Chapter 14
Applications of Biodegradable Green Composites

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1 Introduction

Increased uncontrolled environmental pollution in recent years has increased concerns all over the world. The fact that the oil reserves are limited and the recycling of petroleum-based polymers is difficult has led to the need to turn to the production of new polymers that can replace these materials. Green polymers and green composites have been used in many areas to produce solutions to rapidly increasing environmental problems. Materials called biodegradable green composites consisting of matrices and reinforcers made entirely from natural resources, besides being lightweight, can be used for mechanical, thermal, etc. They can also fulfill the features [1].

Biocomposites can supplement and replace petroleum-based composite materials in many applications. This can offer powerful advantages. Since biocomposites are derived from renewable resources, material costs can be reduced significantly with their large-scale use. Also, the green composites being biocompatible and biodegradable have widespread their use in biomedical applications such as tissue engineering. Enzymatic or hydrolytically degradable implants used in the regeneration and repair of damaged tissues are becoming more and more preferable in the medical sector today [2]. Besides being used frequently in the medical sector, green polymers and composites are also preferred in short-lived disposable product applications such as

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S. Thomas and P. Balakrishnan (eds.), *Green Composites*,
Materials Horizons: From Nature to Nanomaterials,
https://doi.org/10.1007/978-981-15-9643-8_14

packaging, bottles, beverage cans, and textile products [1]. The fact that the automotive sector, other than the medical and packaging sector, has regulations regarding sustainability, encourages this sector to use renewable materials as well. The introduction of green composites in the automotive industry took place in 1940 when Henry Ford produced the first green automotive part with soybean extract. However, cheaper production of petroleum-based polymers at that time reduced interest in biopolymer-based materials, but later the need to reduce vehicle weight and use sustainable materials began to increase interest in green materials [3]. The samples of green composite applications in the literature were bio-based roof [4], hemp reinforced sunglasses, PLA-based golf ball holder, PLA/kenaf composite prototype car roof, door panel (Kestrel Hemp Car). Biomobile vehicle is given. Besides, some natural polymers and their composites, especially cellulose, chitosan, starch, alginate, etc., are biodegradable and sustainable and are easily used in adsorption [5, [6]], electronic devices [7], and construction [8] area because of their attractive properties such as environmentally friendly, disposal, or composting.

As the application of green composites in different industries increases, it is known that the interest in using these multifunctional materials as an alternative to conventional materials will increase. Therefore, the purpose of this book chapter is to provide guidelines for the selection and application of some important composite materials. To provide a better overview of the progress in this area, it is to classify composites according to their applications. This specific chapter aims in providing detailed information about various applications of green biodegradable composites in biomedical applications, food packaging, adsorption, electronics, construction, and some other areas.

2 Applications of Green Composites

2.1 Biomedical Applications

It is known that biopolymers are already widely used in medical applications [9]; however, the inclusion of new green composite materials, which offer unmatched performance and functionality, has recently taken place [10]. The new developments to be achieved are exciting in terms of offering life-changing medical treatments, for example, soy-derived polymers as bone fillers; bacterial nanocellulose has also been reported to be beneficial for artificial blood vessels. Besides, nanofiller can be applied to clinical medicine as biodegradable composite materials. Biodegradable nanocomposites are very useful in tissue engineering for regeneration of primary tissue structures [11–13] Various applications of different polymer composite biomaterials [14] are given in Fig. 1. Since biomedical applications are broadly given in the other part of the book, they will not be mentioned further.

