	Linolenic Acid, Linoleic Acid, and Oleic Acid	$C_{18}H_{30}O_2$, $C_{18}H_{32}O_2$, and $C_{18}H_{34}O_2$	NS	[42]
Plasma treatment	Glycidyl methacrylate; NA	$C_7H_{10}O_3$; NA	NS; NA	[43, 44]
Ultraviolet-ozonolysis	NA	UV/O_3	NA	[45]
Solid State Shear Milling	NA	NA	NA	[46]
Steam explosion	NA	NA	NA	[23]
Ligninolytic enzymes	Laccase, Lignin Peroxidases, and Manganese Peroxidases	$(CH_3O)_2C_6H_3NH_2$; NS; and NS	300 U mL^{-1}	[21, 49]
Hydrothermal	NA	NA	NA	[17, 30]
Organic Solvent	Methyl Isobutyl Ketone	$C_6H_{12}O$	44 wt %	[47]

NA: Not Applicable NS: Not specified.

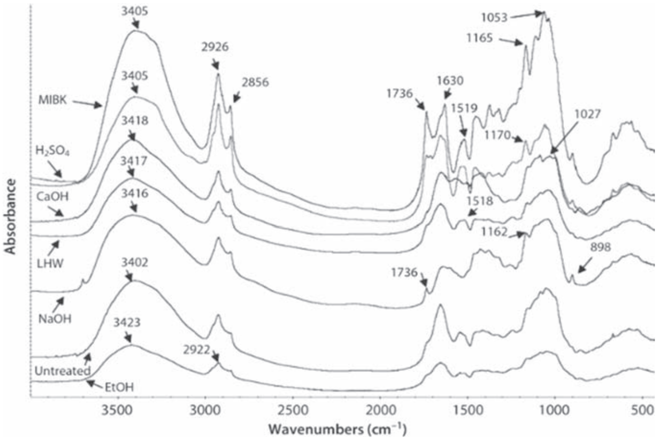

Figure 2. FTIR spectra of untreated and treated wheat fibres (Source: [47]).

was found to improve its tenacity by about 165%, Young's Modulus of elasticity by 125% and breaking strain by 125%. The specific crushing force also reached 4.444 kN/m for the injected wheat straw, while it was 0.421 kN/m for untreated straw [55].

Wheat fibre could be subjected to different mechanical processes, such as impact, cutting and ball milling (IM, CM and BM). The contact angle test shown that the interfacial adhesion was improved in the order of BM $>$ IM $>$ CM, whereas the fiber elongation (aspect ratio) decreased in the order of CM $>$ IM $>$ BM [56, 57]. In addition, the energy required to fractionate wheat straw increased with decreasing final particle size, i.e. in the order of CM $<$ IM $<$ BM, the choice of an excessive milling, such as ball milling appeared not economically viable [57]. However, it was reported that high-energy ball milling process was an interesting way to produce the BCB and to improve their properties [58]. After successfully removing 50% of lignin from wheat fibres, it was confirmed that high lignin content in the lignocellulose fibres is not a necessary condition to obtain a good fiber/matrix adhesion, provided the lignin concentration is enough to cover fibre surface [59]. Although, further studies are still in progress to develop lignin extracting procedures that will allow reaching higher extraction level without degrading the inner structure of the fibres.

In an attempt to find more eco-friendly packaging materials that can be used in the food industries, the potential use of wheat fibres as filler in a poly-3-hydroxybutyrate-co-valerate (PHBV) biopolymer, was compared to brewing spent grains and olive mills. Due to 3.5-fold increase exhibited by the wheat straw, it was deduced that PHBV/wheat straw fibres BCB appeared as promising materials to reach the packaging requirements of respiring food products [60]. The comparison of the mechanical properties shown that the BCB exhibited higher Young modulus and lower values of stress and strain to bre ak [61] . Alkali treatment of wheat straw fibers further enhanced strain break and impact strength of PHBV composites by approximately 35% [62]. In another research, the impact of fibre moisture at the time of the manufacturing process was examined on wheat fibre/PHBV BCB. The relat ionships between the structure of PHBV/wheat fibre BCB and their final mechanical properties, with a special focus on the interphase role, was monitored [63]. The molecular weight of PHBV decreased significantly with increasing fibre moisture content, which may be due to hydrolysis reactions induced by residual water molecules. The BCB crystallinity increases along with initial fibre moisture content which was attributed to the observed decrease of molecular weight. Regardless of the structural differences, the tensile properties were similar for all the BCB [63]. Therefore, the initial fibre moisture content was not a predominant factor in controlling the mechanical properties of PHBV/wheat fibre BCB. It is worthy to note that PHBV-biomass (natural fibres) composite is considered as the most interesting material for many industrial sectors by virtue of its possibility of full biobased system (figure 3).

Hydrophobicity of wheat straw fibres could be modify using torrefaction treatment. This treatment improved fibre-matrix interfacial attraction of the BCB prepared by melt-extrusion. The molecular weight and crystallinity of matrix polymers remained intact when compared to untreated fibres. Furthermore, the fibre torrefaction treatment showed no relevant improvement on the mechanical properties of PHBV/wheat straw fibre BCB [64]. The lack of improvement in the BCB may be associated with a reduction in tensile failure strength and strain energy of oven dried and torrefied wheat straw fibres as shown by increasing torrefaction temperature from 200 to 300 °C [65]. Higher storage modulus, hardness and tensile strength properties were achieved in BCB samples from polycaprolactone and wheat fibres [66]. Wheat fibres in a polymer matrix could be successfully applied as a low-cost substitute of lignocellulose wood composites. Although, the use of polyester (poly(butylene adipate-co-terephthalate)) and polyolefin (a copolymer of polyethylene and polypropylene) as

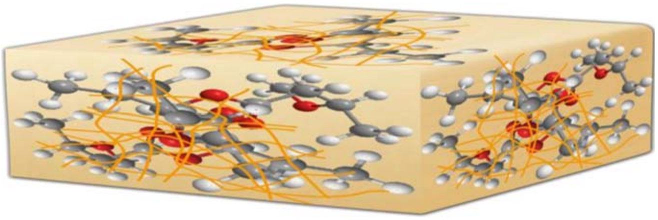

Figure 3. Wheat straw/PHBV biobased composite board.

polymer matrix should be avoided, since they exhibited low formation of intermolecular bonds and brittle nature respectively [67]. Recently, more attention was put on the use of wheat fibre gluten because the glassy gluten matrix has comparable properties as an epoxy resin [68]. Due to this, various methods were employed to process wheat gluten composites reinforced with other fibres. In one of the findings, wheat gluten BCB treated with alkaline and silane provided an 80% increase in strength and showed superior fiber–matrix interfacial adhesion. Furthermore, using extrusion of an aqueous gluten dough at 30–110 °C and 70% ethanol at 110 °C in a pressurized reactor, there was an improvement in the mechanical properties of the experimental samples [69]. In addition, the use of silica particles for coating the alumina particles with silane coupling agents in the wheat gluten matrix exhibited better physical and mechanical properties [70].

3.2. Rice fibre bio-composite boards

The main part of rice fibre contains 41–57, 33, 8–19, and 8%–38% of cellulose, hemicelluloses, lignin and wax respectively [71]. Nevertheless the husk, has drawn major attention to BCB panel. The husk component consists of 30%–51% Cellulose, 18.5%–25.71% hemicelluloses, 20%–25.42% lignin, 15%–17% silica, 2%–5% soluble materials and moisture content of 5%–10% [71–73]. Like rice straw or wheat straw, rice husk is a cellulose based fibrous materials [74] and has been proved to be useful for various applications due to its toughness, resistant to weathering, abrasiveness, unique chemical composition and high availability [75–80]. In addition, it was tested to exhibit some insulating properties that would make it suitable as an insulator in the production of organic chemicals [81] and panel boards [82].

Various research has been carried out to characterize the behavior of the biomass when incorporated into polymer matrix. Rice straw/husk was observed to exhibit weak interaction with various polymer matrix, especially when compared with its contemporary products from wheat straw and wood composites [83] [84, 85]. The weak bond-line interaction is as a result of the high content of silica, wax and low aspect ratio of fibres, although, it possessed some benefits over BCB produced from other fibre straw. The boards from rice husk is very tough, biodegradable, high resistance to weathering, low weight and economically affordable [86, 87]. In addition, when compared with BCB from wheat straw, it has higher termite resistance with better dimensional stability. These properties make it suitable for various applications such as house and automotive constructions [88].

