Environmental and Human Health Impact of Disposable Face Masks During the COVID-19 Pandemic: Wood-Feeding Termites as a Model for Plastic Biodegradation

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Accepted: 21 October 2022/Published online: 12 November 2022
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Abstract

The ongoing COVID-19 pandemic has resulted in an unprecedented form of plastic pollution: personal protective equipment (PPE). On the eve of the COVID-19 pandemic, there is a tremendous increase in the production of plastic-based PPE. To control the spread of the virus, face masks (FMs) are used as primary PPE. Thus, the production and usage of FM significantly increased as the COVID-19 pandemic was still escalating. The primary raw materials for the manufacturing of FMs are non-biodegradable synthetic polymers derived from petrochemicals. This calls for an urgent need to develop novel strategies for the efficient degradation of plastics. Furthermore, most of these masks contain plastic or other derivatives of plastic. The extensive usage of FM generates millions of tons of plastic waste for the environment in a short span of time. However, their degradation in the environment and consequences are poorly understood. Therefore, the potential impacts of disposable FM on the environment and human health during the COVID-19 pandemic are clarified in the present study. Despite structural and recalcitrance variations, lignocellulose and plastic polymers have physicochemical features, including carbon skeletons with comparable chemical bonds as well as hydrophobic properties in amorphous and crystalline regions. In this review, we argue that there is much to be learned from termites by transferring knowledge from research on lignocellulose degradation by termites to that on plastic waste.

Keywords COVID-19 · Wood-feeding termite · Plastic waste · Disposable face masks · Lignocellulose · Biodegradation
Introduction

One of the distinguishing qualities of human development has been the ability to adapt to new resources and habitats. As a result, considerable changes have occurred in the atmosphere, oceans, land surface, and climate [1–3]. Human activities have changed the composition of 30–50% of the biosphere [4], causing a reorganization of life on earth. The fact that man-made masses currently outnumber all living biomass is one of the Anthropocene’s defining traits. Plastics, polycyclic aromatic hydrocarbons (PAHs), insecticides, and pharmaceutically active medications are examples of “xenobiotic” compounds [5–8]. Plastics and other synthetic polymers, for example, have evolved to the point where they are now an essential component of modern life. Every piece of plastic ever manufactured is still on the planet in some form, and it has posed a persistent threat to the natural world since its introduction [9–11]. The onset of the COVID-19 outbreak has made the problems that were already present in relation to the handling of plastic trash even worse. On the other hand, planetary danger thresholds are being exceeded due to the accumulation of agroindustrial biowaste and xenobiotic contaminants, which is leading to a waste overload crisis across the globe [4]. Some of these recalcitrant wastes are potential sources of energy and value-added products that can be identified by utilizing the wide metabolic variety of microorganisms.

The widespread application of plastics and other synthetic polymers, in conjunction with the inherent resistance of these materials to breakdown, has created a significant environmental challenge [8]. On the other hand, there is a general rise in the number of cases of COVID-19 all over the world. Consequently, it has become abundantly clear that massive volumes of personal protection equipment (PPE) are required. Despite the fact that these PPE contain a significant amount of plastic, they appear to be the most cost-effective and reliable protection against COVID-19 virus transmission [12]. Because the COVID-19 virus spreads from person to person through the air, health care workers and other frontline workers are required to wear PPE. The public’s demand for PPE kits has increased as a result of the discovery of a greater number of asymptomatic instances, particularly one-time-use, disposable FMs, gloves, and face shields, without respect for the processes involved in their disposal after use. As a direct consequence of this, worldwide manufacturing and output have both seen significant increases [13].

