Socio-Economic Assessment of Natural Fibers

Subjects: Forestry
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Natural fibers, which are renewable and ecologically acceptable sources of raw materials for producing environmentally friendly products, have played a significant part in human civilization. Natural fibers are desirable bio-sourced materials as an alternative to non-sustainable glass and carbon fiber reinforced composites owing to their availability and technical viability. Natural fibers have been successfully applied to a wide range of applications, for instance, furniture, automotive, electronic industries, and building construction.

Keywords: natural fibers ; socio-economic assessment ; sustainability ; renewable resources

1. Classification for Natural Fibers

The most common classification for natural fibers is from botanical forms. Natural fibers can be classified into five types [1]: Other forms include (1) bast fibers (for example abaca, sisal, pineapple), (2) leaf fibers (such as ramie, flax, kenaf), (3) seed fibers (coir, cotton, and kapok), (4) grass and reeds (wheat, corn, and rice), and (5) wood and roots. A more comprehensive list of fiber classifications can be found in **Figure 1**. A variety of fibers are produced by several plants. For example, jute, flax, hemp, and kenaf have both bast and core fibers, whereas agave, coconut, and oil palm have both fruit and stem fibers. Both stem and hull fibers can be found in cereal grains [2].

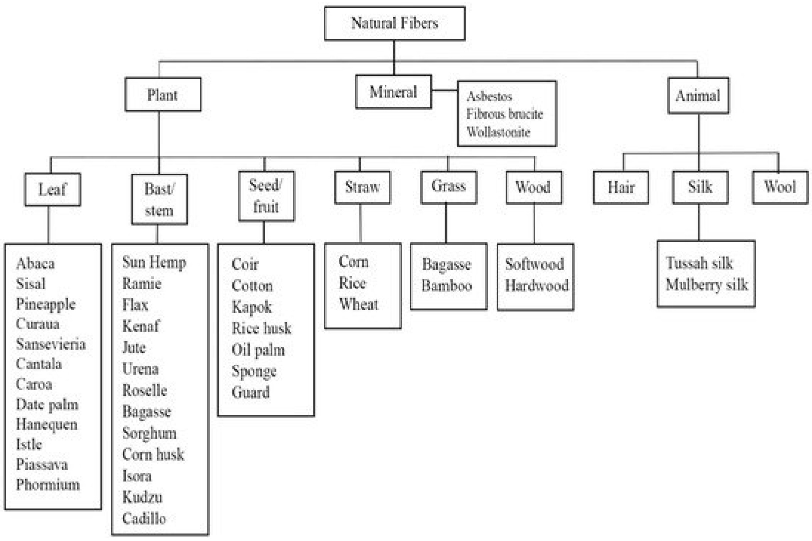

Figure 1. Schematic representation of fiber classification, reprint with permission from ref. [1]. Copyright © 2021 Woodhead Publishing Limited.

2. Social and Economic Aspects on Utilization of Natural Fibers

Since prehistoric times, natural fibers have played a vital role in human society as a sustainable and ecologically beneficial source of raw materials that are easily degraded into environmentally friendly items and have the ability to absorb enough moisture. Natural fibers have a variety of fascinating properties, including low density, light weight, low cost, biodegradability, abundant accessibility, minimal health hazards during processing, relatively good basic strength and modulus, good thermal and acoustic insulation characteristics, physical properties, and ease of availability [3][4].

Natural fibers have been favored over synthetic fibers because of their superior qualities [3][4]. Natural fiber has been used as a raw material in a variety of industries, including aerospace, automotive, marine, building and construction, sports and leisure items, electronic appliances, military vehicles, biomedical purposes [5][6][7][8][9][10][11][12][13] as shown in **Figure 2**: Natural fiber applications are also increasing in textiles, packaging, printed goods, filters, automobiles, furniture, particleboard, insulation board, and other materials [14][15][16][17]. Woven-kenaf aramid and pineapple leaves were used in military vehicles, especially for ballistic purposes [13], and hard armor plate [13][18], respectively. In biomedical applications, natural fibers are in fiber-reinforced composites (FRC), such as various clinical fields [19] as described in **Table 1**. Hemp and sisal have been reported for utilization as cementitious construction and fancy materials in the construction field [20][21]. In the biomedical field, the most promising natural fiber candidate is undoubtedly cellulose, in the form of nanofibers. Nanocellulose has a variety of biomedical applications, including drug delivery, vascular grafts, skin tissue regeneration, antimicrobial membranes, medical implants, biosensors and diagnostics, and scaffolds [22]. Several methods have been developed to improve the compatibility of natural fibers and polymer matrices in order to enhance the physical and mechanical properties of targeted bioproducts. However, the acceptability of natural fiber and biocomposite materials by the human body is a critical requirement that must be addressed [23].