The possibility of producing rice husk composites with Acacia mimosa tannin-based resin as a polymer matrix has been investigated [89]. The high silica content in rice husk, often retards the surface interaction of the husk with polymer matrix. Although some improvements in the properties of the BCB have been reported to be related to the harmer-milling process of the rice husk fibre, further research is still required to ascertain the influence of different conversion methods on the properties of BCB filled with rice husk. Despite the issue of surface interaction with polymer matrix, some previous studies reported that rice husk BCB could be used in furniture and interior fitments manufacturing, although, the physical and mechanical properties of the boards were lower than those of the BCB made from wood particles [83–85]. Further research was carried out by using a fibre surface treatment with 4% wt of NaOH and 3% wt of Maleic anhydride polyethylene (MAPE) coupling agent [90]. Fourier transform infrared (FTIR) analysis was performed on the treated and untreated rice husk fibre. The implication of the surface modification and the effect of filler loading of 50 to 80% wt was examined. Substantial improvement in Young's modulus and tensile strength, as well as, the total reduction in hygroscopicity was noticed for the MAPE treated samples. The rice husk BCB treated with NaOH at 70% wt shown the highest tensile and modulus strength. Although the Scanning electron microscope showed a rough surface of the treated samples, but the fibre treatment proved effective [90].

Reduction of the silica in rice husk may result in better mechanical properties of the BCB. Battegazzore and his team [91] extracted silica powder from rice husk using a simple extraction approach for preparing polylactic BCB with different filler contents of 5, 10, 20, and 30 wt%. The examination of the morphological, thermal and mechanical properties of the BCB indicated that, the extraction of silica induced significant improvements in

Young's modulus as well as a slight reduction of the oxygen permeability of polylactic. The collected values at 10 and 30% wt were compared with similar samples prepared using a commercial silica and they found that the mechanical properties turned out to be higher than those observed in homologous samples. The economic analysis of the materials and the whole process (BCB preparation and silica extraction) showed that the production with a 20 wt% silica can be considered economically viable, when the energy recovered from the rice husk burning is reused [72] [91]. In addition, the collected data by thermogravimetry and mechanical analysis showed that all the formulations investigated could be used to manufacture materials for some packaging applications such as boxes, containers and crates [91].

Contrary to the general findings that silica is the only chemical component that retards the surface interaction of BCB filled with rice husk fibre, Mohammadi-Rovshandeh and his group [92] investigated the possibility of using bleached rice husk (BRH) in powdery form and the effect of lignin removal on mechanical and thermal properties of husk polylactic and starch composites. It was revealed that the lignin removal resulted in an increase in the toughness and Young's modulus of the BCB. In addition, the filler improved the hardness and tensile strength of polylactic/starch blend. The result of the mechanical test showed that 5 to 10% of rice husk or BRH may be used in BCB. BRH samples displayed higher hardness, modulus and charpy impact strength when compared with BCB filled with rice husk. Regardless of the higher elongations values at the break of rice husk BCB, the mechanical properties shown a significant improvement from 25 to 50% due to the lignin removal. Also, the differential scanning calorimetry thermograms shown an increase in crystallization behavior and reduction of T_g from 47 to 31 °C in the BRH filled polymer composites. In relation to their observations, BRH could have the ability of wide use in the bio-plastics and food packaging industries [92]. Further chemical isolation may be needed to fully understand the behavior of rice husk with different matrix materials.

While the major findings based on the utilization of rice husk for BCB are rather extensive, the opportunities that may avail its stalk have not been fully tapped. This curiosity led Jayamani and his research group to study the performance of rice stalk filled BCB with maleic anhydride polypropylene (MAPP) serving as matrix materials [93]. Similar to what Chen *et al* did in 2015, the stalk was treated with 5% wt of NaOH at 30 °C for 30 min, and then a combinations of 10 to 25% wt and 2% wt of MAPP was used. It was found that, the BCB treated with NaOH gave higher tensile strength, thermal stability, sound absorption and fibre-matrix adhesion than the untreated fibre BCB. The sound absorption measurement showed that the acoustic properties were closely related to higher fibre content. The changes in the peak of FTIR spectrum revealed the removal of lignin and hemicelluloses from the rice stem fibres [93]. Liu also assessed the flexural properties of BCB using rice stalk fibre as filler with bio-based adhesive (corn starch) serving as the matrix material. Other samples were produced using cassava and potato starch as polymer matrix. The rice stalk fibres were treated with NaOH and hot-water to evaluate the effect of the fibre pre-treatments on the BCB performance [94]. Due to the NaOH treatment, the rice stalk composite with corn-based adhesive showed higher flexural properties [94, 95]. However, the BCB samples produced from hot-water treated rice stalk had a better interface and higher flexural properties. In addition, the strength and elastic modulus reached peak values at the starch content of 10% and a composite density of 0.7 kg m^{-3}. Finally, the microstructure under scanning electron microscope showed that corn-based adhesive could wrap the stalk surface more uniformly. The phenomenon was due to a better mobility of corn-based adhesive on the rice stalk surface, making it adhere better with the granules [94].

3.3. Corn fibre bio-composite boards

The properties of corn stalk fibres, such as the crystallinity, structures, morphology and defects, have great impacts if the fibres are reinforce by polymer matrix. Depending on the source and preparation methods, the chemical constituents of corn stalk lignocellulosic bio-fibres may vary. However, the main chemical composition of natural fibres generally includes cellulose, hemicellulose, lignin, and a small amount of wax and pectin [96]. The combined effect of these chemicals determines the overall mechanical and thermal properties of corn stalk fibres. The chemical composition of corn stalk fibre consists of 41.7% cellulose, 47% hemicelluloses, 7.4% lignin [97]. Corn stalk cellulose is a linear chain with an amorphous and crystalline region (figure 4), the former can easily be penetrated by water (hydrophilic). The mechanical properties of corn stalk fibres are influence by their moisture content and voids between fibres [19]. The need for corn fibre modification is necessary in order to form an interlocking network with the hydroxyl group on the cellulose chain. Also, fibre modification serves as a means of enhancing the fibre interfacial interaction with the polymer matrix. The degree of surface interaction between corn fibres and matrix material affects the physical and mechanical performance of bio-fibers reinforced board and the reinforcing efficiency of the fibers [98, 99] . Therefore, surface modification treatment is an indispensable corn stalk fiber-matrix interfacial bonding treatment that could improve the bondability of the BCB mixture. Surface modification treatments used for corn fibre includes benzoylation, acetylation, alkali, and electric discharge treatment [100–102], although alkaline treatment is the most widely used among the fibre treatments.

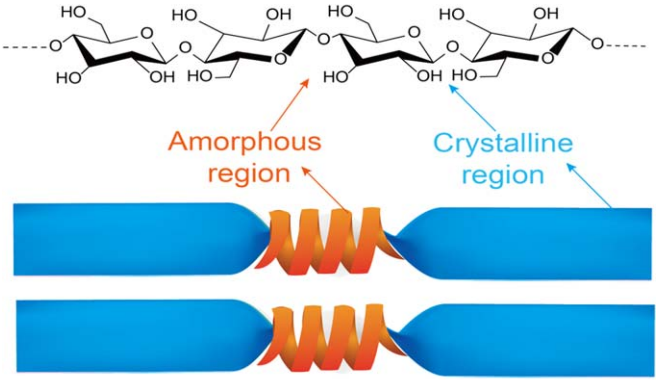

Figure 4. Linear structure of corn stalk cellulose.

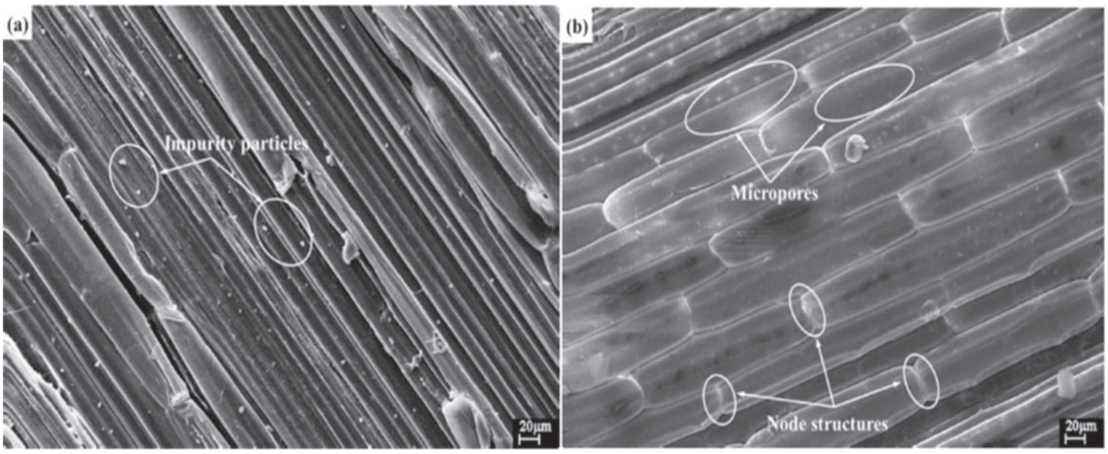

Figure 5. Micrographs of (a) untreated and, (b) treated corn stalk fibers (source: [105]).

