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(Review Article)

Industrial *Cannabis sativa* (hemp or fibre): Hemp Cellulose Based Bioplastic Production

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Abstract

India has shown increasing interest in bio-plastics due to growing environmental concerns and a focus on sustainability. The Indian government has been taking steps to promote sustainable practices, and initiatives supporting bio-based products, including bio-plastics, have gained attention. Biodegradable plastics are being the substitute for synthetic plastics and widely been used in order to combat plastic pollution. Industrial *Cannabis sativa* (hemp or fibre), hemp plastic stands out as a viable solution to address the environmental challenges posed by traditional plastics. Hemp bioplastic is derived from the plant's stems, specifically from the fibers containing 70%-80% cellulose. Because hemp stalk (outside bast fibre and inner hurd) is rich in cellulose fibers, it can be utilized as a raw material for cellulose extraction. Hemp plastics can be a good solution for limiting global pollution. The process of creating hemp plastic involves extracting cellulose from hemp fibers. Cellulose measured at nanoscale is known as nanocellulose. Nanocellulose is a biodegradable and renewable biomaterial, which has great potential to be incorporated into bioplastic packaging materials to enhance their physical and functional properties. Bioplastic preparation includes the hemp based cellulose and mixed with the plastisizers. Hemp cellulose is mixed with plasticizers and plastic additives to enhance the final product properties. The mixture then goes under heat pressure treatment to produce the hemp bioplastic desired. The addition of a natural plasticizer like glycerin to get greater flexibility in finished hemp plastic product. The exact ratios will depend on project and the desired properties of hemp plastic.

Keywords: Bioplastic; Biopolymer; Bast Fibres; Cellulose; *Cannabis Sativa*; Glycerin; Hurd; Plasticizer; Nanocellulose, Plastic

1. Introduction

In the global food market, conventional plastic packaging is often not biodegradable and thus poses a serious threat to the environment [24, 45-64-78, 85, 86]. Petroleum-based polymers dominate the modern material market, providing solutions for a broad range of industries. Unfortunately, the ever-growing demand for petroleum-based plastics is unsustainable and negatively affects the environment in the form of non-degradable waste [24, 45-64, 85, 86]. To address this problem, bio-plastic materials are developed as a green alternative since they are made from biodegradable polymer or biopolymers [24, 45-62, 85, 86]. Today, the environmental impact caused by traditional plastics is truly devastating [24, 45-65, 85, 86]. In various forms, microplastics have already entered the food chain of animals and humans, and the effects on the body do not bode well [24, 45-64, 87-93]. Food packaging has been traditionally used for food preservation [24, 45-62-76, 85, 86]. Most plastic food packaging is made of non-biodegradable materials and designed for single use[24, 45-63, 85, 86]. Petroleum-derived plastics are widely regarded as the primary materials for

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food packaging owing to their affordability, favourable chemical stability, exceptional barrier properties, and convenient moldability [24, 45-62, 85, 86, 88-93]. However, most of such synthetic polymers in use today lack biodegradability that results in their long-lasting presence in the environment ultimately contributing to environmental contamination and posing a threat to wildlife when they are released into nature [24, 45-63-76, 85, 86]. Food packaging serves a crucial function by safeguarding food from environmental risks and ensuring its freshness and safety throughout the storage and transportation processes[24, 45-65-78, 85, 86]. Moreover, food packaging plays a pivotal role in enhancing product sales with appealing colors and designs [24, 45-65-78]. In addition, conventional food packaging are inert materials that cannot inhibit the growth of food borne pathogens and spoilage bacteria [24, 45-63-74, 85, 86]. The increasing concerns about environmental pollution and food safety problems arising from the extensive utilization of petroleum-derived polymers in food packaging have driven scientists to explore eco-friendly and secure alternatives [24, 45-62, 85, 86]. To address this problem, researchers have paid considerable attention to developing bioplastics as alternatives to the conventional plastics [24, 45-62-78]. Since bio-plastics are made from biodegradable synthetic polymers or biopolymers, they are sustainable and eco-friendly[24, 45-62-76]. Thus, antimicrobial food packaging has been developed to improve food safety and quality. However, the mechanical and barrier properties of bioplastics remain to be improved [24, 45-65-78, 85, 86]. Therefore, recently there are many examples of composite thin films loaded with plant material were developed for the food packaging industries as a alternative to the toxic petroleum-derived plastics [24, 45-62-78, 85, 86].