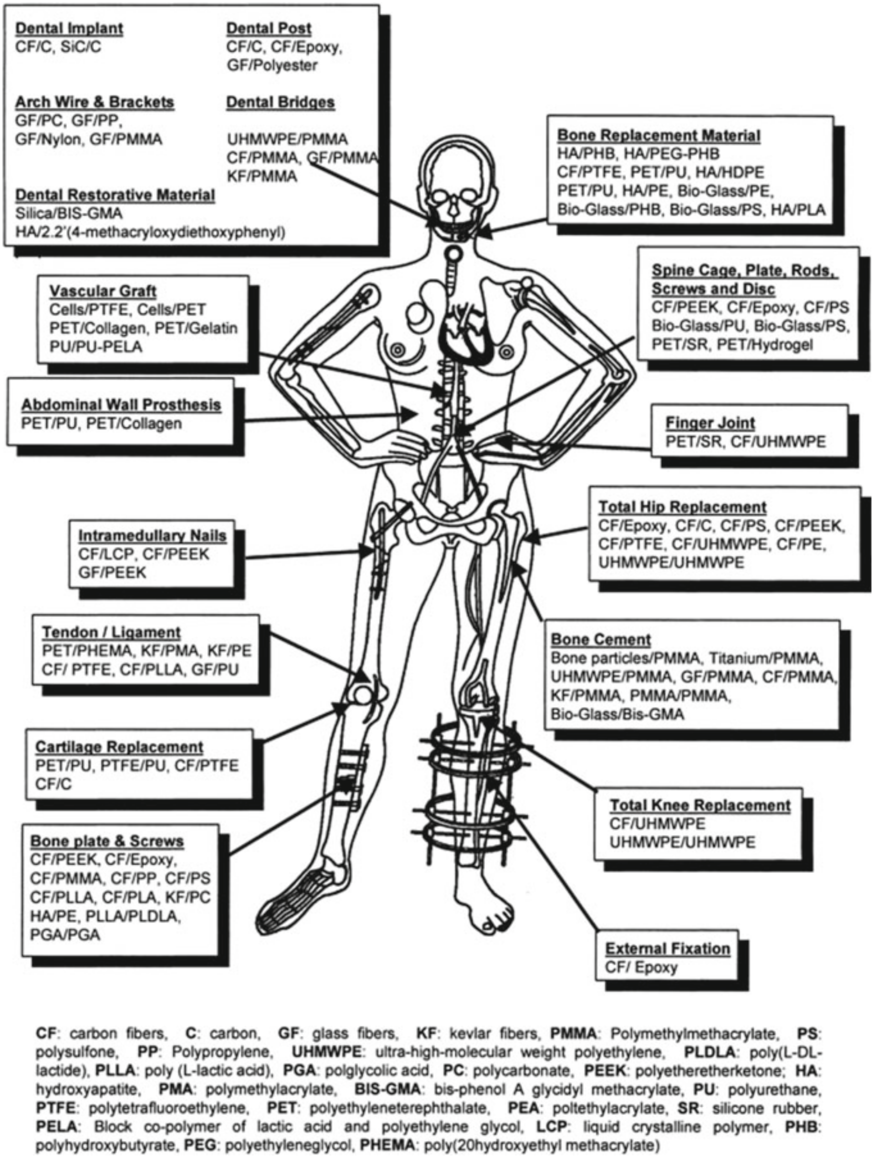

Fig. 1 Various applications of different polymer composite biomaterials [14]

2.2 *Food Packaging*

Basically, a food package should delay moisture gain or loss due to its mechanical, optical, and thermal properties, prevent microbial contamination, and provide barrier properties against the penetration of compounds such as water vapor, oxygen, carbon

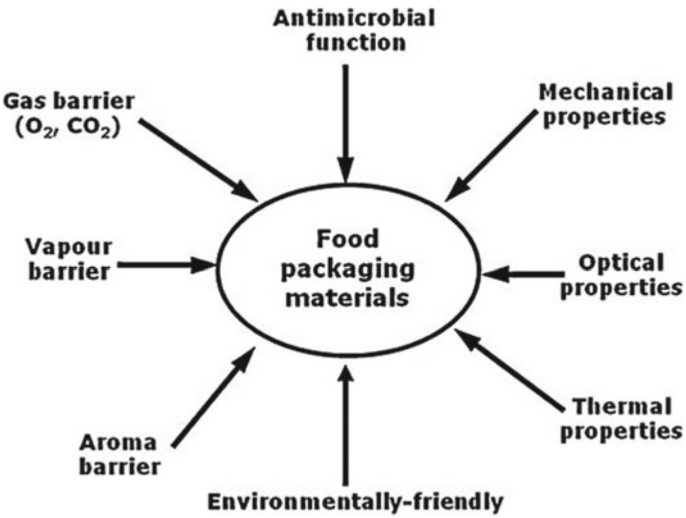

Fig. 2 Required properties of food packaging materials (Rhim et al. 2013)

dioxide, aroma, and paint [15]. The properties of food packaging materials are given in Fig. 2 (Rhim et al. 2013).

Today, consumer demands are directed toward less processed, food-free, and healthy food products. Packaging used for food is an important factor affecting food quality and preserving its shelf life. There has been an increasing consumer demand for better quality, fresh-like, and convenient products; therefore, food packaging becomes important more than ever to provide safe products and minimize food losses. Most of the food packaging materials are based on nondegradable synthetic polymers, thus representing a serious global environmental problem. Besides, the dependency on fossil resources brings the sustainability problem for raw materials of food packaging production. Biopolymer-based packaging materials represent an alternative to plastic films, and they are originated from naturally renewable resources as polysaccharides, proteins, and lipids; from chemical synthesis of bio-derived monomers, such as polylactate; and from polymers naturally produced by microorganisms, such as polyhydroxybutyrate and polyhydroxyvalerate [16]. Table 1. summarizes the advantages of natural biopolymer films over traditional synthetic films (Source: Rhim and Ng [17]).

The well-known application of biodegradable polymers in food packaging is as edible films that are used for individual coating of small food products or placed within the food. Biopolymer films can also improve the quality of food products and act as an efficient carrier agent for incorporating various additives including antimicrobials, antioxidants, coloring agents, and other nutrients [16]. The economic production of bio-based food packaging materials requires using raw material abundant in nature.