In a research conducted in China, alkali treatment was used as fiber surface modification to improve the corn stalk fibre compatibility with the matrix material. The fibre rinds were ground to 3–4 mm in length before treatment. The fibres were dipped in 1% aqueous NaOH solution at 30 °C for about 20 min and thoroughly washed in distilled water until it became neutral (pH 7). Excessive solvent and moisture was removed from the corn stalk fibers after treatment in a ZK350S vacuum drying oven at 90 °C for 4hrs [103]. The surface morphology of the untreated fibres shown smooth surfaces with some impurity particles (figure 5(a)), while after NaOH treatment, the fibre surfaces became cleaner with the presence of large number of node structures and micropores (figure 5(b)) [104]. These indicated that corn stalk fibers were significantly modified [105, 106]. These changes may be as a result of natural and artificial impurities removal (e.g. wax, lignin, pectin and oils) and an increase in the amount of exposed cellulose on the corn fiber surfaces [98, 107]. The corn fibre treatment also increased the mechanical properties of the BCB board [108]. In a similar research, the flexural strength of corn fibre BCB showed a declining trend with an increase in the filler loading (10, 20, 30 and 40% wt) and the impact strength showed an increasing trend with the increase in the wire mesh size (50 ∼ 100, 100 and 300) [109] observed that the thermal conductivity and diffusivity of the corn husk composites decreased with fibre loading. Using periodic temperature ramp method, the incorporation of corn fibre induces a decrease in both thermal conductivity and thermal diffusivity [110].

In another very interesting research, the acoustic properties of NaOH treated corn fibres were experimentally investigated. In order to get an accurate results, five different types of boards were produced and the acoustical properties were studied using a two-microphone impedance tube test. The sound absorption and tensile properties of the treated fibres BCB were found to be better than the untreated ones; due to the higher airflow resistivity and low porosity. The scanning electron micrographs of the corn fibres surface also revealed that different sound absorption properties of these BCB may be due to the changes in roughness and lumen structures of the fibres [111].

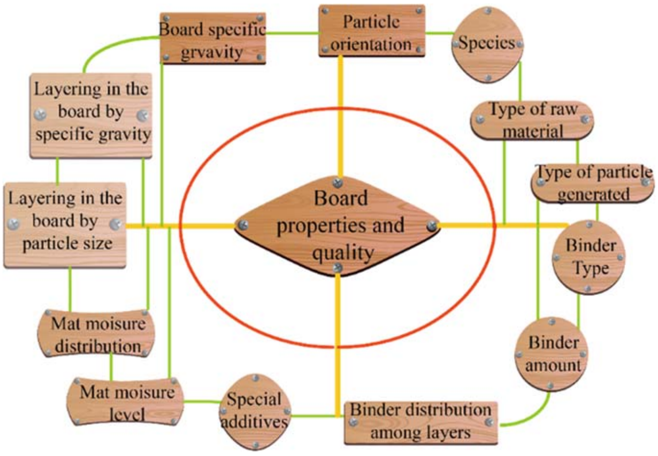

Figure 6. Factors affecting the properties of BCB.

3.4. Mechanical properties of straw fibre bio-composite boards

The strength of a material is one of the major consideration in the construction industries. The ability of a material to withstand stresses imposed by load is as a result of strength of such material [112]. Constructional failure in service is often caused by over-loading, which could be death or live load. Death/static load is a permanent loads which were fixed, while live/fluctuation load is a moveable loads exerted on the construction material [113]. Live load is a major reason for failure of materials in service because most users rarely obey restriction on structural failure factors. Straw fibres BCB is not an exception to this problem as Mohammed *et al*, extensively studied the energy features of rice husk/polypropylene BCB to ascertain fatigue behavior of straw fibres BCB under stresses. Based on the structural analysis, catastrophic failure in rice husk BCB was found when the interfacial fibres-matrix materials system turned weak due to fibre sliding and fibre pull-out during loading/unloading process [114]. However, using different experimental approach, Kumar *et al*, observed improvement in the wear resistant of BCB when rice husk fibres were admixed with other type of fillers [115]. Improvement in wear resistant could be associated to the higher levels of cellulose, lignin, and crystallinity in straw fibres [116]. Generally, strength of a biopolymer material could be determined by various factors such as the density, stiffness, polymer matrix, material type, and processing conditions among other factors as presented in figure 6. Like every other materials, several studies on the mechanical properties of straw fibres BCB has been conducted and reported. The variation in the mechanical properties of straw fibres BCB collected from selected findings are shown in tables 2 and 3 in term of the fibre type, polymer matrix, fibre processing method, fibre treatment, board thickness, and fibre content. According to Maslowski *et al*, increasing filler content could decrease the rigidity (elastomer) of the BCB regardless of the type of cellulosic material but improved the mechanical properties (at limited fillers proportion) except for tensile properties due to the deterioration of fillers dispersion and formation of agglomerates [117]. However, this could be further affected by other factors as presented in tables 2 and 3.

4. Potential application of straw fibres bio-composite boards

The conventional uses of straw fibres have been in the pulp and paper industry, particleboard industry, building, packaging, animal feed and bedding [131]. However, there has been series of critical researches that established the potential functionality of the material for various applications. In recent years, continuous increase in the industrial development and urbanization brought about escalation in noise pollution. Finding an effective way to subdue the noise pollution has attracted the interest of many scientists. Meanwhile, it was previously established that a good noise insulator must possess internal resonant effect [132, 133]. As a result, blended mastication-hot processing was used to fabricate discarded degummed corn husk fibre and thermoplastic polyurethane (TPU) particles into a micro-slit plate having the potential of an excellent absorption acoustic performance. The double layer micro-slit plate based on corn husk fibre and TPU was found having a good noise absorption band [134]. It was also reported in another findings that the fibro-granular BCB made from rice husk fibres are sustainable noise absorption material in high frequency as well as in low frequency regions. The influence of fibre diameter, thickness, grain size on noise absorption characteristics was also studied [135]. In another interesting research, sound absorption performance of corn husk fibres was assessed by using impedance tube method (ASTM 1050 standing test method). Just like rice husk, it was also found that corn husk

Table 2. Selected mechanical properties of straw fibre bio-composites (stress at break (σb), strain at break (ε_b) and young modulus (E)).

Fibre type	Polymer matrix	Fibre processing method	Fibre content (%)	σb (MPa)	ε_b (%)	E (GPa)	References
Wheat straw	wheat gluten	cut milling	11.1	40.90	1.80	25.50	[57]
Wheat straw	wheat gluten	impact milling	11.1	40.80	2.00	23.20	[57]
Wheat straw	poly(3-hydroxybutyrate-co-valerate)	impact milling	20	16.90	1.10	2.60	[63]
Wheat straw	Natural rubber	ball milling	20	1.50	6.17	N.S	[117]
Wheat straw	wheat gluten	ball milling	11.1	35.90	1.60	23.70	[57]
Wheat straw	polyhydroxy-(butyrate-co-valerate)	dry grinding	20	17.00	1.10	2.60	[118]
Wheat straw	Polypropylene	N.S	30	22.28	N.S	3.41	[109]
Wheat husks	poly(lactic acid)	N.S	N.S	20.10	9.70	N.S	[29]
Rice husk	poly(3hydroxybutyrate)	melt blending	10	N.S	1.20	3.90	[119]
Rice husks	poly(lactic acid)	N.S	N.S	10.90	6.60	N.S	[29]
Rice husk	poly(3hydroxybutyrate)	melt blending	20	N.S	0.70	4.27	[119]
Rice Husk	Polypropylene	N.S	30	25.60	N.S	2.80	[109]
Rice husks	poly(lactic acid)	N.S	20	54.43	2.75	4.94	[91]
Corn stalk	Natural rubber	ball milling	20	1.30	6.32	N.S	[117]
Corn stalk	poly(lactic acid)	N.S	N.S	46.00	N.S	N.S	[120]
Corn stalk	Polyethylene	cut milling	20	13.27	N.S	N.S	[110]
Corn husks	Polypropylene	dry grinding	20	27.95	2.05	N.S	[121]

N.S: Not specified.

Table 3. Selected mechanical properties of straw fibre bio-composites(Flexural (MPa), Tensile (MPa), and Impact (kJ/m^2).