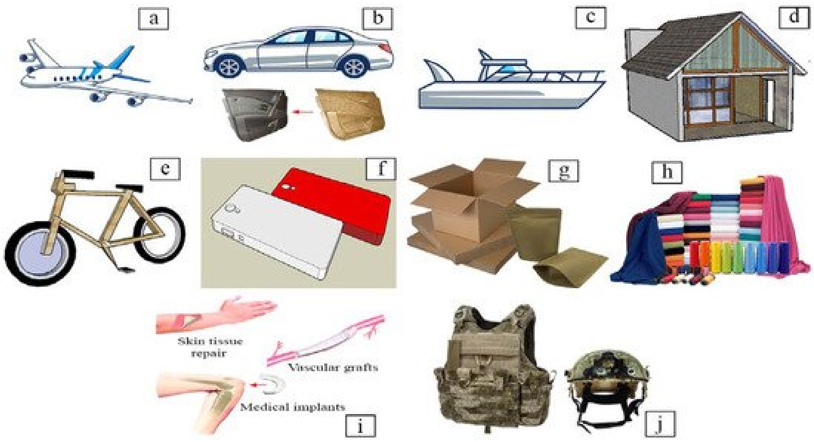

Figure 2. Potential application of natural fibers in many sectors such as (**a**) aerospace, (**b**) automotive, (**c**) marine such as boat hulls, (**d**) building and construction such as insolation board, (**e**) sport and leisure goods, (**f**) electronic appliances such as handphone casing, (**g**) paper and packaging, (**h**) textile, (**i**) biomedical, and (**j**) military fields.

Table 1. Application of natural fiber composites in biomedical field.

Specific Area Application of Fiber Composite	Source of Fiber	References
• Blood bag • Drug/gene delivery scaffold	**Pineapple, rambutan and banana skin**	[24]
• Ancient medicine • Modern functional food	**Flax and flaxseed oil**	[25]
• Wound dressings	**Flax**	[26]
• Drug delivery	**Cotton**	[26]
• Wound healing	***Bombyx mori* silk**	[27]
• Tissue engineering • Drug delivery • Wound dressing • Medical implants • Cardiovascular implants • Scaffolds for tissue engineering	**Pineapple leaf**	[28][29]

Specific Area Application of Fiber Composite	Source of Fiber	References
• Prosthodontics • Orthopedics • Cosmetic orthodontics	-	[23]
• Dental application	-	[30][9][10]

Natural fibers are a type of biomaterial used for reinforcement of polymer-based composites. Some agricultural plants, including ramie, sisal, and pineapple leaf fiber [31][32][33][34][35] and hybrid fibers of Egyptian and Qatari palm trees [23] and woven cotton fabrics [36] have reported used as bioresources of FRC. The manufacture of natural fiber composite materials or eco-friendly composites has become a popular topic as people become more aware of environmental sustainability. To minimize material weight, natural fibers may be a suitable option for replacing synthetic materials. Natural fiber reinforced polymer and resin composites have been widely used in a variety of industries, including automotive and aviation interior components, as well as military vehicles [13][37][38][39]. Because of their high specific qualities at a lower cost than synthetic fibers, they are appealing for several applications.

Miller [14] mentions the usage of hemp fiber in textile manufacture. The mechanical properties of the bio-based textile composites studied in this review are like those of some traditional materials. The use of pineapple leaf fiber as a reinforcement in the fabrication of yam starch films with packing potential was defined by Mahardika et al. [15]. Asrofi et al. [40] created a bioplastic made of tapioca starch and sugarcane stem fiber for reinforcement. The interior components of an automobile are composed of hemp fiber/polypropylene composites [16], while kenaf and wheat straw were used as vehicle spall-liners and quarter trim panel storage [41]. Natural fiber mats, aluminum sheets, and epoxy resins provide excellent electromagnetic interference prevention while keeping high mechanical qualities in hybrid composites [17]. Good specific properties, low cost, low density, good formability and processability, good mechanical properties, and a plentiful and sustainable source of raw materials are all the benefits of using natural fibers over synthetic fibers. Natural fibers, on the other hand, have a high moisture sensitivity [42][43]. The development of natural fiber composites in a variety of applications has paved new avenues in both academia and industry for the future applications of sustainable natural fibers.

As previously stated, several of the shortcomings of natural fibers should be addressed during the optimization of natural fiber applications. When used as a composite, the hydrophilic nature of natural fibers makes it difficult to adhere to a hydrophobic matrix, resulting in poor mechanical characteristics and processability [44]. Surface treatment methods applied include chemical and enzymatic treatments, corona treatment, and coupling agent addition [45][46][47][48][49][50][51][52]. Furthermore, the handling of the interfacial region before processing with thermoplastics at a temperature up to 200 °C, the interfacial treatment (surface treatment resins, additives, and coating) must be reinforced to address the low degradation temperature of natural fibers [31][53].

The Indonesian government has taken steps to encourage the use of natural fibers, such as appointing an institution to focus on the development of natural fibers and establishing a multi-stakeholder research community, namely, the Indonesian Ramie Consortium (KORI), to study specific natural fibers, primarily ramie. Ramie is a type of natural fiber that has become a national priority in Indonesia for widespread use. **Figure 3** depicts the strategy for manufacturing of ramie development in Indonesia.