Industrial *Cannabis sativa* (hemp or fibre), hemp plastic stands out as a viable solution to address the environmental challenges posed by traditional plastics [1-44, 45-62, 76-81-86]. With a fully biodegradable nature and the ability to replace petroleum-based synthetic plastics in numerous applications, hemp plastic offers hope for a sustainable future. One of the most significant advantages of hemp plastic is its biodegradability [1-44, 45-62, 79-81-86]. Unlike traditional plastics that contribute to plastic pollution, hemp plastic decomposes fully, minimizing environmental impact. Industrial *Cannabis sativa* (hemp or fibre), hemp plants absorb large amounts of carbon dioxide during their growth, acting as a highly absorbent agent for greenhouse gases [1-44, 45-62, 81-86]. This carbon sequestration capability further positions hemp as an environmentally friendly choice in plastic production. Industrial *Cannabis sativa* (hemp or fibre), hemp plastics offer a myriad of applications, from everyday items like plastic bags and sanitary products to specialized uses like barrier films and cellophane film [1-44, 45-62, 85, 86]. The versatility of hemp plastic makes it a sustainable alternative across various industries [1-24, 44-62, 79-81-86].

Hemp bioplastic is derived from the plant's stems, specifically from the fibers containing 70%-80% cellulose [24, 45-63, 85, 86], and his high cellulose content contributes to the extraordinary strength of the material [24, 45-62, 81-84]. The first production phase involves extracting as much cellulose from the plant as possible. The hemp **stems** and **fibers** are crushed and soaked in acid [24, 45-62, 85, 86]. The next step is soaking the extracted cellulose in water and chemical solutions to remove the acid [24, 45-64]. The cellulose undergoes thermal treatment, producing various types of material referred to as hemp plastic [24, 45-62, 85, 86]. Another significant advantage of hemp plastic is that it is 3.5 times stronger and much lighter than traditional petroleum-based plastic [24, 45-62, 81-86]. This makes its use extremely versatile, replacing any known application of petroleum-based plastic, from electronics, various packaging, and furniture to automotive and aircraft components [24, 45-62, 85, 86]. The superiority of hemp plastic over synthetic materials is so significant that **Lego,** a company producing iconic building blocks, declared that hemp plastic would be their main material for toy production by 2030 [24, 45-62, 85, 86].

2. Hemp Cellulose Plastic

Industrial *Cannabis sativa* (hemp or fibre), hemp has been cultivated for centuries as the sources of oilseeds, fiber products and herbal medicines [1-44, 45-62, 85, 86]. The hemp stalks are treated as green wastes, which are rich in cellulose fibers that can be further processed to produce a value-added product known as nanocellulose [24, 45-62, 85, 86]. Industrial *Cannabis sativa* (hemp or fibre), hemp is known for its swift growth and remarkable sustainability, requiring significantly less water, an adaptable cultivation to a wide range of climates when compared to other fibers sources, making it a practical and environmentally friendly choice for packaging materials [24, 45-62]. In the last decade, hemp has gained popularity as a multifunctional crop with good compatibility with colder climates, high yields, and good resistance to environmental factors [1-44, 85, 86]. Industrial *Cannabis sativa* (hemp or fibre), hemp stalk is composed of two parts: **bast** (20%-40%) and **hurd** (60%-80%) [1-44, 45-64, 85, 86]. Bast is the long, tough fiber on the outer layer of hemp stalk that contains 57%-77% cellulose, 5%-9% lignin, and 9%-14% hemicellulose [1-44, 45-62, 85, 86]. Hurd is the short, soft fiber located in the inner part of hemp stalk that comprises 40%-48% cellulose, 21%-24% lignin, and 18%-24% hemicellulose [1-44, 45-63]. Because hemp stalk is rich in cellulose fibers, it can be utilized as a raw material for cellulose extraction. Hemp plastics can be a good solution for limiting global pollution[1-44, 45-64]. It does not contain **toxic** substances such as polylactic acid, PBS and PHA, is biodegradable and does not endanger the fauna of our planet. Cellulose, the most abundant biopolymer, has been the key focus of new material development [1-

44, 45-63, 85, 86]. The main aim of the cellulose based-bioplastics is to reduce costs and yield products that compete with petroleum-based alternatives [1-44, 45-63, 85, 86]. The hemp stalks remain the most underutilized part of the plant [44-63, 85, 86]. The high content of cellulose, around 70 wt% and yearly harvest make hemp an excellent source of renewable raw material for developing bio-based composites and plastics [1-44, 45-63]. However, the hemp stalks and roots are produced as wastes in the hemp industry and normally end up in landfill. There is a critical need to convert these green wastes into value-added products [1-44, 45-63, 85, 86].