Fibre type	Polymer matrix	Fibre treatment/coupling agent	Board thickness (mm)	Flexural (MPa)	Tensile (MPa)	Impact (kJ/m^2)	References
Wheat straw	Polypropylene	Nano-TiO	NS	29.27	14.38	4.55	[122]
Wheat husk	Urea-formaldehyde	Alkaline, plasma treatment and hydrothermal	6	0.044, 0.083, and 0.083	0.008, 0.023,and 0.029	NS	[123]
Wheat straw	Polyvinyl alcohol	Enzymatic	1	NS	64.73	NS	[49]
Whea t straw	polyvinyl chloride	Silane	7	31.28	15.35	NS	[116]
Wheat straw	Polypropylene	NaOH	NS	74.5	35.5	NS	[124]
Rice straw	Polyvinyl chloride	Silane	7	29.89	13.31	NS	[116]
Rice husks	Polypropylene	Hydrothermal	3	24.09	NS	25	[125]
Rice husk	Polyethylene	NaOH	NS	23.7	19.8	60.25	[126]
Rice husk	Polypropylene	None	NS	39.8	33.2	NS	[127]
Corn straw	Polyvinyl chloride	Silane	7	28.04	12.28	NS	[116]
Corn straw	Phenolic resin	Silane	4	NS	NS	0.74	[128]
Corn straw	High-density polyethylene	None	4	46.10	26.58	NS	[129]
Corn straw	Polypropylene	Maleic anhydride	NS	49	27	46	[130]

N.S: Not specified.

had good sound absorption properties at high frequency and low frequency due to its thinner thickness and light weight [136]. Sari *et al*, also investigated the acoustic properties of corn husk fibres and polyester composites. The effect of volume fraction of corn husk fibres on the acoustic performance was studied. The samples of different volume fraction of fibres was tested in an impedance tube. Samples with 80% corn husk fibres volume revealed the highest acoustic performance compared to other samples [137]. Therefore, there is a big opportunity to use straw fibres BCB as a noise suppressant in buildings [138].

Development of materials with good thermal insulator in buildings is very paramount due to the high cost of cooling in summer and heating during winter. In respect of these needs, corn stalk particles (using cutting mill at 1000 rpm) were reinforced with epoxy resin. The effect of the epoxy/corn stalk particles ratio were assessed on the thermal properties of the BCB. Theoretically, when the thermal conductivity coefficients of the insulation materials are below 0.1 W m^{-1} K^{-1}, a material is classified as good insulator according to TS 805 EN 601 [139]. In relation to the standard value, the results showed that BCB with 60/30% corn stalk and epoxy resin had lowest thermal conductivity coefficients (0.075 W m^{-1} K^{-1}). Interestingly, the mixtures (60/30%) also showed the lowest ultrasonic sound penetration velocity coefficient (0.15 km s^{-1}) [139]. Luo *et al*, observed improvement in the thermal resistant of corn fibre reinforced with polylactide after fibres surface sizing treatment. It could be suggested that sizing treatment of corn fibre could be a promising method to produce high performance thermal insulator [140]. Similarly, surface treated wheat husk fibre BCB exhibited thermal conductivity as low as 0.0714 W m^{-1} K^{-1} [123]. Interestingly, the wheat fibre chaff showed excellent thermal conductivity coefficient under steady-state and dynamic conditions (0.307 W m^{-1} K^{-1} and 0.298 W m^{-1} K^{-1}, respectively) [141]. Several research also established the good thermal resistance of straw fibres BCB [127, 142–146]. Therefore, straw fibres BCB have good thermal insulation effect, which could be mainly used as filling materials in the refrigerator, chemical transportation pipeline insulation material, and thermal insulation layer of building wall surface etc just like in the case of rigid polyurethane foams manufactured from corn straw powder [147].

The use of low density and fire resistance materials in an uprising building is one of the major requirement in building construction. It is expected that the density of material should decrease as the building rises. Also, the use of low density materials has been one of the major considerations in aeronautic industries. Fabrication of low density materials with improved fire performance without jeopardizing its mechanical strength has been one of the yardsticks for selecting material for constructional purposes. According to Antunes, *et al*, rice straw fibre BCB is a suitable material for buildings refurbishment due to its bulk density, thermal conductivity, ultrasound velocity, flexural strength, abrasion and fire resistance [148]. Rice straw fibres reinforced with ammonium polyphosphate polyelectrolyte modified high-density polyethylene had good limited oxygen index (LOI) of 23.5%, and peak heat release rate of 488.4 kW m^{-2} [149]. It was also confirmed that the addition of ammonium polyphosphate increased the flame retardancy of the polypropylene and straw fibre BCB with a significant increase in LOI [125]. Furthermore, straw fibres BCB exhibited excellent flexural strength, modulus of elasticity, impact resistant, tensile strength, and young modulus when compared to the reference materials, despite having very low bulk density of 0.41 g cm^{-3}. As observed by Zou, *et al*, the low bulk density allows wheat straw fibres to be packed very tightly, leaving a few voids [50]. The inner voids in BCB were reduced at high concentrations of wheat fibre, thereby enabling production of lightweight materials with outstanding mechanical properties. Stepha *et al*, also observed the lowest density in alkaline treated husks despite its higher thickness compared to the reference materials [123]. It is interesting to know that straw fibres also possessed good drilling abilities in addition to lightweight, making it easy to couple into certain shape for specific application. Jayaprakash *et al*, studied the drilling parameters of rice husk/epoxy resin BCB. Based on the optimization result from Taguchi design, it was reported that feed rate of 0.06 mm/rev, speed of 1250 rpm with the minimum thrust force of 217.23 N and torque of 0.83 Nm were selected for carbide tipped drill [150]. It could be seen that the addition of rice husk could reduce the cost associated with drilling time and the drill's life of the machine tools. Meanwhile, grafting of maleic anhydride on polymer matrices could further enhance the withdrawal strength of fasteners, thereby enable coupling of rigid structure at low cost. However, the quantity of the fillers should be less than 50% in order to obtain optimum result [151].

5. Life cycle of straw fibres bio-composite boards

The shelf-life of a material is an important factor to be considered before subjecting them to a particular use. The life cycle of straw fibre BCB has been assessed using various methods but the most advanced technology for this test is fluorescence lifetime. The Leica SP8 module with TCSPC (Time-Correlated Single Photon Counting) is an important set-up for this test. In a robust experiment recently conducted, the effect of different treatments (hydrothermal, plasma and alkaline treatments) on the life cycle of wheat husk fibre BCB were tested. Untreated and alkaline pre-treated wheat husks exhibited the highest and lowest fluorescence lifetime, respectively. In addition, both hydrothermal and plasma pre-treated wheat husk did not cause statistical significant differences in fluorescence lifetime when compared with reference materials. The higher lignin content in alkaline pre-treated wheat husk (as reported) is responsible for the lowest fluorescence lifetime [123]. It was further confirmed by the highest peak of alkaline pre-treated husks in the normalized photon count of fluorescence decay curve. Nevertheless, degrade-ability of material after use is a positive benefits regardless of storage period of any products. Pradhan, *et al*, assessed the biodegradation of polylactic acid (PLA), and wheat straw BCB under simulated aerobic compost (ASTM D 5338). Close to 90% of the BCB materials were degraded within 70 days of exposure [152].Therefore, the BCB of wheat straw reinforced PLA have been clearly demonstrated to be compostable products despite the low fluorescence lifetime earlier recorded.

6. Conclusion and future prospect

Introducing wheat, rice and corn fibre into the polymer matrix could allow reduction in the manufacturing costs of BCB through the use of significant amount of inexpensive and renewable fillers as reported in this review. The straw fibre BCB has been proved suitable for many applications as backed up by various findings. The behavior of straw fibre reinforced polymer BCB depends on several factors, such as the interaction of fibre with the polymer matrix, fillers content, particle sizes, fibre processing methods, fibres chemical composition, physical, and mechanical properties etc In order to effectively expand the use of straw fibres for BCB and improve their performances, it is essential to understand their fibre characteristics. Wheat straw fibre bonded with wheat gluten seems to possess the most outstanding strength properties with stress at break of 40.90 MPa and also young modulus of 25.50 GPa. Based on the intended application, robust mechanical properties test would be needed to fully ascertain the differences in the various straw fibre BCB samples. It is positive to see that more research on straw fibre BCB are now focusing on the use of biodegradable polymer matrices and this should further be encouraged to increase the production of greener materials. The industrial production and applications of the fibres are still limited or undocumented even though most of the straw fibres type were experimentally converted to value-added products. The properties of straw fibres differ among cited works because different fibres and testing methods were employed. The straw fibre processing methods (e.g. extrusion, filament winding, compression, and injection moulding etc) and suitable processing conditions (e.g. board orientation, particle size, and moderate temperatures (below 200 °C) had significant effect on the BCB parameters. Therefore, manufacturing engineers must identify the most suitable processing method to fabricate straw fibre reinforced BCB, also consider the production design, and the manufacturing cost. However, there is still an urgent needs for further research in order to experimentally establish the most appropriate production methods that would be fitted for industrial production of straw fibre BCB on large scale. The characteristics of the straw fibre BCB (e.g. board thickness and density) must also be consistently reported as this could greatly influence the properties of the final products and also would enable adequate comparison of the different research. All the fibre surface treatment considered were found suitable with some exceptional results. Although, few specific fibre comparison of the treatment methods were found, and for effective selection of the optimum and most suitable treatment, an holistic comparison of the treatments are needed for each fibre treatments discussed in this review. In addition, there are few development in the use of statistical design (e.g. Taguchi and response surface methodology) for optimization of the production variables. This would be needed for generating the optimum conditions and predictive model for the straw fibre BCB production. Understanding of the scientific rationale responsible for the interaction of material constituents form the major aspect of research breakthrough. However, the mechanism of formation for most of the reviewed works are still missing, this will be needed for future development of straw fibres BCB.