Table 1 Advantages and application areas of natural biopolymer-based packaging materials

• They are biodegradable
• They can be used as edible coatings
• They can increase the nutritional value of foods enhance its characteristics like appearance, odor, and flavor
• They can be used as active packaging with the incorporation of antimicrobial agents and antioxidants
• They can control the transfer of moisture, gases, lipids, and solutes
• They can be used for microencapsulation and controlled release of antimicrobial agents, antioxidants, and active ingredients
• They may be component of a multilayer food packaging materials with non-edible films
• They have low cost
• They are abundant and annually renewable resources
• They are suitable for individual packaging of particulate food such as nuts
• Using them lead to reduced packaging volume, weight, and waste
• They can extend shelf life and improve the quality of usually non-packaged items

Source: Rhim and Ng [17]

Being a natural polysaccharide, chitosan can be used in many fields such as pharmaceutical, agriculture, food, cosmetics, textile and water treatment, directly or indirectly, as well as its biodegradability and biocompatibility properties [18–20]. Also, good film-forming and mechanical properties make chitosan an important edible film component and can create transparent films that can meet a variety of packaging needs [21].

Jridi et al. (2014) investigated the physicochemical and mechanical properties of chitosan (obtained from shrimps), cuttlefish gelatin, and composite films in their work. The results showed that the chitosan film had higher tensile strength and lower tensile elongation compared to other films. In their study, Boran et al concluded that the films they obtain by producing laboratory-scale chitosan and pectin-based films from industrial wastes provide practical applications in food products as coating or packaging materials and may reveal many desired features in the future. [22] have prepared chitosan and gelatin-based biodegradable films that can be used as packaging materials. In a study conducted by Sun et al. [23], it was aimed to characterize physical, mechanical, and bioactive chitosan films combined with thinned immature apple phenols. In this study, they concluded that chitosan films combined with immature apple phenols can be an alternative to synthetic materials and can contribute to the extending shelf life of foodstuffs [23].

In addition to composite materials consisting of biopolymers such as chitosan, nanotechnology is seen from studies that have been able to provide a new lightweight material with stronger packaging barriers that protect food quality during transportation, prolong the freshness of fruits and vegetables during storage, and protect meats or poultry from pathogens. Today, it is known that these nanomaterials have been used in a variety of food contact packaging and containers as a new alternative additive to improve the polymeric properties of packaging materials [24].

Recently, nanoparticles have been used as additives to improve polymer performance. Nanoclays (layered silicates) [25], cellulose nanowhiskers [26], ultra-fine layered titanate [27], and carbon nanotubes can be counted as various nanoreenforms currently being developed [28]. However, among them, it is stated that only layered inorganic silicates such as clay have attracted great interest by the packaging industry [29]. Nanotechnological advances can enable more environmentally friendly economic degradable materials in this regard.

2.3 Adsorption Applications

Uncontrolled discharge of industrial waste and sewage waters leads to increased amounts of undesirable inorganic and organic pollutants in water resources. Due to their very high toxicity, these contaminants that cause many symptoms such as nephritis, acute diarrhea, gastrointestinal ulceration, skin irritation, severe headaches, and cancer in the digestive system become a serious problem. Different efforts have been promoted to develop various physical and chemical methods to eliminate this problem. Because of its low-cost, high efficiency, and activity for removing a large number of organic pollutants, dyes and heavy metals from wastewater, adsorption is one of the most favorable appreciable methods compared to various conventional methods used such as ion exchange, precipitation, reverse osmosis, solvent extraction, coagulation, and filtration [18, 30, 31].

For an ideal adsorbent to be preferred for removing water contaminants, it should have the advantages of high adsorption capacity, efficiency, low cost, environmental safety, and easy regeneration [6]. Therefore, due to their biocompatibility and biodegradability, a great deal of research is supported for natural biomaterials and their composites. In particular, those that are nontoxic, biodegradable biocompatible, and natural biopolymers that are abundant in natüre are preferred as biosorbents for the treatment of various wastewater systems including industrial wastewater.

Among the possible adsorbents to be used, biodegradable green materials such as cellulose, chitosan, alginate, starch, and agricultural wastes are suitable adsorbents media shown in Fig. 3. When their economic and environmental importance is made remarkable, biodegradable green materials have been extensively preferred as green efficient adsorbents for wastewater treatment fields regarding the economic feasibility and environmental importance of them. It is of great importance in their preference that they have superior properties such as easy modification, high biodegradability, low cost, non-toxicity, biocompatibility, and environmental friendliness. However,