FM is one of the pieces of PPE that should be utilized for the purposes of either tracking the origin of an outbreak or shielding healthy people from coming into contact with infected individuals. N95 is the PPE of choice during a COVID-19 pandemic. This is typically a three-layered structure made of PP fibers, with the outside layer having a thickness of 40 µm, the middle layer having a thickness of 8 µm, and the inner layer having a thickness of 40 µm. The designation N95 refers to a filtration capacity that is greater than 95% and can stop particles as fine as 0.1 µm. The size of the COVID-19 virus is approximately 100 nm. Coronavirus is mostly spread in the form of droplets, with a droplet size of 5–10 µm [14]. In response to the COVID-19 pandemic, many countries have imposed strict rules on the general population in an effort to limit the spread of the virus. However, these rules have been issued without taking into consideration the rise in medical waste that they would produce. The most widely practiced regulation of the “new normal” is donning an FM and visor whenever one is inside an enclosed place, such as a store or a public transportation vehicle.

FMs that do not require surgical incisions are now required to be worn publicly in a number of cities and countries all over the world as part of COVID-19’s spread limitation.
It has been brought to the attention of the general public that FMs are an essential tool for protecting human health and cutting down on the spread of COVID-19 within a population. Although the level of protection offered by various types of FMs varies, they all contribute to the accumulation of waste in landfills and are difficult to wear for extended periods of time. Coloring FMs, like coloring any other type of fabric, serves primarily the purpose of boosting the items’ visual attractiveness. In spite of the fact that they are used consistently in printing, textiles, and other applications, different dyes provide varying degrees of danger to the environment [15–22]. The vast majority of FMs that are sold commercially in order to limit the COVID-19 pandemic are made out of plastic layers, which are known to have negative impacts on both human health and the environment. In addition to the hazardous nature of plastics, the dyeing process for textiles is a major contributor to pollution that is both toxic and persistent. Figure 1 depicts the potential ecotoxicological effects of disposable FMs on terrestrial and aquatic ecosystems.

Insects that are capable of digesting plastics through the microbiota in their guts are receiving interest in the context of bioremediation, despite the fact that the benefit to the environment is debatable [23]. Termites are the major soil insect that are also capable to degrade plastics using their gut microbiota [24]. The presence of symbiotic microbiota in the guts of several insects provides the host insects with advantages that have contributed to their evolutionary success. These advantages include the ability to digest meals that are indigestible, protection against predators, and the elimination of toxins. These specific capabilities of gut symbionts have been improved by natural selection over enormous expanses of time, which is why they are intrinsically sophisticated [25]. Natural selection has occurred over the course of vast evolutionary epochs. Microbes that can break down plastic have recently come into focus as a potential solution to the widespread problem
of plastic pollution. *Ideonella sakaiensis*, which was isolated from sediment, for example, grew well on polyethylene terephthalate (PET) film and totally degraded the film in a period of 6 weeks by secreting plastic-degrading enzymes known as PETase and MHETase [26]. Recently, there has been a lot of interest in the value of termite gut microbiota as a prospective source for industrial and medical uses (Fig. 2). The diverse microbial populations found within termite guts have been shown to contribute to the degradation of plastic polymers by the mandibles of termites that feed primarily on wood [27].

Even though plastic polymers are different from lignocellulose polymers because they lack hydrolysable C–C or C-O bonds and have higher recalcitrance, there are similarities, such as both being mixtures of hydrophobic polymers with amorphous and crystalline regions and requiring hydrolases and oxidoreductases for degradation. Therefore, this review aims to address an important knowledge gap on the basic environmental and human health risks relevant to disposable FMs generated during the COVID-19 pandemic, taking lessons from lignocellulose degradation by termites and their gut symbionts.

**Impact of Disposable FM on the Environment and Human Health**

Figure 3 depicts the impact of the life cycle of disposable plastic waste on ecosystems and human health. FMs are promoted to the public as a great instrument for protecting human health and reducing disease transmission throughout the population in order to prevent the spread of COVID-19. On the market, there are now a lot of FMs, and each one has a different color and slogan on it. Coloring FMs serves primarily the purpose of boosting the items’ visual attractiveness. In spite of the fact that they are used consistently in inks, textiles, printing, and other applications, different dyes provide varying degrees of hazards to the environment. The vast majority of FMs that are sold commercially are made out of plastic layers, which are known to have negative impacts on both human health and the