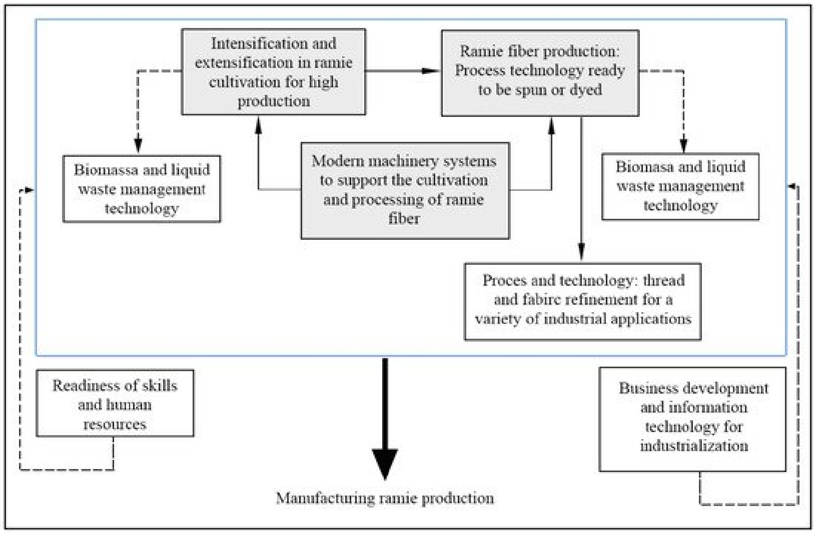

Figure 3. Manufacturing integration strategy in the ramie production system in Indonesia.

Manufacturing integration strategies in ramie processing systems to support large-scale production are to be developed with an emphasis on three main sub-systems: cultivation, fiber processing technology, and machining. The ramie-based industry will be able to support the functional value of the fiber or fabric of ramie for functional enhancement of the products. Strategies in business concepts and supply of human resources with competence in all aspects of processing systems will be able to support the realization of the manufacturing of ramie production in Indonesia. This research strategy is currently supported by the Indonesian government in the National Research Program, for the period 2020–2024.

Additionally, the Indonesia Natural Fiber Council (DSI) was founded in Indonesia to assist scientists, policymakers, and other stakeholders in the development of bioproducts generated from natural fibers. DSI proposed a road map for the Indonesian fiber sector from 2020 to 2024, with abaca, kenaf, bamboo, pineapple, sisal, cotton, and ramie as types of promising fiber to be further developed [54]. Furthermore, biduri (*Calotropis gigantea*) is a natural fiber that has the potential to be developed in Indonesia as a thermal and acoustic insulation material and filler material [55] and for winter jacket [56]. Biduri fiber production is predicted to be around 3.6 tons per hectare per year [55]. Some bioproducts, such as biopellets, food, textiles, biocomposites, and ecofriendly shoes, have been launched into the Indonesian market as a result of continued efforts. In addition, several small local businesses extract fiber from fresh pineapple leaves using basic techniques such as retting followed by decortication for clotes, handycraft, and other items. However, the process output is still low, with 2.5 kg of air-dry pineapple fiber produced from 100 kg of fresh leaf fiber and 97.5% of decorticator waste that has yet to be used (visualized in **Figure 4**). Banana stems are treated in a similar way to make banana fibers in this local enterprise. Until now, cotton has been the main fiber source in the Indonesian textile industry, but the qualities of local cotton have not met the requirements, so nearly all of it is imported, while the other fibers have been used to their full potential. Considering the potency and challenge, continual efforts to disseminate information about the various uses of natural fibers in the community are required.

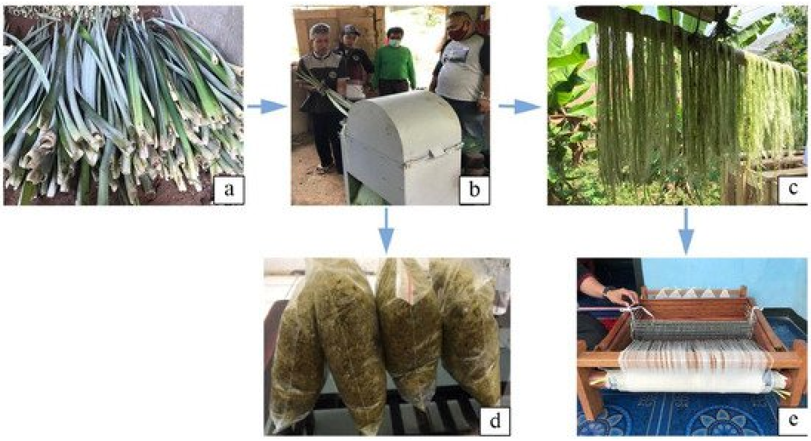

Figure 4. The process production of extracted fiber from fresh leaf pineapple, (**a**) fresh leaf fiber, (**b**) decorticator process, (**c**) wet extracted fiber, (**d**) decorticator waste, (**e**) dried fiber that ready for spinning.