Acknowledgments

This paper is supported by the Scientific Research Foundation of Graduate School of Fujian Agriculture and Forestry University (1122YB033).

Conflicts of interest

The authors declare no conflict of interest

ORCID iDs

Yongqun Xie https://orcid.org/0000-0001-8466-5680

References

[1] Haruna V N, Abdulrahman A S, Zubairu P T, Isezuo L O, Abdulrahman Abdulmalik M and Onuoha D C 2014 *Prospects and challenges of composites in a developing country.* **9** 1069–75

[2] Callister W D 2000 *Fundamentals of Materials Science and Engineering* (London: Wiley) 471660817

[3] Mohanty A K, Misra M and Drzal L T 2002 Sustainable bio-composites from renewable resources: opportunities and challenges in the green materials world *J. Polym. Environ.* **10** 19–26

[4] Al-Mosawi A I, Ammash H K and Salaman A J 2012 *Properties of Composite Materials Databook: Composites and Rubbers* (LAP LAMBERT Academic Publishing)

[5] Satyanarayana K G, Arizaga G G C and Wypych F 2009 Biodegradable composites based on lignocellulosic fibers—an overview *Prog. Polym. Sci.* **34** 982–1021

[6] Piotrowski S, Carus M and Essel R 2015 Global Bioeconomy in the conflict between biomass supply and demand *Ind. Biotechnol.* **11**

[7] Wedin R J C 2004 *Chemistry on a high-carb diet.* 23–7

[8] Zini E and Scandola M 2011 Green composites: an overview *Polym. Compos.* **32** 1905–15

[9] Eder A J C C F W C and Chemistry W 2006 Worldwide market report on 'Wood-Plastic Composites *Advance Reviced Edition* **2006**

[10] Uddin N 2013 *Developments in Fiber-Reinforced Polymer (FRP) Composites for Civil Engineering* (Woodhead Publishing, Elsevier) p 558

[11] Van Ittersum M K, Cassman K G, Grassini P, Wolf J, Tittonell P and Hochman Z 2013 Yield gap analysis with local to global relevance—a review *Field Crops Research.* **143** 4–17

[12] Rana A K, Mandal A and Bandyopadhyay S 2003 Short jute fiber reinforced polypropylene composites: effect of compatibiliser, impact modifier and fiber loading *Compos. Sci. Technol.* **63** 801–6

[13] Jawaid M and Abdul Khalil H P S 2011 Cellulosic/synthetic fibre reinforced polymer hybrid composites: a review *Carbohydrate Polym.* **86** 1–18

[14] Faruk O and Sain M 2014 *Biofiber Reinforcements in Composite Materials* (Woodhead Publishing, Elsevier) p 772

[15] Mohanty A K, Vivekanandhan S, Pin J M and Misra M 2018 Composites from renewable and sustainable resources: challenges and innovations *Science (New York, N.Y.).* **362** 536–42

[16] Gurunathan T, Mohanty S and Nayak S K 2015 A review of the recent developments in biocomposites based on natural fibres and their application perspectives *Composites Part A: Applied Science and Manufacturing* **77** 1–25

[17] Liu M 2016 Pretreatment of hemp fibers for utilization in strong biocomposite materials *Danmarks Tekniske Universitet: Kgs. Lyngby.* **208**

[18] Xie Y, Xiao Z, Grüneberg T, Militz H, Hill C A S, Steuernagel L and Mai C 2010 Effects of chemical modification of wood particles with glutaraldehyde and 1,3-dimethylol-4,5-dihydroxyethyleneurea on properties of the resulting polypropylene composites *Compos. Sci. Technol.* **70** 2003–11

[19] Faruk O, Bledzki A K, Fink H-P and Sain M 2012 Biocomposites reinforced with natural fibers: 2000–2010 *Prog. Polym. Sci.* **37** 1552–96

[20] Chu P K, Chen J Y, Wang L P and Huang N 2002 Plasma-surface modification of biomaterials *Materials Science and Engineering: R: Reports* **36** 143–206

[21] Ahmad Z, Bajwa M A and Iqbal H M N 2017 Enzyme-treated wheat straw-based PVOH bio-composites: development and characterization *BioResources.* **12** 2830–45

[22] Bledzki A K, Mamun A A, Jaszkiewicz A and Erdmann K 2010 Polypropylene composites with enzyme modified abaca fibre *Compos. Sci. Technol.* **70** 854–60

[23] Kaushik A and Singh M 2011 Isolation and characterization of cellulose nanofibrils from wheat straw using steam explosion coupled with high shear homogenization *Carbohydr. Res.* **346** 76–85

[24] Manalo A C, Wani E, Zukarnain N A, Karunasena W and Lau K-T 2015 Effects of alkali treatment and elevated temperature on the mechanical properties of bamboo fibre–polyester composites *Composites Part B: Engineering* **80** 73–83

[25] Sood M, Dharmpal D and Gupta V K 2015 Effect of fiber chemical treatment on mechanical properties of sisal fiber/recycled HDPE composite *Materials Today: Proceedings* **2** 3149–55

[26] Johar N, Ahmad I and Dufresne A 2012 Extraction, preparation and characterization of cellulose fibres and nanocrystals from rice husk *Ind. Crops Prod.* **37** 93–9

[27] Kärcher M A, Iqbal Y, Lewandowski I and Senn T 2015 Comparing the performance of Miscanthus x giganteus and wheat straw biomass in sulfuric acid based pretreatment *Bioresour. Technol.* **180** 360–4

[28] Lee Y, Iyer P and Torget R W 1999 Dilute-acid hydrolysis of lignocellulosic biomass *Recent progress in bioconversion of lignocellulosics* (Berlin: Springer) pp 93–115

[29] Tran T P T, Bénézet J-C and Bergeret A 2014 Rice and Einkorn wheat husks reinforced poly(lactic acid) (PLA) biocomposites: effects of alkaline and silane surface treatments of husks *Ind. Crops Prod.* **58** 111–24

[30] Pihlajaniemi V, Sipponen M H, Pastinen O, Lehtomäki I and Laakso S J G C 2015 Yield optimization and rational function modelling of enzymatic hydrolysis of wheat straw pretreated by NaOH-delignification, autohydrolysis and their combination *Green Chem.* **17** 1683–91

[31] Venkatachalam N, Navaneethakrishnan P, Rajsekar R and Shankar S 2016 Composites, P, Effect of pretreatment methods on properties of natural fiber composites: a review *Polym. Polym. Compos.* **24** 555–66

[32] Zhang G, Huang K, Jiang X, Huang D and Yang Y 2013 Acetylation of rice straw for thermoplastic applications *Carbohydrate Polym.* **96** 218–26

[33] Fan G, Wang M, Liao C, Fang T, Li J and Zhou R 2013 Isolation of cellulose from rice straw and its conversion into cellulose acetate catalyzed by phosphotungstic acid *Carbohydrate Polym.* **94** 71–6

[34] Bassyouni M and Hasan S W U 2015 The use of rice straw and husk fibers as reinforcements in composites *Biofiber reinforcements in composite materials* (Amsterdam: Elsevier) pp 385–422

[35] Kalaprasad G, Francis B, Thomas S, Kumar C R, Pavithran C, Groeninckx G and Thomas S 2004 Effect of fibre length and chemical modifications on the tensile properties of intimately mixed short sisal/glass hybrid fibre reinforced low density polyethylene composites *Polym. Int.* **53** 1624–38

[36] Mohammadi-Rovshandeh J and Sereshti H 2005 The effect of extraction and prehydrolysis on the thermoplasticity and thermal stability of chemically modified rice straw *Iran. Polym. J.* **14** 855–62