![Fig. 2 The proposed potential of termite gut symbionts in various bioremediation, medical, and biofuel applications](image)
In addition to the hazardous nature of plastics, the dyeing process for textiles is a major contributor to pollution that is both toxic and persistent [8, 9]. Inhaling particles of dye may result in adverse skin reactions, sneezing, and irritated eyes. Long-term use of colored FMs can hurt the lungs, liver, and kidneys, as well as the brain and reproductive systems [28]. Volatile organic compounds (VOCs) (e.g., benzene, ethylbenzene, and xylenes, known as BTEX) and organic solvents (e.g., ethyl acetate and isopropyl alcohol) in dyes are responsible for these health problems [29]. There has been a significant amount of research published in the scientific literature regarding the impact of VOCs on human health [30, 31]. In recent years, there has been a rise in the number of studies that focus on the reduction of the VOC content that is produced by dyes and inks. This is likely attributable to the growing awareness of the need to protect the environment [32, 33]. In addition to being a VOC, BTEX is one of the most prevalent chemical compounds that can be found in landfills. BTEX is a chemical that has the potential to cause cancer in humans and has also been shown to have other negative effects on human health [34, 35]. Toluene and xylene both have the potential to cause damage to the nervous system as well as the reproductive system. Benzene and ethyl-benzene are both carcinogens that have an effect on the nervous system. The lungs, liver, and kidneys are the primary organs that are harmed by these cancer-causing substances [36].

The usage of FMs on a monthly basis across the globe is 129 billion [37]. This enormous use of PPE has resulted in an insurmountable burden being placed on conventional methods of solid waste management all over the world, which has led to an increase in the amount of pollution caused by plastic and the development of new types of litter. Both direct and indirect pathways can put people at risk of contamination associated with COVID-19 personal protective equipment (COVID-19 PPE) (Fig. 4). While FMs can protect users from airborne respiratory particles, they also pose a danger of inhaling microplastics (MPs) due to the fact that MPs can detach from the surface of the FM while it is
being used [38]. Figure 5 demonstrates that inhaled MPs may have a role in the pathogenicity of a variety of lung diseases. It is unknown whether or not the desorption of pollutants in the respiratory system is related to harmful health effects, although it is known that inhaled MPs are able to translocate to the blood [39]. In the context of COVID-19, MPs originating from FMs may collect in the nasal cavity; hence, nasal lavages would offer a direct evaluation of human exposure to this and other MP sources [40]. Lacking the complicated inorganic chemistry of asbestiform silicates, MP fibers share the fibrous structure implicated in inhibited phagocytosis and the production of lung tissue-damaging reactive
oxygen species [41]. People in a typical setting do not get these occupational disorders; however, the precautionary principle recommends that continuous inhalation of airborne fibrous MPs still poses a health risk [42]. When FM are used repeatedly and then disinfected, this can lead to structural degeneration, which speeds up the process of mask particles detaching from MPs. The toxicity of MPs to cells and other biological systems inside the human body has not been definitively determined, despite the expanding understanding of the inhalation and ingestion of MPs via FMs (Fig. 4). Once breathed in, MPs can cause persistent inflammation, DNA damage, granulomas or fibrosis, cell damage, cytokine production, and oxidative stress. Airborne MPs have demonstrated cellular permeability, teratogenicity, and lung toxicity. Polypropylene (PP) MPs have been found in the amniochorial, maternal, and fetal membranes of human placenta samples from healthy women who gave birth vaginally [43].