Natural fibers play an important role in improving the quality of human life. However, waste can be generated during the product life cycle and during the processing of natural fibers into bioproducts. To achieve the most efficient utilization of resources, waste management should be conducted continuously by recycling and/or upcycling of waste, aside from innovation in the design of bioproducts. Shanmugam et al. [57] recognized recycling and the use of bio-based constituents as essential issues in adopting a circular economy (CE). CE adheres to the principles of reduce, reuse, recycle, and replace. CE is beneficial to the environment, economy, and society when used in FRC manufacturing. Given the numerous sustainability challenges confronting our societies, transitioning to a circular economy and closing resource loops through recycling is a viable solution [58]. **Figure 5** proposes a CE concept based on natural fibers that is more considered than a linear economy concept for future resource conservation and environmental balance. The CE approach is gaining traction and has been proposed in some fields, such as carbon fiber manufacturing [59], agricultural sector [60] and biomass biorefinery [61], for gradually reducing energy consumption during the manufacturing process. Biomaterials in the CE present numerous challenges for the industry in terms of developing new network and commercial opportunities while remaining focused on consumer demands [61].

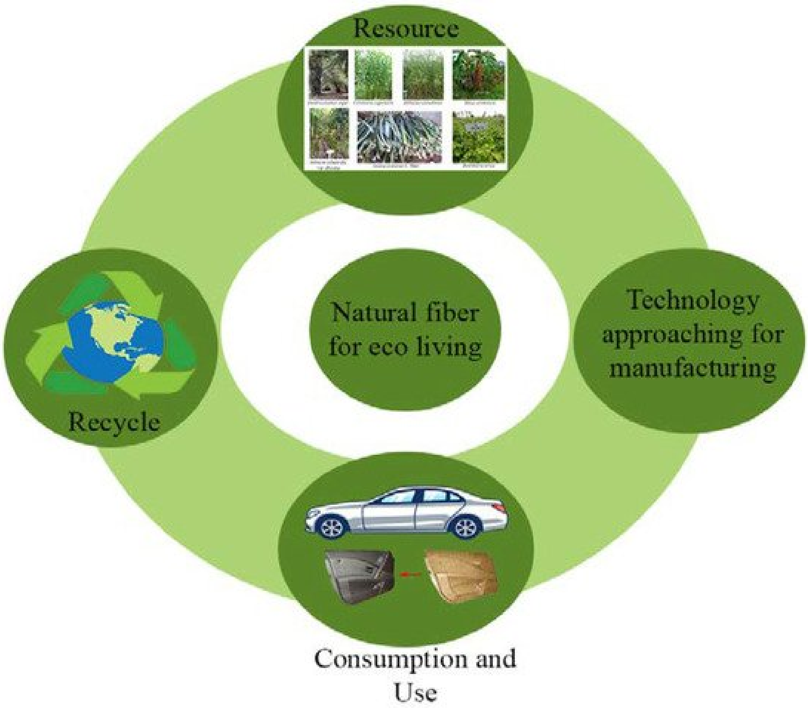

Figure 5. Circular economy concept to conserve the natural fiber for future eco living.

The development of an information system for Indonesian natural fibers, as well as collaboration with a variety of stakeholders such as research and development institutions, industries, policymakers (local and national), and universities, are ongoing efforts to bring Indonesian local industry independence. National innovation products made from natural fibers can be created by local industry in the future and sold at least locally, with Indonesians consuming them.

Natural fiber as lignocellulosic biomass has an economic chance to meet industrial needs, depending on the processing level that has been made to make its derivative products, including its market to accomplish. According to Ruamsook and Evelyn [62], there are four levels in which biomass can be processed and turned into value-added goods before being sold to potential demand markets (**Figure 6**). Farmers become the first important people actors to create their biomass as the major components of industrial needs, as indicated in this picture. Commodities such as corn, wheat, cotton, and hay, as well as other crop farms such as paddy, are the possible resources of rubber and polymer markets. Many industrial polymers and plastics are still made from non-renewable oil and gas resources today. This would cause a supply shock when non-renewable resources are depleted, causing the processed product to bubble to an unacceptably high price [62]. As a result, the growing interest in bio-based polymer and plastic products derived from renewable sources creates a market opportunity for biomass in exchange for enhanced environmental support in reducing climate change pressure.