Industrial *Cannabis sativa* L. (Hemp) contains very low levels of Λ9-tetrahydrocannabinol (THC) (0 to 0.3% of dry weight) grown outside in a large agriculture farms for the production of fiber, seeds and oil [1-44]. Industrial *Cannabis sativa* L. (fiber or Hemp) is legalized by FOOD SAFETY AND STANDARDS AUTHORITY OF INDIA (FSSAI), Government of India, New Delhi since 2021 grown for seed, fiber, medicine, as the functional food, fiber and hempcrete in Uttarakhand state, India. In 2021, Uttarakhand state, India became the first Indian state to permit large-scale commercial cultivation of industrial hemp [1-42]. In 2025, another Indian state, Himachal Pradesh has been legalized for the growth of hemp as pilot plant project [1-42].

Industrial *Cannabis sativa* (hemp or fibre), hemp a versatile and eco-friendly plant, is the foundation of the sustainable material known as hemp plastic [1-42-63, 79-86]. Derived from the fibres of the hemp plant (*Cannabis sativa*), hemp has been utilized for centuries for various purposes, including textiles, paper, and now, plastic [1-42-64]. Hemp stalk is composed of two main parts, including **bast** fibers in the outer layer and **hurd** in the inner part [1-42-63, 85, 86]. Both of them are rich in cellulose and can be used to prepare plastic. The cost of making plastic from hemp is not just a financial consideration; it encompasses the environmental, social, and economic benefits that hemp plastic brings to the table [1-42-63, 79-86]. As technology advances and consumer awareness grows, the demand for sustainable alternatives like hemp plastic is likely to increase. Embracing hemp plastic production on a global scale has the potential to reduce plastic pollution, combat climate change, and usher in a new era of environmentally conscious material usage[1-42-63, 85, 86]. . One is type of plastic is based on cellulose; which is a natural polymer [1-42-64, 79-86]. A common example of a cellulose based plastic is cellophane, the crinkly stuff often used to package snacks. Cellophane is considered to be a bioplastic [1-42-63, 79-86]. An ideal plant for extracting cellulose from that does not involved felling trees and destroying forests is industrial hemp. It grows very quickly with comparatively minimal inputs [1-42-63, 85, 86]. Hemp bast fibers are made up of around 70% cellulose, while the woody core (hurd) has 40% cellulose content. A single hectare of industrial hemp can provide around 5 tons of cellulose a year [1-42-63, 79-86].

Hemp cultivation for plastic production involves considerations such as seed costs, field preparation, and harvesting [24, 45-64]. However, the fast growth cycle of hemp and its minimal need for pesticides make it a cost-effective crop [24, 45-64]. The process of creating hemp plastic involves extracting cellulose from hemp fibers [24, 45-63]. Acid solutions are commonly used to break down the extracted cellulose into nanocrystals, contributing to the formation of the desired plastic compounds [24, 45-63]. This process is energy-efficient and eco-friendly compared to traditional plastic production methods[24, 45-63]. Some hemp plastics are enhanced with composite materials, creating versatile and durable options for applications such as building materials, car panels, and barrier films [24, 45-64]. While the inclusion of hemp takes these composites may affect costs, the benefits often outweigh the expenses [24, 45-65]. Hemp plastic, often referred to as hemp bioplastic, is a type of biodegradable material crafted from the cellulose fibers of the hemp plant (*Cannabis sativa*) [24, 45-63]. Unlike traditional plastics derived from petroleum, hemp plastics present a renewable resource that has the potential to revolutionize the plastic industry [1-42-64, 79-86]. The industrial *Cannabis sativa*, hemp plant serves as a rich source of biomass, with its cellulose fibers standing out as the key raw material for hemp plastic[24, 45-63]. The hemp cellulose is extracted from the hemp plant's cell walls, offering a sustainable and organic polymer for manufacturing[24, 45-63, 79-86].