Once released into the environment, PPE will be subject to continuing weathering and mechanical stress owing to exposure to environmental variables (Fig. 4). Photolysis is considered to be the most important step in the chain of events that leads to the degradation of plastics, which often involves free radical-mediated processes that are initiated by sunlight [44]. In a similar manner, plastics would go through thermo-oxidative reactions at high temperatures, which would break lengthy polymer chains and produce radicals that are capable of self-proliferating until the energy input is halted. A higher temperature results in a faster oxidation rate, as was proven by Kamweru et al. [45] in their research on the synergistic effects of temperature and UV light on the degradation of plastics. Polyester and polyolefin plastics might potentially be degraded if they were exposed to extreme temperature variations, such as the freezing and thawing that occurs in aquatic systems [8, 9]. It is possible for MPs to be produced through the interaction of UV irradiation and/or mechanical abrasion [46] (Fig. 4). In addition, leachates obtained from commercially available FMs in the UK revealed the presence of potentially dangerous heavy metals, VOCs, and additives (such as dye-like compounds), which raised concerns about the potential long-term health risks that FMs pose [47]. In most cases, the antibacterial agents, nasal clips, and other components of FMs contain heavy metals. During the production process of plastic, metal ions like zinc, magnesium, chromium, iron, and aluminum can be used as
cross-linkers to encourage sulfur vulcanization. In recent years, antimicrobial metal oxide nanoparticles have been included in the layers of FMs [48]. The engagement of heavy metals in FMs would increase the risks of leached compounds (Fig. 4). MPs can be absorbed by humans by eating, inhalation, and skin contact. The predominant route of biological entry for humans is inhalation, and it is estimated that a person inhales between 26 and 130 MP per day [49]. Synthetic fibers and abraded plastic materials are common sources of airborne MPs in both indoor and outdoor settings [50]. It should be noted, however, that the size, density, and hydrophobicity of MP particles will affect their deposition and absorption in the respiratory system [51]. It has been reported that getting rid of accumulated MPs in the lungs can be difficult since MPs have polymeric structures and fibrous morphologies, both of which cause inflammation in the lungs [49]. In addition, fibrous MPs have the ability to sidestep the natural process of self-cleaning that occurs in the lungs, which can have cytotoxic effects on the respiratory system [52]. The surface of MPs is an ideal place for harmful bacteria and viruses to form biofilms, and it could also serve as a platform for microorganisms to multiply [53].

It is recommended that the surface of the FM not have any written slogans on it in order to lessen the negative effects that are caused by its use. It is imperative that writing be restricted on FMs. In addition, in order to protect both human health and the natural environment, the choice of dyes should be made in accordance with industry standards that are recognized internationally. Because different colors of FMs might have different effects on people’s health, it is essential to investigate this topic and come to a worldwide agreement on the matter. Certain dyes are harmful to human health as well as the health of animals and plants, and their impacts can be both short term and long term. These dyes can also be persistent. Lastly, governments should encourage individuals to only use their FMs once and then throw them away as medical waste in the authorized manner.

**Similarities Between Lignocellulose and Plastic**

In most cases, animals are unable to digest the principal component of plant cell walls, known as lignocellulose. This component is comprised of a convoluted network that includes lignin, cellulose, and hemicellulose (Fig. 6). Because of the molecular interactions between these components, recalcitrant lignocellulosic fibers are produced. These fibers impose physicochemical impediments on the biodegradation process. Lignocellulosic biomass is composed of polysaccharide polymers (~70% dry weight) and non-polysaccharide polymers (~25% dry weight) [54, 55]. Cellulose, hemicelluloses, and pectins are polysaccharide polymers. Lignins are a category of highly branched phenylpropanoid polymers found in lignified cell walls that are non-polysaccharide polymers [56, 57]. In the cuticle of land plants, a non-polysaccharide polymer called cutin can also be discovered. Cutin is responsible for the plant’s defense against predators [58].

The primary components of refractory lignocellulosic biomass require specialized enzymes so that their polymeric forms can be cleaved into shorter chains or monomers for use in subsequent conversion processes [59–64]. Lignocellulolytic activity commences with an oxidative attack that depolymerizes lignin, the most resistant component of the cell wall, allowing hydrolases access to complex polysaccharide polymers [65]. On the other hand, petroleum-derived polyethylene terephthalate (PET), polyvinyl chloride (PVC), polyethylene (PE), polyurethane (PUR), polypropylene (PP), and polystyrene (PS) comprise the majority of plastic polymers currently produced [8]...
Plastics have been introduced as trash into natural habitats since the 1960s. Because of their stability and endurance, plastics hamper the natural process of biodegradation. It is reasonable to anticipate that synthetic polymers will degrade slowly because of their extremely high molecular weights, robust C–C bonding, hydrophobic surfaces, and the presence of both amorphous and crystalline regions [8, 9].