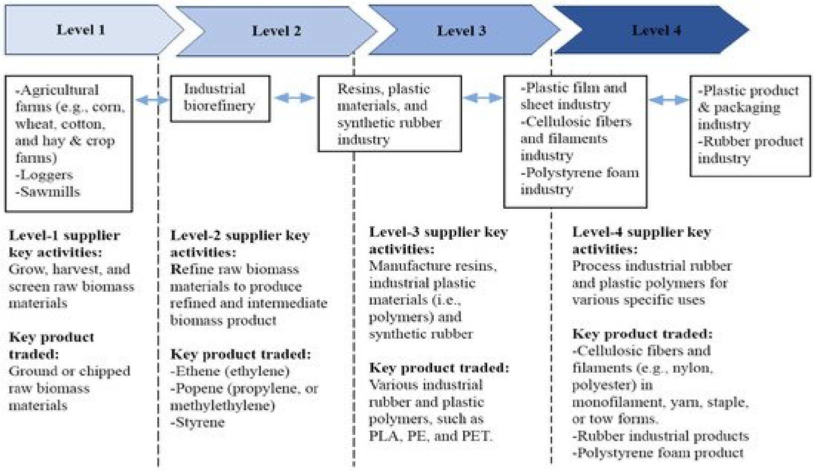

Figure 6. Simplified example of multi-level rubber and polymer markets for biomass (adapted from [62]).

Farmers will benefit from the potential use of paddy waste as an alternative source of packaging because they have been heavily reliant on agriculture without any additional revenue, as most farmers are still subsistence and have a low-middle income. On the other hand, this will contribute to reducing future climate change issues by allowing farmers to benefit from better climate conditions through sustainable agriculture. Nonetheless, the government must promote this innovation to increase economic potential and to provide an instrument for industrial businesses to improve their knowledge of the sustainable industrial environment. It may not be easy, but once the government steps in to regulate the industrial ecosystem by paying more attention to reducing plastic waste and implementing sustainable bioplastic for bio-packaging for both large industrial ecosystems and small-medium enterprises, it could have structural potential. One of the studies that uses paddy-waste as bioplastic is the usage of rice straw cellulose (*Oryza sativa*) as bioplastic by the pulping process and phase inversion method [63].

Building an ecosystem of sustainable industry, particularly for consumer behavior, is to use more sustainable packaging or bio-packaging that can be created from natural fiber. As it is known that the production of food packaging made from plastic as well as styrofoam is about 14.000 tons per year, it has affected the use of plastic packaging for food [58]. However, this material is not environmentally friendly and could cause a significant impact both on the user and the environment after its usage, with a long-term impact on climate change. Thus, the government could develop bio packages as a particular potential both for reducing environmental issues and improving the economic opportunity of farmers from the paddy waste produced. Basically, this novel innovation could be started by a small-scale industry where a group of farmers could start to process the paddy waste materials where generally they would not be sold except for burning.

On the other hand, the development of bio-packages made of paddy straw benefits not only farmers in terms of economic earnings, but also consumers, as they have paid more for the environmentally friendly food package to have both future-health preservation as well as the original flavor and scent of stored food from this bio-package material, compared to a conventional plastic food package, which has more influence on their food, particularly when the foods are still at high temperatures. With these kinds of benefits, coupled with intense regulatory aspects, consumers would indeed be willing to pay more to get this type of food package if the government could guarantee that it would not harm them and be rigid in implementing environmental policy in general. If this is accomplished, the introduction of novel food packages made of paddy straw will be imminent, benefiting farmers who are the primary source of this material. Many countries have taken steps to encourage the use of natural fibers, such as appointing an institution to focus on the development of natural fibers and establishing a multi-stakeholder research community.

References

1. Rowell, R.M. The Use of Biomass to Produce Bio-Based Composites and Building Materials; Woodhead Publishing Limited: Oxford, UK, 2014.
2. Rowell, R.M. Natural Fibers: Types and Properties; Woodhead Publishing Limited: Boca Raton, FL, USA, 2008.
3. Vinod, A.; Vijay, R.; Singaravelu, D.L.; Sanjay, M.R.; Siengchin, S.; Moure, M.M. Characterization of untreated and alkali treated natural fibers extracted from the stem of Catharanthus roseus. Mater. Res. Express 2019, 6, 085406.
4. Sanjay, M.R.; Siengchin, S.; Parameswaranpillai, J.; Jawaid, M.; Pruncu, C.I.; Khan, A. A comprehensive review of techniques for natural fibers as reinforcement in composites: Preparation, processing and characterization. Carbohydr.

Polym. 2019, 207, 108–121.