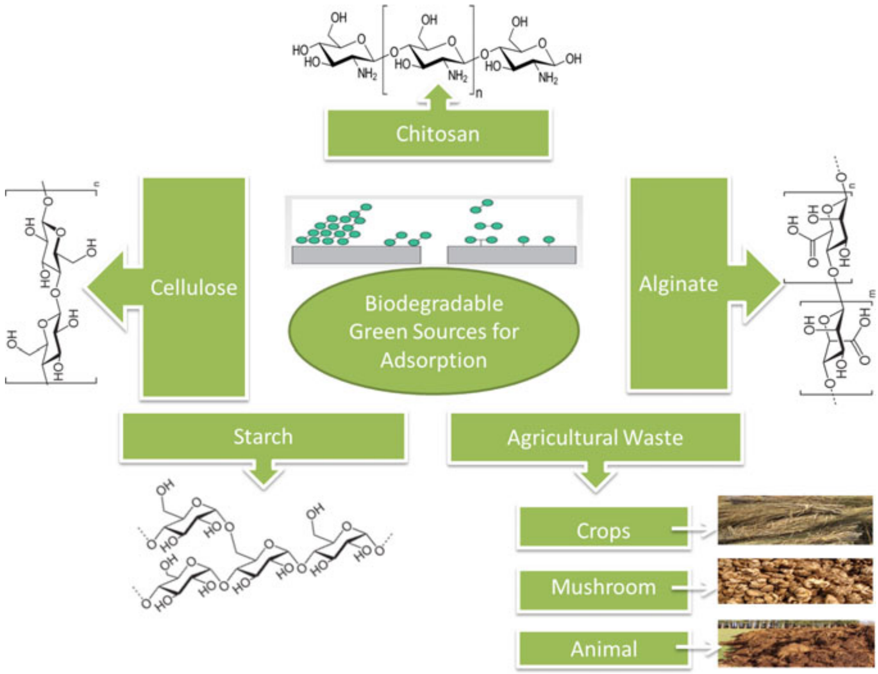

Fig. 3 Biodegradable green sources for adsorption mechanism

their application is limited due to their low surface area, dissolution, and low mechanical strength. Due to overcome of the above-mentioned disadvantages, their transformations into composites have become much more attractive by providing physical and chemical modification processes to increase the adsorption capacities of these structures and provide better conditions for their weak mechanical properties [32, 33].

Many partially/completely green biodegradable composites have been used to enhance the adsorption capacity of adsorbents to remove pollutants from wastewater. Composite materials can generally enhance adsorption capacities compared to the capacity of elements of composite alone. Table 2 shows the summary of possible green and biodegradable composites and their adsorption capacities for the treatment of wastewater pollutants.

Cellulose is the most common organic compound and biopolymer in the world. Approximately, 33% of plants, 90% of cotton, and 50% of wood are composed of cellulose. Biodegradable cellulose has a wide range of uses due to its natural availability on Earth. Cellulose can be obtained from cotton, trees, straw plant sources, and also some bacteria sources [36, 55]. Natural cellulose has a high surface area and tensile strength, transparency, biocompatibility, biodegradability, and impressive mechanical properties. These properties make natural cellulose a very important choice in composite formation as backing for green composites. Cellulose ingredients

Table 2 Biodegradable green composites for removal of wastewater pollutants

Composite	Type of removed material	Biosorption capacity (mg/g)	References
Cellulose extracted (rhizomes of Alpinia nigra)/organophillic montmorillonite composite	Eosin Y dye	199.9	[34]
Cellulose/gelatin composite hydrogel	Cu(II)	28.4	[35]
Bacterial cellulose/gram-negative species of bacteria composite	Pb(II)	52.00	[36]
Cellulose/montmorillonite hydrogels	MB	277 mg/g	[37]
Magnetic nanocomposites of cellulose	Pb (II)	21.5	[38]
Chitosan-based composite hydrogels	RB MB	21.74 9.66	[39]
Chitosan-blended/polyvinyl alcohol composite	Pb(II)	76.60	[40]
Chitosan/polyacrylic acid/bentonite composites	Malachite green	454.55	[18]
Xanthate-modified chitosan/poly(N-isopropylacrylamide) composite hydrogel	Cu(II) Pb(II) Ni(II)	115.1 172.0 66.9	[41]
Poly(1-vinylimidazole)-modified-chitosan composite	Cr (VI)	196.1	[42]
Chitosan–montmorillonite nanocomposite	Fe(III)	78.13	[43]
Polyurethane/chitosan bio-based composite	Food Red 17	267.24	
Magnetic glutamic acid/chitosan and silica-coated composite	MB CV CLY 7GL	180.01 375.4 217.3	
Nanochitin-contained chitosan nanocomposite hydrogels	Cu(II)	64.9	
Chitosan/polyaniline composite	Tartrazine	584.0	[44]
Magnetic alginate/rice husk beads biocomposite	MB	274.9	[45]
Calcium alginate/clay hybrid composites	Organic acid anions	3.6	[46]
Organic montmorillonite-sodium alginate composites	PAH	1.2	[47]
N-doped carbon dots/alginate composite	Gd (III)	201.21	[48]
Alginate/natural bentonite composite	MB CR	1171 95.55	[49]
A silica sand/anionized-starch composite	MB CV Cu(II)	653.31 1246.40 383.08	[50]