In spite of their structural and recalcitrance differences, plastic and lignocellulose polymers have a number of similarities in their physical and chemical properties (Fig. 6). These similarities include hydrophobic nature, carbon skeleton, and amorphous/crystalline regions [66, 67]. Natural plant polymers are likely to be degraded by enzymes that can also breakdown synthetic polymers. As a result of microbiological approaches to dealing with such properties, plastic polymers could be depolymerized by the activity of lignocellulolytic enzymes [68]. Indeed, plastic and lignin have several similarities in their chemical and physical structures, including non-phenolic aromatic rings, ether linkages, and a carbon skeleton. Plastic and lignin also have certain physical qualities, such as hydrophobicity [8, 9]. Because of these shared characteristics, lignin-modifying enzymes like laccase and manganese peroxidase are able to degrade both PE and PP [69]. Furthermore, lignin-modifying enzymes employ non-specific radical oxidation to target plastics, aromatic dyes, chlorophenols, and aromatic hydrocarbons [8, 70–72]. Throughout the entirety of the process of lignocellulose decomposition, lignocellulolytic enzymes play an important role. This process begins with the depolymerization of hydrophobic lignin polymers, continues with the degradation of hemicellulose, and comes to a head with the release of fermentable single-unit sugars (Fig. 6). Because of these characteristics, lignocellulolytic enzymes are considered promising candidates for the bioremediation of environmentally hazardous pollutants [73, 74]. A greater understanding of the natural mechanisms responsible for lignocellulose degradation might make it easier to deal with highly recalcitrant synthetic polymers [68].
**Termites and Lignocellulose Degradation**

The most abundant renewable resource on earth is lignocellulose, which is also a main component of plant cell walls. Furthermore, the chemical components of lignocellulose make it a particularly desirable biotechnological substrate. As a direct consequence of this, there has been a rise in the level of interest shown by the scientific community in the development of methods for making use of such a massive bioresource in industry, in particular the production of biofuels. The process of conversion consists of two basic steps: the depolymerization of cellulose into simple sugars and the fermentation of simple sugars into ethanol, with the first step proving to be the most challenging. The inherent complex and recalcitrant structures of plant cell walls make lignocellulose extremely resistant to both thermochemical pretreatments and enzymatic attacks. This has led to an increase in the cost of cellulolytic enzymes as well as bottlenecks in the biofuel industry that have not been addressed. Investigating the natural ecosystems in which lignocellulose can be broken down in an effective manner is one approach to overcoming this challenge.

Despite the fact that some insects, such as termites, have evolved their own lignocellulosic enzymes, certain species of xylophagous animals and insects possess gut symbionts that facilitate the digestion of lignocellulosic biomass [58]. Therefore, the termite intestines can be seen as a sophisticated ecosystem with complex microbial communities. During the passage through the digestive tract of food, both lower and higher termites degrade cellulose and hemicellulose, but with different digestive strategies (Fig. 7). Termites are now thought to be an informational bioreactor capable of successfully degrading lignocellulose. They are an influential group of social insects that are notorious for the tremendous damage they can cause to human property. Termites, in fact, play an important role in global carbon recycling in natural ecosystems because they can dissipate digested cellulose and hemicellulose as a primary energy source [54, 58]. Clearly, the unique ability of termites to thrive on recalcitrant plant biomass and

![Fig. 7](image_url)

**Fig. 7** Different digestive strategies of lignocellulosic biomass in termites involve activities of both the host and its gut microbiota
their widespread distribution make termites an ideal biological model to improve the current biorefinery processing of cellulosic biomass [55, 60].