5. Sanjay, M.R.; Siengchin, S. Natural fibers as perspective materials. KMUTNB Int. J. Appl. Scie. Tech. 2018, 11, 233.
6. Sanjay, M.R.; Arpitha, G.R.; Naik, L.L.; Gopalakrishna, K.; Yogesha, B. Applications of natural fibers and its composites: An overview. Nat. Res. 2016, 7, 108.
7. Ahmed, M.J.; Balaji, M.A.S.; Saravanakumar, S.S.; Sanjay, M.R.; Senthamaraikannan, P. Characterization of Areva javanica fiber—A possible replacement for synthetic acrylic fiber in the disc brake pad. J. Ind. Text. 2018, 49, 294–317.
8. Davoodi, M.M.; Sapuan, S.M.; Ahmad, D.; Ali, A.; Khalina, A.; Jonoobi, M. Mechanical properties of hybrid kenaf/glass reinforced epoxy composite for passenger car bumper beam. Mater. Des. 2010, 31, 4927–4932.
9. Scribante, A.; Vallittu, P.K.; Özcan, M. Fiber-reinforced composites for dental applications. BioMed Res. Int. 2018, 2018, 4734986.
10. Adekomaya, O.; Majozi, T. 23-Industrial and biomedical applications of fiber reinforced composites. In Fiber Reinforced Composites; Joseph, K., Oksman, K., George, G., Wilson, R., Appukuttan, S., Eds.; Woodhead Publishing: Sawston, UK, 2021; pp. 753–783.
11. Puglia, D.; Biagiotti, J.; Kenny, J.M. A Review on Natural Fibre-Based Composites—Part II. J. Nat. Fibers 2005, 1, 23–65.
12. Nurazzi, N.M.; Asyraf, M.; Khalina, A.; Abdullah, N.; Aisyah, H.A.; Rafiqah, S.A.; Sabaruddin, F.A.; Kamarudin, S.H.; Norrrahim, M.; Ilyas, R.A.; et al. A Review on Natural Fiber Reinforced Polymer Composite for Bullet Proof and Ballistic Applications. Polymers 2021, 13, 646.
13. Yahaya, R.; Sapuan, S.M.; Jawaid, M.; Leman, Z.; Zainudin, E.S. Investigating ballistic impact properties of woven kenaf-aramid hybrid composites. Fibers Polym. 2016, 17, 275–281.
14. Miller, S.A. Natural fiber textile reinforced bio-based composites: Mechanical properties, creep, and environmental impacts. J. Clean. Prod. 2018, 198, 612–623.
15. Mahardika, M.; Abral, H.; Kasim, A.; Arief, S.; Hafizulhaq, F.; Asrofi, M. Properties of cellulose nanofiber/bengkoang starch bionanocomposites: Effect of fiber loading. LWT 2019, 116, 108554.
16. Al-Oqla, F.M.; Sapuan, S.M.; Ishak, M.R.; Nuraini, A.A. A decision-making model for selecting the most appropriate natural fiber—Polypropylene-based composites for automotive applications. J. Compos. Mater. 2015, 50, 543–556.
17. Xia, C.; Yu, J.; Shi, S.Q.; Qiu, Y.; Cai, L.; Wu, H.F.; Ren, H.; Nie, X.; Zhang, H. Natural fiber and aluminum sheet hybrid composites for high electromagnetic interference shielding performance. Compos. Part B Eng. 2017, 114, 121–127.
18. Luz, F.S.D.; Garcia Filho, F.D.C.; Oliveira, M.S.; Nascimento, L.F.C.; Monteiro, S.N. Composites with Natural Fibers and Conventional Materials Applied in a Hard Armor: A Comparison. Polymers 2020, 12, 1920.
19. Murali Mohan, S.; Mahesh Gowda, E.; Shashidhar, M.P. Clinical evaluation of the fiber post and direct composite resin restoration for fixed single crowns on endodontically treated teeth. Med. J. Armed Forces India 2015, 71, 259–264.
20. Anidha, S.; Latha, N.; Muthukkumar, M. Effect of polyaramid reinforced with sisal epoxy composites: Tensile, impact, flexural and morphological properties. J. Mater. Res. Technol. 2020, 9, 7947–7954.
21. Zhou, X.; Saini, H.; Kastiukas, G. Engineering properties of treated natural hemp fiber-reinforced concrete. Front. Built Environ. 2017, 3, 33.
22. Luzi, F.; Puglia, D.; Torre, L. Natural Fiber Biodegradable Composites and Nanocomposites: A Biomedical Application; Elsevier Ltd.: Kidlington, UK, 2019.
23. Namvar, F.; Jawaid, M.; Md Tahir, P.; Mohamad, R.; Azizi, S.; Khodavandi, A.; Rahman, H.S.; Nayeri, M.D. Potential use of plant fibres and their composites for biomedical applications. BioResources 2014, 9, 5688–5706.
24. Ahad, N.; Rozali, F.; Hanif, N.; Rosli, N. Oils and water absorption behavior of natural fibers filled TPU composites for biomedical applications. J. Eng. Res. Educ. 2018, 10, 16–21.
25. Goyal, A.; Sharma, V.; Upadhyay, N.; Gill, S.; Sihag, M. Flax and flaxseed oil: An ancient medicine & modern functional food. J. Food Sci. Technol. 2014, 51, 1633–1653.
26. Kulma, A.; Skórkowska-Telichowska, K.; Kostyn, K.; Szatkowski, M.; Skała, J.; Drulis-Kawa, Z.; Preisner, M.; Żuk, M.; Szperlik, J.; Wang, Y.F.; et al. New flax producing bioplastic fibers for medical purposes. Ind. Crop. Prod. 2015, 68, 80–89.
27. Song, J.; Chen, Z.; Liu, Z.; Yi, Y.; Tsigkou, O.; Li, J.; Li, Y. Controllable release of vascular endothelial growth factor (VEGF) by wheel spinning alginate/silk fibroin fibers for wound healing. Mater. Des. 2021, 212, 110231.
28. Cherian, B.M.; Leão, A.L.; de Souza, S.F.; Thomas, S.; Pothan, L.A.; Kottaisamy, M. Isolation of nanocellulose from pineapple leaf fibres by steam explosion. Carbohydr. Polym. 2010, 81, 720–725.