The hemp to plastic process can vary, as there are several different ways to turn hemp into plastic [24, 45-63, 79-86]. The main step in the process is to extract cellulose from the hemp plant. This can be done by pulping hemp plants and separating the cellulose using water, acid solutions, and/or heat and pressure[24, 45-63, 85, 86]. The extracted cellulose can then be made into several different types of hemp bioplastic, including: **Hemp cellulose:** An organic polymer that is mainly used to make paper but can also be made into a wide range of other plastics[24, 45-63]. **Cellophane and rayon:** Classified as regenerated cellulose fibers, these fibers are used to make cellophane film, the material you put over that bowl of leftover salad, or rayon fiber which can be used in all sorts of fabrics, from sheets to curtains or even the clothes you're wearing right now[24, 45-63]. **Cellulose nanocrystals:** Can be used in different applications, including nanopaper, barrier films, and more[24, 45-63]. **Nanocellulose:** A "pseudoplastic" that can alternate between a gel-like substance or a liquid. Nanocellulose has multiple valuable uses, including as a highly absorbent agent that has been used to clean up oil spills and used in sanitary products[24, 45-65]. **Composite hemp plastics:** Plastics that incorporate cellulose as well as a range of other polymers that may be natural or synthetic[24, 45-63]. Composite products are highly variable and can be used in a huge range of ways, including to make building materials, boats, car panels, and more[24, 45-63, 79-86].

3. Hemp Cellulose

Cellulose is the most abundant biomass and natural biopolymer on earth [24, 45-62, 85, 86]. It has been gaining increasing attention due to its renewability, biodegradability, and remarkable physical and mechanical properties. Cellulose is a linear polysaccharide consisted of repeating anhydro-D-glucopyranose units joint by β-1,4-glucosidic linkages and has a basic chemical formula of $(C_6H_{10}O_5)n$ [24, 45-62, 79-86]. This biopolymer accounts for approximately one-third of plant tissues that may be regenerated via photosynthesis. Cellulose chains are hierarchically combined together to produce microfibrils [24, 45-62]. This process involves the formation of van der Waals forces as well as intermolecular and intramolecular hydrogen bonds among molecular chains [24, 45-62]. Every cellulose microfibril is constituted of repeating well-ordered (crystalline) and disordered (amorphous) regions [24, 45-62]. Bundles of cellulose microfibrils are assembled into aggregates (macrofibrils) with combination of lignin and hemicellulose [24, 45-63]. In nature, cellulose fibers function as an important structural element to support plant cell walls and are present in the tissues of algae and the cell membranes of tunicates [24, 45-62, 85, 86]. Cellulose and its derivatives have been applied in various fields to produce diverse products, such as paper, tensile products, packaging, food additives, and biomedical materials for drug delivery and wound dressing. They can also be disintegrated into a nanoscale to prepare cellulosic nanomaterials with superior mechanical and surface properties [24, 45-62]. Cellulose does not dissolve in water, but swelling results in significant structural defects [24, 45-62]. The cross linking approach can increase molecular weight and structural rigidity in mimicking high molecular weight commodity polymers. In addition, cross-linking can link cellulose particles and obtain uniform material, which is beneficial when working with various waste materials such as biomass dust, flour, and small fibres[24, 45-62]. However, coated and chemically treated cellulose is less resistant to water migration effects and does not benefit from increased molecular weight, thus retaining issues with water plasticization and swelling [11,12]. As an alternative, a less-known one-step cross-linking method has emerged in recent years based on citric acid cross-linking [15]. For this purpose, glycerol has been applied in combination with citric acid to enhance the degree of cross-linking, thus making materials stiffer [24, 45-62]. Hemp plastic offers a greener alternative to conventional plastics, as it is biodegradable and renewable[24, 45-62, 85, 86].