(continued)

Table 2 (continued)

Composite	Type of removed material	Biosorption capacity (mg/g)	References
Corncob biochar-based montmorillonite composite	Pb(II) At	139.78 86.86	[51]
White-rot edible fungi Pleurotus ostreatus-based-chitosan nanocomposite	RO16	65.5	[52]
Argania spinosa tree nutshells bio sourced composite	Diclofenac carbamazepine sulfamethoxazole	153.8 105.3 125.0	[53]
Encapsulated cellulose-based modified citrus peels/calcium alginate composite	MB CV	881.36 923.07	[54]

can be widely used in packaging industries, cigarette filters, textile fibers, coatings, membrane filtration, lamination, nano-macro composites, various medical and pharmaceutical products [56–58]. Besides, its large surface area and multiple functional groups make cellulose attractive in adsorption applications. The functional groups on the cellulose structure have structural auxiliaries such as reactive surfaces and the ability to change surface chemistry, which empowers it as a promising additive for various composites for biosorbents. Nowadays, biodegradable natural cellulose-based composites are getting increasing attention as nontoxic sorbents toward the removal of the wastewater contaminants.

Goswami and Das investigated the biosorption performance of cellulose extracted from rhizomes of *Alpinia nigra*/organophilic montmorillonite composite onto the Eosin Y toxic dye [34]. Biodegradable cellulose/gelatin composite hydrogel has been synthesized as biosorbent for copper (II) (Cu(II)) ions biosorption with 79.5% biodegradability rate [35]. Also, cellulose/montmorillonite hydrogels have been prepared for adsorption of methylene blue (MB) dye [37]. In another study, biodegradable bi-functional cellulose derivatives and cellulose/clay composites have been used to remove calcium (Ca(II)), magnesium (Mg(II)), iron (Fe(II)), lead (Pb(II)), and Cu(II) metal ions from widespread underground water. The removal result order was as Pb(II) > Mg(II) > Fe(II) > Cu(II) > Ca(II) [59]. Also, bacterial cellulose/gram-negative species of bacteria composite has been prepared and investigated for biosorption of Pb(II) metal ion [36].

Another substance used as a biosorbent is chitosan.. It is the second-most abundant biological material in nature, which is biologically and chemically compatible with low cost. This is because the macroporous chitosan has extreme biological properties such as biocompatibility, biodegradability, anti-antigenic, nontoxic, excellent film-forming ability, bio-adsorptive, as well as super absorbency. All these important features make chitosan a very interesting ingredient that can be used in environmental and biological fields [60, 61]. Chitosan is an ecologically interesting and promising natural polysaccharide for removing many pollutants from the aqueous wastewater system through the presence of a large number of hydroxyl and primary amine groups. There are many studies in the literature where chitosan-based composites are prepared and used as a biosorbent, which shows a very good adsorption capacity in the purification of pollutants that cause water pollution. For example, rhodamine B (RB) and MB dye adsorption were examined by chitosan (CS) / by graphene oxide, carbon nanotubes, and layered double hydrotalcite composites [39]. In another study, chitosan-blended polyvinyl alcohol composite was prepared for adsorption of Pb(II) metal ions, and adsorption capacity was found as 76.60 mg/g [40]. Xanthate-modified chitosan/poly(N-isopropylacrylamide) composite hydrogel was used for the adsorption of Cu(II), Pb(II), and Ni(II) metal ions [41]. Poly(1-vinylimidazole)-modified-chitosan composite was performed for adsorption of chromium (VI) (Cr (IV)) ions as adsorption capacity 196.1 mg/g [42]. Chitosan–montmorillonite nanocomposite for ferric (III) (Fe(III)) ions adsorption was investigated [43]. A full biodegradable magnetic adsorbent based on glutamic acid-modified chitosan and silica-coated Fe_3O_4 composite was prepared and used for adsorption of MB, crystal violet (CV), and cationic light yellow 7GL (CLY 7GL).

Another conspicuous substantial nature biosorbent is alginate that could be extracted from brown seaweed as a natural and renewable polysaccharide polymer material, owning affluently hydroxyl and carboxyl functional groups. Due to its superior properties such as affinity, hydrophilicity, easy separation, non-toxicity, biocompatibility, and strong alginate, it has a wide range of applications such as tissue repair, drug release, wastewater treatment, and adsorption [59, 62]. By combining all these extraordinary properties with some other substances, green biosorbents with extraordinary selective detection and adsorption have been obtained in the application of adsorption.