29. Giri, J.; Adhikari, R.; Campus, T. A brief review on extraction of nanocellulose and its application. Nepal J. Online 2013, 9, 81–87.

30. Murdiyanto, D. Potensi serat alam tanaman Indonesia sebagai bahan fiber reinforced composite kedokteran gigi. J. Mater. Kedokt. Gigi 2017, 6, 14–22.

31. Vinod, A.; Vijay, R.; Singaravelu, D.L. ThermoMechanical characterization of Calotropis gigantea stem powder-filled jute fiber-reinforced epoxy composites. J. Nat. Fibers 2018, 15, 648–657.

32. Jothibasu, S.; Mohanamurugan, S.; Vijay, R.; Lenin Singaravelu, D.; Vinod, A.; Sanjay, M.R. Investigation on the mechanical behavior of areca sheath fibers/jute fibers/glass fabrics reinforced hybrid composite for light weight applications. J. Ind. Text. 2018, 49, 1036–1060.

33. Vijay, R.; Lenin Singaravelu, D.; Vinod, A.; Sanjay, M.R.; Siengchin, S.; Jawaid, M.; Khan, A.; Parameswaranpillai, J. Characterization of raw and alkali treated new natural cellulosic fibers from Tridax procumbens. Int. J. Biol. Macromol. 2019, 125, 99–108.

34. Munawar, S.S.; Umemura, K.; Kawai, S. Manufacture of oriented board using mild steam treatment of plant fiber bundles. J. Wood Sci. 2008, 54, 369–376.

35. Alharbi, M.A.H.; Hirai, S.; Tuan, H.A.; Akioka, S.; Shoji, W. Effects of chemical composition, mild alkaline pretreatment and particle size on mechanical, thermal, and structural properties of binderless lignocellulosic biopolymers prepared by hot-pressing raw microfibrillated Phoenix dactylifera and Cocos nucifera fibers and leaves. Polym. Test. 2020, 84, 106384.

36. Daunton, C.; Kothari, S. A history of materials and practices for wound management. Wound Manag. 2012, 20, 174–186.

37. Asim, M.; Saba, N.; Jawaid, M.; Nasir, M. 12-Potential of natural fiber/biomass filler-reinforced polymer composites in aerospace applications. In Sustainable Composites for Aerospace Applications; Jawaid, M., Thariq, M., Eds.; Woodhead Publishing: Kidlington, UK, 2018; pp. 253–268.

38. Potluri, R. Natural Fiber-Based Hybrid Bio-composites: Processing, Characterization, and Applications. In Green Composites: Processing, Characterisation and Applications for Textiles; Muthu, S.S., Ed.; Springer: Singapore, 2019; pp. 1–46.

39. Arockiam, N.J.; Jawaid, M.; Saba, N. 6-Sustainable bio composites for aircraft components. In Sustainable Composites for Aerospace Applications; Elsevier: Selangor, Malaysia, 2018; pp. 109–123.

40. Asrofi, M.; Sapuan, S.M.; Ilyas, R.A.; Ramesh, M. Characteristic of composite bioplastics from tapioca starch and sugarcane bagasse fiber: Effect of time duration of ultrasonication (Bath-Type). Mater. Today Proc. 2021, 46, 1626–1630.

41. Baltazar-Y-Jimenez, A.; Sain, M. Natural Fibres for Automotive Applications; Woodhead Publishing Limited: New Delhi, India, 2012.

42. Moudood, A.; Rahman, A.; Khanlou, H.M.; Hall, W.; Öchsner, A.; Francucci, G. Environmental effects on the durability and the mechanical performance of flax fiber/bio-epoxy composites. Compos. Part B Eng. 2019, 171, 284–293.

43. Fuentes, C.A.; Ting, K.W.; Dupont-Gillain, C.; Steensma, M.; Talma, A.G.; Zuijderduin, R.; Van Vuure, A.W. Effect of humidity during manufacturing on the interfacial strength of non-pre-dried flax fibre/unsaturated polyester composites. Compos. Part A Appl. Sci. Manuf. 2016, 84, 209–215.

44. Okubo, K.; Fujii, T.; Yamamoto, Y. Development of bamboo-based polymer composites and their mechanical properties. Compos. Part A Appl. Sci. Manuf. 2004, 35, 377–383.