The delicate digestive tracts and versatile symbiotic microbial systems that termites have developed over millions of years have allowed them to develop bioreactors that are extremely efficient despite their small scale. These bioreactors function in a manner that is analogous to that of commercial biomass conversion systems. They are made up of a grinding mechanism (mandible and proventriculus), a reaction chamber (digestive tract), microbial flora, and their enzymes. Termites have been able to sustain this level of expertise because they have evolved delicate alimentary tracts. Within the confines of this miniaturized bioreactor, a combination of mechanical and enzymatic processes operate in tandem to degrade large amounts of lignocellulose [58]. It is common knowledge that in lower termites, flagellates and bacteria in the termite hindgut help break down cellulose and hemicellulose with the assistance of enzyme cocktails [75]. Termites are able to digest lignocellulose at ordinary temperatures, in contrast to herbivorous mammals. This peculiar quality has been the subject of a great deal of interest in the research and development of new approaches for bioremediation and valorization of lignin and lignin-like compounds [6].

The microorganisms inhabiting insect guts include archaea, bacteria, protists, and fungi. Methanogenic archaea are best studied in wood-feeding termites and beetles. However, while bacterial species are the majority of microorganisms in most insect guts, there is high variation in their total number [75]. Fungi are common in detritus feeding insect guts and probably contribute to the process of digestion. The study of xylophagous insect gut symbionts, including termites, has recently increased to investigate the role of xylophagous insects in their metabolic and digestive processes. Termites are characterized by great abundance in terrestrial ecosystems, while their ability to degrade lignocellulose gives them an important role in the global carbon cycle [76]. Termite digestion of lignocellulose is highly effective, with typical bioconversion rates exceeding 95% within a day. This is due to the removal of cellulose (74–99%), hemicellulose (65–87%), and lignin (5–83%) [54]. The extraordinary performance of termites is due to their unique gut symbionts, including archaea, bacteria, yeasts, and fungi. Lower termite symbionts are bacteria and protozoa. This specialized microflora helps termites digest lignocellulose, resulting in evolutionary success (Fig. 8). They also fix and recycle uric acid nitrogen, maintaining a normal redox potential, synthesizing amino acids, creating acetate and other lower fatty acids, and preventing invading bacteria in the hindguts [77]. Of these symbionts, the anaerobic flagellates can degrade cellulosic compounds to produce acetate, CO₂, and H₂ from cellulose. Acetate is absorbed by the gut epithelium, which absorbs acetate that acts as a main carbon source for termites in addition to several functions of microorganisms in the hindgut [77].

Termites are divided into two classes based on the presence or absence of flagellates in the hindgut: “lower” and “higher” termites. Lower termites have several different types of bacteria and protozoa. However, higher termites have only bacteria; but no protozoa were reported [78]. Also, the higher termites degrade cellulose by secreting their own enzymes from their gut and salivary glands [79]. The majority of termite gut flagellates have bacterial symbionts, ectosymbionts, and/or endosymbionts. The symbiotic relationship between bacteria and flagellates was found to be highly specific [80]. Microbial species of the termite hindgut are involved in the digestion of wood and serve a crucial role in complementing the nutrition of the food supply since they support and complement the breakdown of cellulose, hemicellulose, and lignin [81]. Ramin et al. [79] succeeded in isolating three intestinal cellulolytic degrading bacteria from the hindgut of the subterranean termite species Clavibacter agropyri, Enterobacter cloacae, and Enterobacter aerogenes. Furthermore, Sreena et al. [82] isolated five cellulose-degrading bacteria from Odontotermes
and Heterotermes termites’ hind guts that belong to Bacillus spp., Enterobacter sp., and Staphylococcus sp. In total, 2800 termite species have been reported. However, only a few species have had their gut flora studied so far. Only a few cellulolytic microorganisms have been studied because it is hard to find and grow many intestinal microbes [74].