[37] Joseph S, Koshy P and Thomas S 2005 The role of interfacial interactions on the mechanical properties of banana fibre reinforced phenol formaldehyde composites *Composite Interface.* **12** 581–600

[38] Ju K Y and Yong K 2017 *Effect of Water Glass-Polyvinyl Alcohol for Mercerization on Rice Husk and Straw Fibers for Particleboard* **20**

[39] Qin L, Qiu J, Liu M, Ding S, Shao L, Lü S, Zhang G, Zhao Y and Fu X 2011 Mechanical and thermal properties of poly (lactic acid) composites with rice straw fiber modified by poly (butyl acrylate) *Chem. Eng. J.* **166** 772–8

[40] Brandt E 2002 Linseed oil paint as an alternative to wood preservatives *Paper presented at 9th Int. Conf. on Durability of Materials and Components, Brisbane, Austrialia*

[41] Chang C W, Chang J P and Lu K T 2018 Synthesis of linseed oil-based waterborne urethane oil wood coatings *Polymers.* **10** 1235

[42] Belayachi N, Hoxha D and Ismail B 2017 Impact of fiber treatment on the fire reaction and thermal degradation of building insulation straw composite *Energy Procedia* **139** 544–9

[43] Chen W M, Xu Y C, Shi S K, Thiphuong N, Chen M Z and Zhou X Y 2016 Fast enhancement on bondability of wheat straw surface for bio-composites manufacture via dielectric barrier discharge plasma *RSC Adv.* **6** 108566–72

[44] Chen W, Xu Y, Shi S, Cao Y, Chen M and Zhou X 2018 Fast modification on wheat straw outer surface by water vapor plasma and its application on composite material *Sci. Rep.* **8** 2279

[45] Royan N R R, Sulong A B, Yuhana N Y, Chen R S, Ab Ghani M H and Ahmad S 2018 UV/O_3 treatment as a surface modification of rice husk towards preparation of novel biocomposites *PLoS One* **13** e0197345

[46] Yang S, Bai S and Wang Q 2018 Sustainable packaging biocomposites from polylactic acid and wheat straw: enhanced physical performance by solid state shear milling process *Compos. Sci. Technol.* **158** 34–42

[47] Rahman A, Ulven C A, Johnson M A, Durant C and Hossain K G 2017 Pretreatment of wheat bran for suitable reinforcement in biocomposites *J Renew Mater.* **5** 62–73

[48] Elbashiry E M, Chen J, Tuo W, Ren Y and Guo Z 2018 Composites, review of the pretreatment methods for wheat straw building materials *J. Reinf. Plast. Compos.* **37** 35–48

[49] Asgher M, Ahmad Z and Iqbal H M N 2017 Bacterial cellulose-assisted de-lignified wheat straw-PVA based bio-composites with novel characteristics *Carbohydrate Polym.* **161** 244–52

[50] Zou Y, Huda S and Yang Y 2010 Lightweight composites from long wheat straw and polypropylene web *Bioresour. Technol.* **101** 2026–33

[51] Silva G G D, Couturier M, Berrin J-G, Buléon A and Rouau X 2012 Effects of grinding processes on enzymatic degradation of wheat straw *Bioresour. Technol.* **103** 192–200

[52] Kaushik A, Singh M and Verma G 2010 Green nanocomposites based on thermoplastic starch and steam exploded cellulose nanofibrils from wheat straw *Carbohydrate Polym.* **82** 337–45

[53] Smole M S, Kleinschek K, Kreze T, Strnad S, Mandl M and Wachter B 2004 Physical properties of grass fibres *Chem. Biochem. Eng. Q.* **18** 47–54

[54] Panthapulakkal S and Sain M 2007 Manufacturing, Agro-residue reinforced high-density polyethylene composites: fiber characterization and analysis of composite properties *Composites Part A: Applied Science and Manufacturing.* **38** 1445–54

[55] Elmessiry M and Deeb E 2016 Analysis of the wheat straw/flax fiber reinforced polymer hybrid composites *Journal of Applied Mechanical Engineering.* **5** 240

[56] Berthet M A, Angellier-Coussy H, Chea V, Guillard V, Gastaldi E and Gontard N 2015 Sustainable food packaging: valorising wheat straw fibres for tuning PHBV-based composites properties *Composites Part A: Applied Science and Manufacturing.* **72** 139–47

[57] Montaño-Leyva B, da Silva G G D, Gastaldi E, Torres-Chávez P, Gontard N and Angellier-Coussy H 2013 Products, biocomposites from wheat proteins and fibers: structure/mechanical properties relationships *Ind. Crops Prod.* **43** 545–55

[58] Boudria A, Hammoui Y, Adjeroud N, Djerrada N and Madani K 2018 Effect of filler load and high-energy ball milling process on properties of plasticized wheat gluten/olive pomace biocomposite *Adv. Powder Technol.* **29** 1230–8

[59] Muensri P, Kunanopparat T, Menut P and Siriwattanayotin S 2011 Manufacturing, effect of lignin removal on the properties of coconut coir fiber/wheat gluten biocomposite *Composites Part A: Applied Science and Manufacturing.* **42** 173–9

[60] Berthet M-A, Angellier-Coussy H, Machado D, Hilliou L, Staebler A, Vicente A and Gontard N 2015 Products, exploring the potentialities of using lignocellulosic fibres derived from three food by-products as constituents of biocomposites for food packaging *Ind. Crops Prod.* **69** 110–22

[61] Avella M, La Rota G, Martuscelli E, Raimo M, Sadocco P, Elegir G and Riva R 2000 Poly (3-hydroxybutyrate-co-3-hydroxyvalerate) and wheat straw fibre composites: thermal, mechanical properties and biodegradation behaviour *J. Mater. Sci.* **35** 829–36

[62] Ahankari S S, Mohanty A K and Misra M 2011 Mechanical behaviour of agro-residue reinforced poly (3-hydroxybutyrate-co-3-hydroxyvalerate), (PHBV) green composites: a comparison with traditional polypropylene composites *Compos. Sci. Technol.* **71** 653–7

[63] Berthet M-A, Gontard N and Angellier-Coussy H 2015 Technology, Impact of fibre moisture content on the structure/mechanical properties relationships of PHBV/wheat straw fibres biocomposites *Compos. Sci. Technol.* **117** 386–91

[64] Berthet M-A, Commandré J-M, Rouau X, Gontard N and Angellier-Coussy H 2016 Torrefaction treatment of lignocellulosic fibres for improving fibre/matrix adhesion in a biocomposite *Mater. Des.* **92** 223–32

[65] Shang L, Ahrenfeldt J, Holm J K, Sanadi A R, Barsberg S, Thomsen T, Stelte W and Henriksen U B 2012 Bioenergy, changes of chemical and mechanical behavior of torrefied wheat straw *Biomass Bioenergy* **40** 63–70

[66] Hejna A, Formela K and Saeb M R 2015 Processing, mechanical and thermal behavior assessments of polycaprolactone/agricultural wastes biocomposites *Ind. Crops Prod.* **76** 725–33

[67] Le Digabel F, Boquillon N, Dole P, Monties B and Averous L 2004 Properties of thermoplastic composites based on wheat-straw lignocellulosic fillers *J. Appl. Polym. Sci.* **93** 428–36

[68] Hong N V, Pyka G, Wevers M, Goderis B, Van Puyvelde P, Verpoest I and Van Vuure A W 2015 Processing rigid wheat gluten biocomposites for high mechanical performance *Composites Part A: Applied Science and Manufacturing* **79** 74–81

[69] Langstraat T D, Jansens K J, Delcour J A, Verpoest I, Van Puyvelde P and Goderis B 2015 Products, effect of aqueous and alcoholic shear treatments on the properties of rigid plastics from wheat gluten *Ind. Crops Prod.* **77** 146–55

[70] Hemsri S, Asandei A D, Grieco K and Parnas R S 2011 Biopolymer composites of wheat gluten with silica and alumina *Composites Part A: Applied Science and Manufacturing.* **42** 1764–73

[71] Martí-Ferrer F, Vilaplana F, Ribes-Greus A, Benedito-Borrás A and Sanz-Box C 2006 Flour rice husk as filler in block copolymer polypropylene: effect of different coupling agents *J. Appl. Polym. Sci.* **99** 1823–31

[72] Arjmandi R, Hassan A, Majeed K and Zakaria Z 2015 Rice husk filled polymer composites *Int. J. Polym. Sci.* **2015** 32

[73] Wang Z, Li J, Barford J P, Hellgradt K and McKay G 2016 A comparison of chemical treatment methods for the preparation of rice husk cellulosic fibers *International Journal of Environmental & Agricultural Research.* **2** 67–77