Many studies have been done with this biosorbent in the past. To illustrate, magnetic alginate/rice husk beads, an eco-friendly and low-cost biocomposite, are used for MB removal with adsorption capacity as 274.9 mg/g [45]. In another study, organic montmorillonite-sodium alginate composites were prepared and the removal performance of polycyclic aromatic hydrocarbons (PAH) from aqueous medium was investigated [47]. Alginate/natural bentonite composite beads were prepared for adsorption of MB and congo red (CR) dyes [49]. N-doped carbon dots/alginate composite were greenly generated for adsorption of gadolinium (III) (Gd (III) [48].

Starch, the major dietary source of carbohydrates and can be extracted from corn, rice, potato, wheat, cassava, tapioca, and other crops, is abundantly available, highly biodegradable, renewable, and cheap. At high temperatures and pressures, starch loses its crystallinity and becomes thermoplastic, but the films cast from this material are brittle, which limits their applications [63, 64]. Therefore, it has been becoming important to improve its thermal and mechanic properties to make its use areas more extensive by transforming to composite structure. In a conducted research, a silica sand/anionized-starch composite was synthesized and used for adsorption of MB, crystal violet (CV), and Cu(II) metal ions from water. Adsorption capacities were found 653.31, 1246.40, and 383.08 mg/g, for MB, CV, and Cu(II), respectively [50].

Biodegredable agricultural waste-based composites have attracted excellent attention for adsorption process. It provides a convenient way to collect agricultural wastes such as tree nutshell, mushroom, citrus peels, and corncob that are extraordinarily advantageous and biodegradable, and to use them for a greener environment, thus increasing the ability of agricultural wastes to adsorb pollutants in wastewater. Biological waste-based composites are usually impregnated with other biologic materials that can improve the adsorption capacity by increasing their specific surface area, porosity, mechanical and thermal cavity to provide appropriate modifications. In a related study, corncob biochar-based montmorillonite composite was synthesized for the adsorption of Pb(II) and a pharmaceutical emerging organic contaminant Atenolol (AT) [51]. White-rot edible fungi *Pleurotus ostreatus*-based-chitosan nanocomposite was synthesized for investigation of reactive orange 16 (RO16) dye [52]. In another approach presented by Mauchtari et al. [53], high-surface-area-activated carbon was prepared with *Argania spinosa* tree nutshells bio-sourced composite as activated carbon/TiO2 was used for removing pharmaceuticals, diclofenac (DCF), carbamazepine (CBZ), and sulfamethoxazole (SMX) from aqueous solution. Encapsulated cellulose-based modified citrus peels/calcium alginate composite was prepared and used as effective adsobent for MB and CV dyes. The good adsorption capacities were found as 881.36 and 923.07 mg/g for CV and MB, respectively [54].

2.4 Electronics

Electronics that have become an indispensable part of daily life will grow even more in the future and are expected to cover almost every aspect of our life in the future. In this section, we present a versatile and general understanding of electronic applications of different biodegradable green composite materials. Electronics have many applications such as communications, optics, imaging, sensing, energy storage, energy collection, artificial muscles, neuroscience, and bioengineering [65] (Fig. 4) (Yıldırım and Acay). With the rapid development in electronic biomaterials and related production techniques, the use of biodegradable green composite materials in electronic materials is becoming very important. In recent years, great efforts have been made to investigate the synthesis and properties of environmentally friendly biodegradable composites. By combining with some other biological materials, creating composites, the mechanical properties of these green biomaterials can be improved on a large scale, which is promising in the development of electronic devices [66].

Applications of electronic devices such as computers, mobile phones, and medical devices are becoming more and more widespread in our lives with the rapid development of science and technology and provide us with great convenience. Electronics, which are widely used in many fields such as telecommunications, entertainment, and health services, leave a deep impact on people. In particular, the choice of green biodegradable electronics is important to eliminate environmental problems such as electronic waste storage [7]. Preliminary results of synthesized bio-based