Termite host tissues, via transcriptomic analysis, have been shown to produce a litany of cellulases and hemicellulases, as well as lignin-degrading enzymes, thus contributing to lignocellulose degradation [58]. Interestingly, the relationship between termites and microorganisms that break down lignin makes it possible for symbionts in the termite gut to fully break down lignocellulosic biomass, as shown by the small amount of feces they produce at the end. Lignin is the 2nd most abundant portion of lignocellulosic biomass, accounting for up to 30% by weight or up to 40% by energy [83]. This heteropolymer also has a major impact on the physical properties of plant tissues due to its architectural contributions and water transportation. Although lignin units are simple molecules with a phenylpropane backbone, the three-dimensional structure of the produced polymer is extremely complex, and the extremely variable polymer surface can be accessed only by extracellular enzymes. The variety of the lignin bonds also limits the enzymatic activity, leading to the accumulation of lignocellulosic wastes and an environmental burden [59]. Sinapyl alcohol (S), p-coumaryl alcohol (H), and coniferyl alcohol (G) are the three major phenylpropane units (monolignols) that make up lignin, a normal phenolic macromolecule found in the vegetal cell wall (Fig. 9). The composition of lignin is extremely complex, consisting of a three-dimensional randomized net connected to hemicelluloses. In plants, lignin serves as a biological buffer and a glue that holds hemicelluloses and celluloses together to form the cell wall. Plant peroxidase catalyzes the oxidation of substituted para-hydroxycinnamyl alcohols to produce lignin, while quinone methide intermediates are used to add the benzylc hydroxy groups [84].

The chemistry of native lignin varies based on its type, further complicating its molecular structure, while lignin properties depend on plant species, plant tissue type, isolation protocol, and the external atmosphere [85]. Lignin is often categorized based on its
botanical source, with gymnosperm lignin derived mostly from coniferyl alcohol monolignols and angiosperm lignin derived from both coniferyl and synapyl alcohol monolignols. Each form also contains a small number of $p$-coumaryl units (H subunit), while non-woody lignin has a higher fraction of $p$-coumaryl units than woody analogues. Exceptions to the rule include gymnosperm lignin-containing high concentrations of synapyl alcohol units (S subunit) or angiosperm lignin containing only coniferyl units (G subunit), as illustrated in Fig. 9. Other phenolic monolignols have also been identified, but they generally make up a much smaller portion of the lignin molecule [86]. Furthermore, the majority of industrial lignin is produced as a byproduct during the paper pulping process, but it
can also be found in rice and straw. However, despite its widespread availability, lignin’s industrial applications are minimal, in contrast to cellulose, which is used to make paper and natural oils, mostly applied in the food industry [87]. Initially, lignin was used as boiler fuel in the manufacture of octane boosters as well as in the manufacturing of biobased materials and chemicals. Fortunately, over the years, effective ways to recycle and use lignin in order to turn it into high-value-added materials have been developed. The most effective lignin degraders are filamentous fungi, particularly white-red basidiomycetes and yeast [88]. Recent culture-dependent and culture-independent studies demonstrate the great potential of the gut microbiota not only in termites but also in other wood-feeding insects.

Could Termites Provide a Sustainable Solution for Plastic Degradation?

Plastic beats conventional materials because of its resistance to water and ability to repel termites and other microbes [8, 9]. There have been reports of microorganisms that degrade plastic in a variety of marine and terrestrial habitats that have been contaminated, and these studies have come from cultivation as well as metagenomics [89]. Unexpected places where enzymes and microorganisms with the ability to degrade plastic have been found to include the rumen of cows, manure, and even the intestines of insect larvae and adults. It appears that the related microbiota utilize some of the enzymatic pathways for degrading plant biomass in order to degrade synthetic plastic polymers, and this conclusion is based on the chemical and structural similarities between plant and plastic polymers. As a result, plant-degrading and host-associated microbial communities have been investigated as potential sources of enzymes and/or microbial consortia for the strategy of biodegrading plastics [25, 90]. Over the past decade, there has been an increase in interest in the plastic-degrading capabilities of PP, PS, and PVC since these plastics can be biodegraded after being consumed by insect larvae [9, 25]. The capacity of insect larvae to degrade plastic suggests that the enzymatic system used for breaking down plant-derived and recalcitrant polymers could potentially be repurposed for use in breaking down synthetic polymers [91]. Because of this, herbivorous insect hosts appear to be a valuable supply of microorganisms and enzymes for depolymerizing synthetic plastics. These microorganisms and enzymes may have evolved from a microbial community that degrades plants.