45. George, M.; Mussone, P.G.; Bressler, D.C. Surface and thermal characterization of natural fibres treated with enzymes. Ind. Crop. Prod. 2014, 53, 365–373.

46. Poyyamozhi, V.S.; Kadirvel, R. The value of banana stalk as a feed for goats. Anim. Feed Sci. Technol. 1986, 15, 95–100.

47. George, M.; Mussone, P.G.; Alemaskin, K.; Chae, M.; Wolodko, J.; Bressler, D.C. Enzymatically treated natural fibres as reinforcing agents for biocomposite material: Mechanical, thermal, and moisture absorption characterization. J. Mater. Sci. 2016, 51, 2677–2686.

48. Mohammed, L.; Ansari, M.N.M.; Pua, G.; Jawaid, M.; Islam, M.S. A Review on natural fiber reinforced polymer composite and its applications. Int. J. Polym. Sci. 2015, 2015, 243947.

49. Rohit, K.; Dixit, S. A Review—Future aspect of natural fiber reinforced composite. Polym. Renew. Resour. 2016, 7, 43–59.

50. Mahesha, G.T.; Satish, S.B.; Vijaya, K.M.; Bhat, K.S. Preparation of unidirectional Grewia serrulata fiber-reinforced polyester composites and evaluation of tensile and flexural properties. J. Nat. Fibers 2016, 13, 547–554.

51. Safri, S.N.A.; Sultan, M.T.H.; Jawaid, M.; Jayakrishna, K. Impact behaviour of hybrid composites for structural applications: A review. Compos. Part B Eng. 2018, 133, 112–121.

52. Yang, X.; Wang, K.; Tian, G.; Liu, X.E.; Yang, S. Evaluation of chemical treatments to tensile properties of cellulosic bamboo fibers. Eur. J. Wood Wood Prod. 2018, 76, 1303–1310.

53. Shih, Y.-F. Mechanical and thermal properties of waste water bamboo husk fiber reinforced epoxy composites. Mater. Sci. Eng. A 2007, 445, 289–295.

54. Kemenperin. Kemenperin: Kemenperin Akselerasi Penggunaan Serat Alam Jadi Bahan Baku Industri. Available online: https://kemenperin.go.id/artikel/22183/ (accessed on 4 November 2021).

55. Sukardan, D.M.; Natawijaya, D.; Prettyanti, P.; Cahyadi; Novarini, E. Characterization of the fiber from biduri (Calotropis gigantea) and the identification of it's utilization possibility as a textile fiber. Arena Tekst. 2016, 31, 51–62.

56. Sana, A.W.; Noerati, N.; Sugiyana, D.; Sukardan, D.M. The application of biduri natural fiber (Calotropis gigantea) as an insulative filler material in winter jacket. Arena Tekst. 2020, 35, 1–12.

57. Shanmugam, V.; Mensah, R.A.; Försth, M.; Sas, G.; Restás, Á.; Addy, C.; Xu, Q.; Jiang, L.; Neisiany, R.E.; Singha, S.; et al. Circular economy in biocomposite development: State-of-the-art, challenges and emerging trends. Compos. Part C Open Access 2021, 5, 100138.

58. Martina, R.A.; Oskam, I.F. Practical guidelines for designing recycling, collaborative, and scalable business models: A case study of reusing textile fibers into biocomposite products. J. Clean. Prod. 2021, 318, 128542.

59. Khayyam, H.; Naebe, M.; Milani, A.S.; Fakhrhoseini, S.M.; Date, A.; Shabani, B.; Atkiss, S.; Ramakrishna, S.; Fox, B.; Jazar, R.N. Improving energy efficiency of carbon fiber manufacturing through waste heat recovery: A circular economy approach with machine learning. Energy 2021, 225, 120113.

60. Velasco-Muñoz, J.F.; Mendoza, J.M.F.; Aznar-Sánchez, J.A.; Gallego-Schmid, A. Circular economy implementation in the agricultural sector: Definition, strategies and indicators. Resour. Conserv. Recycl. 2021, 170, 105618.

61. Awasthi, M.K.; Sarsaiya, S.; Patel, A.; Juneja, A.; Singh, R.P.; Yan, B.; Awasthi, S.K.; Jain, A.; Liu, T.; Duan, Y.; et al. Refining biomass residues for sustainable energy and bio-products: An assessment of technology, its importance, and strategic applications in circular bio-economy. Renew. Sustain. Energy Rev. 2020, 127, 109876.

62. Ruamsook, K.; Thomchick, E. Market opportunity for lignocellulosic biomass. NewBio 2014, 1–108. Available online: https://farm-energy.extension.org/wp-content/uploads/2019/04/Biomass-Market-Opportunity_Final-2014_0.pdf (accessed on 4 November 2021).

63. Pratiwi, R.; Rahayu, D.; Barliana, M.I. Pemanfaatan selulosa dari limbah jerami padi (Oryza sativa) sebagai bahan bioplastik. Indones. J. Pharm. Sci. Technol. 2016, 3, 83–91.

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