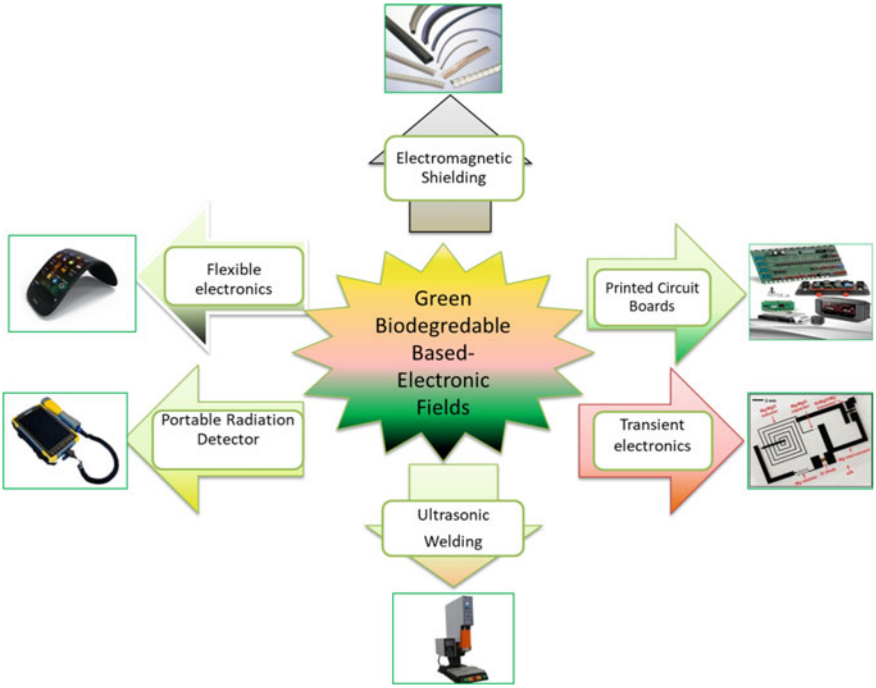

Fig. 4 Green biodegradable-based electronic fields (Yıldırım and Acay)

biodegradable composites have been studied for new and different electronic application fields such as ultrasonic welding, electromagnetic interference shielding, flexibility, transient bioelectronics, and printed circuit boards, as a promising technology for environmental improvement.

Recently, ultrasonic welding used as a suitable fusion bonding technique to combine various engineering components in the electrical and electronics industry has attracted attention. In this technique, which is mostly used for thermoplastic bonding, high-frequency ultrasonic vibrations are provided and shredding is produced by generating heat at the joint interface. Moreover, the advantages of this method are that they do not require additional parts and materials, they are very cheap and environmentally friendly in terms of cost, and they also save time. In a previous study on this field, [47, 67] in their study investigated the ultrasonic welding behavior of the poly(lactic) acid (PLA)/bamboo fully degradable green composite by examining the effect of the welded sample on the tensile failure load with welding parameters (holding time, welding time, and holding pressure) by application of high-frequency (20 kHz) ultrasonic vibration.

With the developing technology, portable and wearable electronics are very popular due to the rapid growth of the internet and digitalization and the development of innovative functional materials in parallel. Besides, the increase in telecommunication systems causes electromagnetic interference difficulties and consequently, data pollution, device reliability, and health negatively affect. In order to prevent such problems, using environmentally friendly solutions that can only benefit humanity by using sustainable and biodegradable all-green composites, also versatile, affordable, and high-performance shielding solutions of electromagnetic interference (EMI) have become inevitable. Emitting electromagnetic fields at various frequencies by electrical devices cause low performance/serious damage to this equipment. Electromagnetic shielding developed for the reflection and/or absorption of electromagnetic radiation by a material is needed against the protection of electrical devices from EMI. In addition, the composites that are especially important for wearable devices offer reasonably low mass densities, often with good stretchability and flexibility. Tolvanen et al. [68], have examined EMI shielding capacity with green composites using biochar obtained from pine nuts, graphite as filler, and poly (lactic acid) as host and highlight that these green composites show rather high efficiency for shielding (shielding effectiveness >32 dB). As a result, they emphasize that the materials developed are suitable for use in wearable and portable radiation-sensitive electronic device applications. In another similar study, biodegradable poly(lactic acid) cheap conductive carbonaceous fillers were developed [69]. In addition, the study has been concluded that the prepared composite shows good mechanical strength and low-density functional properties and thus can be sufficiently used in packaging applications and against electromagnetic interference.

Research has been conducted into the use of biodegradable natural polysaccharide sodium alginate immersed into the $CaCl_2$ crosslinker for producing the alginate fiber [70]. The impedance experiments were performed for conductivity change. Since these and similar materials prepared are biodegradable and do not require conductive cables, they can create versatile applications for environmentally friendly and low-cost flexible electronics.

Liu et al. researched the synthesis of poly(vinyl alcohol)/chitosan composites by evaluation of dynamic mechanical analysis, tensile testing, and thermogravimetric analysis and concluded that obtained composite can be an alternative application in sustainable and transient bioelectronics [71].

Production of printed circuit boards (PCB) is increasing in parallel with the increasing demand for electronic devices. In this application, the approach of using environmentally friendly biodegradable materials is in great demand. Zhan and Wool prepared the bio-based composites from soybean oil resins, chicken feathers, and E-glass fibers for using the printed circuit boards in PCB. They investigated the electrical, thermal, and mechanical properties, also flammability, and peel strength of biocomposites and found that these bio-based materials showed comparable values with traditional materials [72]. In addition, 35, used bio-based composites (natural protein and natural cellulose fiber) from agricultural wastes, natural cellulose fibers extracted from banana stems and wheat gluten, in order to provide the materials for completely biodegradable printed circuit boards and other electronic applications. In the study, it was emphasized that biocomposites did not experience any loss in their performance even after exposure to 90% humidity for 48 h and 100 °C for 8 h [73].