In the context of bioremediation, termites that are capable of degrading plastics through their gut microbiome are attracting great interest, despite the fact that the ecological advantage of this is uncertain. Microbes that can break down plastic have recently come into focus as a potential solution to the widespread problem of plastic pollution. Termites, which belong to the order Isoptera, have adapted to a diverse array of food sources during the course of their evolution [54, 58]. These sources include wood, dung, and humus-rich organic wastes. Termite digestive processes frequently collect enzymatic activity from the host as well as from the gut flora. This is because lignocellulose, in a variety of stages of decomposition, is a consistent component of the diet of all termite feeding groups [75]. Micro(nano)-plastics (MNPs) are also accumulated and transferred in the food chain. It has been demonstrated that the accumulation of plastics in earthworms is influenced by the size of the MPs that are administered to the soil at either 100 or 1,000 mg/kg of soil dry weight [92]. A variety of soil invertebrates, including termites, may be able to ingest and transfer MNPs [93]. As a soil-consuming species, the presence of polyurethane foam MPs in soil may increase the accumulation of polybrominated diphenyl ether (PBDE) flame retardants in *Eisenia fetida* [94].
Termite microbiota are unique, convergent, and adaptive, and they appear to comprise mechanisms for the detoxification of plant defense metabolites and the degradation of lignocellulose [95]. The microbiota has a large number of genes for the modification of xenobiotics, including pathways for the degradation of polycyclic aromatics. However, the mechanism of these processes is not well understood.

Consider fundamental research topics on the biodegradation of plastics in the termite gut and the guts of other insects, such as the factors affecting plastic biodegradation; the enzymes and genes of functional microbes associated with plastic degradation; and the synergistic effect of the host and gut symbionts. The management of plastic waste and the recovery of resources from used plastics, as well as the production of a new generation of plastic products and the development of innovative technologies for bioremediation of existing plastic pollution sites, could all greatly benefit greatly from a better understanding of the mechanisms of insect-related plastic biodegradation.

**Conclusion**

FM is a form of PPE during COVID-19 that is continuing to be imperative despite its consequential risks. The discarded FMs would eventually degrade into MPs, which would then release toxic chemicals into the environment and serve as carriers for pathogens that have deleterious effects on the environment and human health. However, an in-depth investigation into the environmental fate of disposed FMs and their consequential risks is still missing. Therefore, a timely understanding of the impacts of disposable FMs is essential in order to control this waste pollution in the near future. On the other hand, to work towards a circular economy, a multifaceted approach is also necessary to deal with the complexity of the problem. It is vital to scale up innovation and technology to substitute current disposable FMs (petrochemical-based) with bio-based and eco-friendly (potentially biodegradable) alternatives to reduce plastic waste and environmental and health impacts in the near future. The biodegradation approach (to degrade the polymers and produce bio-based polymers from biowaste) seems to be advantageous. Termites are important in the biodegradation of lignocellulosic biomass waste because they have a large variety of microbial machinery in their guts that may digest solid waste, lessening environmental impact. In parallel, knowledge of the methods for understanding lignocellulose degradation by termites could aid in the challenge of dealing with the recalcitrant synthetic polymers spread worldwide.

**Funding** This work was supported by the National Natural Science Foundation of China (31772529), the National Key R&D Program of China (2018YFE0107100), and the Project funded by the Priority of Academic Program Development of Jiangsu Higher Education Institutions (PAPD 4013000011).

**Availability of Data and Materials** All datasets generated for this study are included in the article.

**Declarations**

**Ethics Approval and Consent to Participate** The research does not deal with human nor animal data.

**Consent for Publication** Not applicable

**Competing Interests** The authors declare no competing interests.
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