Cellulose measured at nanoscale is known as nanocellulose [24, 45-62]. Nanocellulose is a biodegradable and renewable biomaterial, which has great potential to be incorporated into bioplastic packaging materials to enhance their physical and functional properties[24, 45-63]. Two types of nanocellulose can be extracted from hemp stalks, which are cellulose **nanocrystals** (CNCs) and cellulose **nanofibrils** (CNFs) [24, 45-63]. CNCs can be obtained through sulphuric acid hydrolysis while CNFs are often extracted through TEMPO-mediated oxidation of cellulose fibers [24, 45-62]. Currently, the demand for antimicrobial food packaging is rising in the meat industry[24, 45-63]. N-halamine antimicrobial surface modification added to bioplastic materials has the potential to reduce meat contamination, which benefits both consumers and producers. Nanocellulose is the cellulose extract with a structure at a nanoscale (1-100 nm) [24, 45-63]. It is derived from various types of sources, such as hemp, cotton, wood, bacteria, tunicates, and industrial biomass. Nanocellulose are lightweight, biodegradable, and renewable [24, 45-62]. It is classified into three main groups, including cellulose nanocrystals (CNCs), cellulose nanofibrils (CNFs), and bacterial nanocellulose (BNC) [24, 45-63, 85, 86].

4. Extraction of Hemp inner Hurd Cellulose

According to the method adopted by Liao (2022) [51], the hemp hurd fibres were ground by using a high-speed grinder [51]. The obtained powder was passed through a metal sieve (mesh size, 1.5 mm) and collected for cellulose extraction, which was conducted according to previous methods with some modifications [51, 62, 63]. Briefly, the powder (50g) was treated by 12% (w/v) NaOH using a solid/liquid ratio of 1:15 at 80°C for 3 h with continuous stir at 500 rpm[51, 62, 63]. The alkaline-treated sample was washed thoroughly by using sterile deionized water for 4-5 times until a neutral pH was achieved [51, 62, 63]. The alkaline treatment was repeated one more time to remove the remaining lignin, hemicellulose, and other impurities [51, 62, 63]. Afterwards, the sample was bleached at 80°C for 4 h with continuous stir in a bleaching solution with a solid/liquid ratio of 1:15 [51, 62, 63]. The bleaching solution was prepared by mixing equal volume of an acetate buffer (54 g NaOH and 150 mL of acetic acid in 2 L of deionized water), 1.7% (w/v) $NaClO_2$ solution, and sterile deionized water [51, 62, 63]. The mixture was then washed by sterile deionized water for 4-5 times [51, 62, 63]. The bleaching step was repeated for at least 3 times to obtain the cellulose fibres with a color close to white. Finally, the product was dried at 60°C in an oven overnight[51].

5. Extraction of hemp outer bast fibre cellulose

Hemp stalk was used as the raw material for cellulose extraction. Hemp stalk was washed, air-dried, manually processed into bast and hurd fibers and then stored at room temperature for further processing [51, 62, 63]. According to the method adopted by Liao (2022) [51], hemp bast fibers (30 g) were cut into small pieces (length, 1.5 cm) and were ground by using a high-speed grinder [51]. The obtained fine powder was treated by 12% (w/v) NaOH using a solid/liquid ratio of 1:25 at 80°C for 3 h with continuous stir at 500 rpm [51]. The alkaline-treated sample was washed thoroughly by using sterile deionised water for 4-5 times until a neutral pH was achieved [51]. The alkaline treatment was repeated one more time to remove the remaining lignin, hemicellulose, and impurities [51, 62, 63]. Moreover, the sample was bleached in a bleaching solution with a solid/liquid ratio of 1:20 at 80°C for 3 h with continuous stir[51, 62, 63]. The bleaching solution was prepared by mixing equal volume of an acetate buffer (54 g NaOH and 150 mL of acetic acid in 2 L of deionized water), 1.7% (w/v), sodium chlorite ($NaClO_2$) solution, and sterile deionized water [51, 62, 63]. The mixture was washed with sterile deionized water for 4-5 times. The sample was bleached again in a bleaching solution with a solid/liquid ratio of 1:20 at 80°C for 1 h with continuous stir at 200 rpm, followed by washing with deionised water for 4-5 times. The final product was dried at 60°C in an oven overnight [51, 62, 63].