[74] Chand N, Sharma P and Fahim M 2010 Tribology of maleic anhydride modified rice-husk filled polyvinylchloride *Wear* **269** 847–53

[75] Rout A K and Satapathy A 2012 Development and characterization of rice husk-filled glass fiber-reinforced epoxy biocomposites *Computations, Applications: An International Journal.* **3** 95–106

[76] Ludueña L, Fasce D, Alvarez V A and Stefani P M 2011 Nanocellulose from rice husk following alkaline treatment to remove silica *Bioresources.* **6** 1440–53

[77] Rahman I, Ismail J and Osman H 1997 Effect of nitric acid digestion on organic materials and silica inrice husk *J. Mater. Chem.* **7** 1505–9

[78] Hessien M M, Rashad M M, Zaky R R, Abdel-Aal E A and El-Barawy K A 2009 Controlling the synthesis conditions for silica nanosphere from semi-burned rice straw *Materials Science and Engineering:* B **162** 14–21

[79] Kwon J H, Ayrilmis N and Han T H 2014 Combined effect of thermoplastic and thermosetting adhesives on properties of particleboard with rice husk core *Mater. Res.* **17** 1309–15

[80] Premalal H G, Ismail H and Baharin A 2002 Comparison of the mechanical properties of rice husk powder filled polypropylene composites with talc filled polypropylene composites *Polym. Test.* **21** 833–9

[81] Das A M, Ali A A and Hazarika M P 2014 Synthesis and characterization of cellulose acetate from rice husk: Eco-friendly condition *Carbohydrate Polym.* **112** 342–9

[82] Mishra P, Chakraverty A and Banerjee H D 1986 Studies on physical and thermal properties of rice husk related to its industrial application *J. Mater. Sci.* **21** 2129–32

[83] Lee Y-K, Kim S-M, Yang H-S and Kim H 2003 Technology, mechanical properties of rice husk flour-wood particleboard by urea-formaldehyde resin *Journal of Korean Wood Science and Technology.* **31** 42–9

[84] Osarenmwinda J O and Nwachukwu J C 2007 In Effect of particle size on some properties of rice husk particleboard *Advanced Materials Research, Trans Tech Publ* 43–8

[85] Garcia D, Lopez J, Balart R, Ruseckaite R A and Stefani P M 2007 Composites based on sintering rice husk–waste tire rubber mixtures *Mater. Des.* **28** 2234–8

[86] Zhao Q, Zhang B, Quan H, Yam R C, Yuen R K and Li R K Y 2009 Flame retardancy of rice husk-filled high-density polyethylene ecocomposites *Compos. Sci. Technol.* **69** 2675–81

[87] Kwon J H, Ayrilmis N and Han T H 2013 Enhancement of flexural properties and dimensional stability of rice husk particleboard using wood strands in face layers *Composites Part B: Engineering.* **44** 728–32

[88] Kim H-S, Lee B-H, Choi S-W, Kim S and Kim H-J 2007 The effect of types of maleic anhydride-grafted polypropylene (MAPP) on the interfacial adhesion properties of bio-flour-filled polypropylene composites *Composites Part A: Applied Science and Manufacturing.* **38** 1473–82

[89] Ndazi B, Tesha J V, Karlsson S and Bisanda E T N 2006 Production of rice husks composites with Acacia mimosa tannin-based resin *J. Mater. Sci.* **41** 6978–83

[90] Chen R S, Salleh M N, Ab Ghani M H, Ahmad S and Gan S 2015 Biocomposites based on rice husk flour and recycled polymer blend: effects of interfacial modification and high fibre loading *BioResources.* **10** 6872–85

[91] Battegazzore D, Bocchini S, Alongi J and Frache A 2014 Rice husk as bio-source of silica: preparation and characterization of PLA–silica bio-composites *RSC Adv.* **4** 54703–12

[92] Mohammadi-Rovshandeh J, Pouresmaeel-Selakjani P, Davachi S M, Kaffashi B, Hassani A and Bahmeyi A 2014 Effect of lignin removal on mechanical, thermal, and morphological properties of polylactide/starch/rice husk blend used in food packaging *J. Appl. Polym. Sci.* **131** 410951–8

[93] Jayamani E, Hamdan S, Rahman M R and Bakri M K 2015 Study of sound absorption coefficients and characterization of rice straw stem fibers reinforced polypropylene composites *BioResources.* **10** 3378–92

[94] Liu J, Jia C and He C 2012 Rice straw and cornstarch biodegradable composites *AASRI Procedia.* **3** 83–8

[95] Liu J J and He C X 2011 In the preparation and properties of rice straw/starch composites *Advanced Materials Research, Trans Tech Publ:* **218** 1129–34

[96] Clemons C M and Caulfield D F 2005 In natural fibers *Functional Fillers for Plastics.* 206

[97] Yeng C M, Husseinsyah S and Ting S S 2015 A comparative study of different crosslinking agent-modified chitosan/corn cob biocomposite films *Polym. Bull.* **72** 791–808

[98] Ghaffar S H, Fan M and McVicar B 2017 Interfacial properties with bonding and failure mechanisms of wheat straw node and internode *Composites Part A: Applied Science and Manufacturing.* **99** 102–12

[99] Ramnath B V, Kokan S J, Raja R N, Sathyanarayanan R, Elanchezhian C, Prasad A R and Manickavasagam V M 2013 Evaluation of mechanical properties of abaca–jute–glass fibre reinforced epoxy composite *Mater. Des.* **51** 357–66

[100] Corrales F, Vilaseca F, Llop M, Girones J, Mendez J A and Mutje P 2007 Chemical modification of jute fibers for the production of green-composites *J. Hazard. Mater.* **144** 730–5

[101] Kabir M M, Wang H, Lau K and Cardona F 2012 Chemical treatments on plant-based natural fibre reinforced polymer composites: an overview *Composites Part B: Engineering.* **43** 2883–92

[102] Merlini C, Soldi V and Barra G M O 2011 Influence of fiber surface treatment and length on physico-chemical properties of short random banana fiber-reinforced castor oil polyurethane composites *Polym. Test.* **30** 833–40

[103] Goriparthi B K, Suman K N S and Rao N M 2012 Effect of fiber surface treatments on mechanical and abrasive wear performance of polylactide/jute composites *Composites Part A: Applied Science and Manufacturing.* **43** 1800–8

[104] Tribot A, Delattre C, Badel E, Dussap C-G, Michaud P and de Baynast H 2018 Design of experiments for bio-based composites with lignosulfonates matrix and corn cob fibers *Ind. Crops Prod.* **123** 539–45

[105] Ma Y, Wu S, Zhuang J, Tong J, Xiao Y and Qi H 2018 The evaluation of physio-mechanical and tribological characterization of friction composites reinforced by waste corn stalk *Materials (Basel).* **11** 901

[106] Sari N H, Wardana I, Irawan Y S and Siswanto E 2017 The effect of sodium hydroxide on chemical and mechanical properties of corn husk fiber *Orient. J. Chem.* **33** 3037–42

[107] Rahman M M and Khan M A 2007 Surface treatment of coir (Cocos nucifera) fibers and its influence on the fibers' physico-mechanical properties *Compos. Sci. Technol.* **67** 2369–76

[108] Kumar N R, Rao C R, Srikant P and Rao B R 2015 Mechanical properties of corn fiber reinforced polypropylene composites using Taguchi method *Materialstoday: Proc.* 2, 3084–92

[109] Jagadeesh D, Sudhakara P, Lee D, Kim H, Kim B and Song J 2013 Mechanical properties of corn husk flour/PP bio-composites *Greencomposites.* **26** 213–7

[110] Trigui A, Karkri M, Pena L, Boudaya C, Candau Y, Bouffi S and Vilaseca F 2013 Thermal and mechanical properties of maize fibres–high density polyethylene biocomposites *J. Compos. Mater.* **47** 1387–97

[111] Sari N H, Wardana I N G, Irawan Y S and Siswanto E 2016 Physical and acoustical properties of corn husk fiber panels *Advances in Acoustics and Vibration.* **2016** 8

[112] Jones R M 2014 Mechanics of composite materials 2nd edn (CRC press) p 538

[113] Zhang L M, McVay M C, Han S J, Lai P W and Gardner R 2002 Effects of dead loads on the lateral response of battered pile groups *Canadian Geotechnical Journal.* **39** 561–75

[114] Mohamed S A N, Zainudin E S, Sapuan S M, Azaman M D and Arifin A M T 2019 Energy behavior assessment of rice husk fibres reinforced polymer composite *Journal of Materials Research and Technology.* (https://doi.org/10.1016/j.jmrt.2019.10.067)