2.5 Construction Applications

When designing construction materials, it is very important to consider issues such as safety, health, and the environment while using the products. Because of this, the development and use of biodegradable green polymers and their composites are considered as one of the substantial ways for reducing the environmental challenge from the use of non-biodegradable petroleum-based polymers in the construction industry.

Recently, various biopolymers as starch, cellulose, lignosulphonate, some water-soluble polysaccharides, and agricultural residues are used in a wide range of applications of construction materials including grouts, concrete, mortars, plasters, and plasterboards, paints, and oil well fluids of drilling. Also, natural fiber-reinforced composites have been gaining a lot of popularity in non-structural construction applications using door and window frames for wall insulation and floor lamination [74]. In addition, biodegradable fiber like bamboo and coconut are studied for both indoor and outdoor applications. Several studies have been carried out over recent years to obtain eco-friendly, biodegradable, low-cost, and lightweight natural polymer composites in this sector.

The use of agricultural residues and by-products for construction directly promotes sustainability and green buildings. Green buildings that use bio-based materials and technologies to reduce the harmful effects of the production, use, and disposal of cement and concrete on the environment are becoming important all over the world. Sugarcane bagasse, abundant and easily available agricultural residues, has been valorized by developing completely biodegradable composites combined with wheat gluten for construction applications [75]. In their study [75], pointed out the conclusion that bagasse-gluten composites have the potential to be an ideal alternative for gypsum-based ceiling coverings. In addition, fiber cement composites containing natural cellulosic fibers are important materials that appear in the building industry. Everaert et al. [76] have investigated the biodegradability of the cellulosic fiber cement composites; thus, the effect of the composite's particle size and material aging has been evaluated. The study carried out by Živkovic et al. [77], highlighted the two types of natural fibers, flax and basalt, and their hybridization composite (flax fiber reinforcement in the central zone, basalt fiber reinforcement in the outer layers) has been used for the construction of boats and yachts. Another study fiber-based composite was examined by Chandekar et al. [78]. They have performed chemical treatment by improving jute fibers, fiber–matrix interface adhesion, and reviewed composites obtained with different polymeric matrices that provide a basic direction for future construction material research of these jute-reinforced composites.

2.6 Other Applications

It is expected that technical innovations for green composites will continue, permanent political and environmental pressures will increase with the definition of new applications and investment in new methods for collecting fibers and processing biological fibers [79].

Toys are one of the potential application areas for green composites. Examples of biodegradable green composite toys (except wooden toys) are limited. However, studies on toys made from recycled plastic with cellulose reinforcement are exciting. This results in both consumer and commercial interest in the use of materials with environmental credentials in toy applications.

It is seen that Boat Hulls and Canoes offer great opportunities for biocomposite applications in the marine sector. The excellent sound behavior of plant fibers makes them a promising material for musical applications. The use of natural composites in snowboards/skis and surfboards is already a reality, and several examples can be found. Biocomposites also offer immense opportunities for an increasing role as alternate material, especially as wood substitutes in the furniture market [2].

The agricultural sector is another area where composite material is evaluated. In addition to PLA, which is the most used polymer in this field, it is used as a mixture of polybutylene adipate terephthalate (PBAT) and PBS polymer or as a composite component [80].

The main biopolymers used in the cosmetics industry are proteins and polysaccharides. While proteins and peptides are used in applications especially on hair and skincare, peptides are also used in topical moisturizer applications [81]. Increasing demands from different markets will tend to increase the application areas of biocomposite materials.

3 Conclusion

The use of biodegradable polymers as matrices and the use of natural fibers as reinforcements in composite materials appear to contribute to the development of green composites in terms of performance and sustainability. Green composites provided important commercial markets especially for value-added products in the packaging industry. Applications in the automotive, construction, and electronics industry, usage for furniture, luggage, grinding disks, and safety helmets have also been proposed by scientists and manufacturers. Also, using the adsorption technique for the removal of contaminants from the aquatic environment by using bio-based composites is a great research area. However, to cover other areas, scientists and researchers still need to speed up work on scaling up products. Therefore, launching laboratory-scale ideas is an expected effort from the scientific community. In the future, depending on further development and research of these green composites, an increase is expected in different areas of use, such as structural applications. However, it seems that several problems need to be resolved before green composites become fully competitive with synthetic fiber composites. In recent years, great progress has been the establishment of nanocomposites (i.e., the use of nanocellulose as fibers made from crystals or natural fibers). These nanomaterials are thought to compete with components made from conventional materials. Nanotechnology can offer many opportunities to improve the properties of green composite products. For example, the use of cellulose nanocrystal and cellulose nanofibers has been researched for a variety of uses as it is stronger than steel and harder than aluminum. As more bio-based composites are developed and designed, used, and disposed of in the future, green composites are expected to enter daily life with enormous environmental benefits, and this will last for years.

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