[115] Kumar S, Mer K K S, Gangil B and Patel V K 2019 Synergy of rice-husk filler on physico-mechanical and tribological properties of hybrid Bauhinia-vahlii/sisal fiber reinforced epoxy composites *Journal of Materials Research and Technology.* **8** 2070–82

[116] Jiang L, He C, Fu J and Chen D 2017 Wear behavior of straw fiber-reinforced polyvinyl chloride composites under simulated acid rain conditions *Polym. Test.* **62** 373–81

[117] Masłowski M, Miedzianowska J and Strzelec K 2017 Natural rubber biocomposites containing corn, barley and wheat straw *Polym. Test.* **63** 84–91

[118] Berthet M-A, Mayer-Laigle C, Rouau X, Gontard N and Angellier-Coussy H 2017 Sorting natural fibres: A way to better understand the role of fibre size polydispersity on the mechanical properties of biocomposites *Composites Part A: Applied Science and Manufacturing.* **95** 12–21

[119] Sánchez-Safont E L, Aldureid A, Lagarón J M, Gámez-Pérez J and Cabedo L 2018 Biocomposites of different lignocellulosic wastes for sustainable food packaging applications *Composites Part B: Engineering.* **145** 215–25

[120] Luo H, Zhang C, Xiong G and Wan Y 2016 Effects of alkali and alkali/silane treatments of corn fibers on mechanical and thermal properties of its composites with polylactic acid *Polym. Compos.* **37** 3499–507

[121] Chitra N J and Vasanthakumari R 2012 Research, E, Studies on polypropylene bio composite with corn husk waste *International Journal of Scientific and Engineering Research.* **3** 3

[122] Wang D, Xuan L, Han G, Wong A H H, Wang Q and Cheng W 2020 Preparation and characterization of foamed wheat straw fiber/polypropylene composites based on modified nano-TiO_2 particles *Composites Part A: Applied Science and Manufacturing.* **128** 105674

[123] Hýsek Š, Podlena M, Bartsch H, Wenderdel C and Böhm M 2018 Effect of wheat husk surface pre-treatment on the properties of husk-based composite materials *Ind. Crops Prod.* **125** 105–13

[124] Panthapulakkal S, Zereshkian A and Sain M 2006 Preparation and characterization of wheat straw fibers for reinforcing application in injection molded thermoplastic composites *Bioresour. Technol.* **97** 265–72

[125] Arjmandi R, Ismail A, Hassan A and Abu Bakar A 2017 Effects of ammonium polyphosphate content on mechanical, thermal and flammability properties of kenaf/polypropylene and rice husk/polypropylene composites *Constr. Build. Mater.* **152** 484–93

[126] Fávaro S L, Lopes M S, Vieira de Carvalho Neto A G, Rogério de Santana R and Radovanovic E 2010 Chemical, morphological, and mechanical analysis of rice husk/post-consumer polyethylene composites *Composites Part A: Applied Science and Manufacturing.* **41** 154–60

[127] Hidalgo-Salazar M A and Salinas E 2019 Mechanical, thermal, viscoelastic performance and product application of PP- rice husk Colombian biocomposites *Composites Part B: Engineering.* **176** 107135

[128] Liu Y, Lv X, Bao J, Xie J, Tang X, Che J, Ma Y and Tong J 2019 Characterization of silane treated and untreated natural cellulosic fibre from corn stalk waste as potential reinforcement in polymer composites *Carbohydrate Polym.* **218** 179–87

[129] Luo Z, Li P, Cai D, Chen Q, Qin P, Tan T and Cao H 2017 Comparison of performances of corn fiber plastic composites made from different parts of corn stalk *Ind. Crops Prod.* **95** 521–7

[130] Kumar N R, Rao C H R, Srikant P and Rao B R 2015 Mechanical properties of corn fiber reinforced polypropylene composites using Taguchi method *Materials Today: Proceedings.* **2** 3084–92

[131] Panthapulakkal S and Sain M 2015 14 - The use of wheat straw fibres as reinforcements in composites *Biofiber Reinforcements in Composite Materials* ed O Faruk and M Sain (Woodhead Publishing) 423–53

[132] Cobo P and de Espinosa F M 2013 Proposal of cheap microperforated panel absorbers manufactured by infiltration *Appl. Acoust.* **74** 1069–75

[133] Arenas J P and Ugarte F 2013 A note on a circular panel sound absorber with an elastic boundary condition *Appl. Acoust.* **114** 10–7

[134] Lv L, Bi J, Wei C, Wang X, Cui Y and Liu H 2015 Effect of micro-slit plate structure on the sound absorption properties of discarded corn cob husk fiber *Fibers Polym.* **16** 1562–7

[135] Mamtaz H, Fouladi M H, Nuawi M Z, Namasivayam S N, Ghassem M and Al-Atabi M 2017 Acoustic absorption of fibro-granular composite with cylindrical grains *Appl. Acoust.* **126** 58–67

[136] Tang X, Zhang X, Zhang H, Zhuang X and Yan X 2018 Corn husk for noise reduction: robust acoustic absorption and reduced thickness *Appl. Acoust.* **134** 60–8

[137] Sari N, Wardana I N G, Irawan Y and Siswanto E 2017 Corn husk fiber-polyester composites as sound absorber: nonacoustical and acoustical properties *Advances in Acoustics and Vibration.* **2017** 1–8

[138] Bhingare N H, Prakash S and Jatti V S 2019 A review on natural and waste material composite as acoustic material *Polym. Test.* 106–42

[139] Binici H, Aksogan O and Demirhan C 2016 Mechanical, thermal and acoustical characterizations of an insulation composite made of bio-based materials *Sustainable Cities and Society.* **20** 17–26

[140] Luo H, Xiong G, Ma C, Chang P, Yao F, Zhu Y, Zhang C and Wan Y 2014 Mechanical and thermo-mechanical behaviors of sizing-treated corn fiber/polylactide composites *Polym. Test.* **39** 45–52

[141] Pavelek M, Prajer M and Trgala K 2018 Static and dynamic thermal characterization of timber frame/wheat (Triticum Aestivum) chaff thermal insulation panel for sustainable building construction *Sustainability.* **10** 2363

[142] Xia T, Huang H, Wu G, Sun E, Jin X and Tang W 2018 The characteristic changes of rice straw fibers in anaerobic digestion and its effect on rice straw-reinforced composites *Ind. Crops Prod.* **121** 73–9

[143] Qin L, Qiu J, Liu M, Ding S, Shao L, Lü S, Zhang G, Zhao Y and Fu X 2011 Mechanical and thermal properties of poly(lactic acid) composites with rice straw fiber modified by poly(butyl acrylate) *Chem. Eng. J.* **166** 772–8

[144] Zhao Y, Qiu J, Feng H, Zhang M, Lei L and Wu X 2011 Improvement of tensile and thermal properties of poly(lactic acid) composites with admicellar-treated rice straw fiber *Chem. Eng. J.* **173** 659–66

[145] Zhu L, Qiu J, Liu W and Sakai E 2019 Mechanical and thermal properties of rice straw/PLA modified by nano attapulgite/PLA interfacial layer *Composites Communications.* **13** 18–21

[146] Muthuraj R, Lacoste C, Lacroix P and Bergeret A 2019 Sustainable thermal insulation biocomposites from rice husk, wheat husk, wood fibers and textile waste fibers: elaboration and performances evaluation *Ind. Crops Prod.* **135** 238–45

[147] Jiang D, Wang Y, Li B, Sun C and Guo Z 2020 Environmentally friendly alternative to polyester polyol by corn straw on preparation of rigid polyurethane composite *Composites Communications.* **17** 109–14

[148] Antunes A, Faria P, Silva V and Brás A 2019 Rice husk-earth based composites: a novel bio-based panel for buildings refurbishment *Constr. Build. Mater.* **221** 99–108

[149] Jiang D, Pan M, Cai X and Zhao Y 2018 Flame retardancy of rice straw-polyethylene composites affected by *in situ* polymerization of ammonium polyphosphate/silica *Composites Part A: Applied Science and Manufacturing.* **109** 1–9

[150] Jayaprakash V, Sivasaravanan S, Bupesh Raja V K, Anish M, Raman N and Laxman N 2019 Optimization of drilling parameters of epoxy/rice husk composite material *Materials Today: Proceedings.* (https://doi.org/10.1016/j.matpr.2019.05.370)

[151] Madhoushi M, Nadalizadeh H and Ansell M P 2009 Withdrawal strength of fasteners in rice straw fibre-thermoplastic composites under dry and wet conditions *Polym. Test.* **28** 301–6

[152] Pradhan R, Misra M, Erickson L and Mohanty A 2010 Compostability and biodegradation study of PLA–wheat straw and PLA–soy straw based green composites in simulated composting bioreactor *Bioresour. Technol.* **101** 8489–91