The cellulose content of samples was determined according to a reported method by Liao (2022) [51] with some modifications (Song et al., 2019) [51, 61]. Hemp holocellulose collected from the previous procedures was treated with a 17.5% (w/v) NaOH solution at room temperature for 5 h with continuous stir at 500 rpm [51, 61]. The obtained cellulose was vacuum-filtrated and washed thoroughly with deionized water for 3 times [51, 61]. The obtained cellulose was oven-dried at 60°C overnight and weighed. The cellulose content was calculated by dividing the obtained cellulose mass by the initial sample mass [51, 61].

Main components in hemp bast fibers and hurd include lignin, cellulose, and hemicellulose. Hemp hurd fibers had 20% cellulose and 17% lignin. Liao (2022) [51] reported that the lignin content was close to the reported result (21%-24%), while the cellulose content was lower than the reported result (40%-48%) [51]. Liao (2022) [51] is also of the opinion that this phenomenon was possibly due to the loss of cellulose caused by the pre-treatment and the differences in growth conditions [51]. After alkaline and bleaching treatments, the cellulose content was increased to 85%, and the levels of hemicellulose and lignin significantly decreased [51]. Thus, most impurities were removed during the extraction process [51]. The bleaching process produced several free radicals, such as hydroxyl free radicals and oxygen-derived free radicals, which could damage the chromophore of lignin[51]. Meanwhile, the alkaline treatment effectively broke down the bonding between cellulose and lignin and solubilized hemicellulose, which promoted the release of cellulose from hemp hurd [51, 62-62].

Liao (2022) [51] reported that the cellulose content of hemp bast fibers was almost three times higher than that of hemp hurd [51]. In addition, hemp bast fibers showed a lower lignin and hemicellulose content compared with hemp hurd [51]. After alkaline treatment and bleaching treatments, the final product achieved a high cellulose purity (97%), and its lignin and hemicellulose contents were controlled at a low level [51]. Therefore, according to the study conduced by Liao (2022) [51], the hemp bast cellulose has a higher purity than hurd cellulose because hemp bast has a higher cellulose content but lower lignin and hemicellulose content [51]. As a result, cellulose in hemp bast could be more easily released than cellulose in hemp hurd [51].

6. Preparation of Hemp Cellulose Plastic

Hemp fibres were collected and dried in under sunlight conditions. Then fibres were cleaned to remove the dust and impurities. Hemp oil, also known as hemp seed oil, acts as a binding agent for hemp plastic mixture [1-51, 62-65-86]. Plasticizer is used to bind the hemp fibers together and give hemp plastic its malleable properties. One common option is polylactic acid (PLA), a bioplastic derived from corn starch. Begin by cutting or shredding the hemp fiber into small pieces. The size and texture of the fibres will affect the final appearance and texture of hemp plastic. Therefore, grind the fibres to produce a powder which is further used for making the hemp plastic. In a mixing bowl, combine the shredded hemp fibre powder with hemp oil [1-51, 62-65-86]. Then addition of a natural plasticizer like glycerin to get greater flexibility in finished hemp plastic product[1-51, 62-65-86]. The exact ratios will depend on project and the desired properties of hemp plastic. Use a spoon to thoroughly mix the ingredients until a consistent, dough-like texture is achieved [1-51, 62-65-86]. Press the mixture into chosen mold, making sure it is evenly distributed. A tool is used to shape the hemp plastic as needed [1-51, 62-65-86]. Allow hemp plastic to dry and set. The drying time may vary depending on the size and thickness of project. Generally, it may take a day or more for the hemp plastic to fully harden. Once hemp plastic is completely dry and solid, carefully remove it from the mold [1-51, 62-65-86].

7. Hemp Cellulose Composite Film

Nanocellulose can be utilized as a biodegradable material for use in bioplastics to improve their mechanical and barrier properties [51]. Liao (2022) [51] reported that hemp bast cellulose was selected as the raw material for the synthesis of hemp nanocellulose due to its high cellulose content (97%) and yield (49.6%)[51]. Hemp cellulose nanocrystals (CNCs) were synthesized through sulfuric acid hydrolysis for 30 min [51]. The CNC product had a high colloidal stability in aqueous suspension and had an average diameter of 16 nm and an average length of 244 nm[51]. Hemp cellulose nanofibrils (CNFs) were produced by the TEMPO-mediated oxidation with the addition of 8 mmol of NaClO/g cellulose [51]. The cellulose nanofibrils (CNFs) product had a high dispersity and possessed an average diameter of 24 nm and an average length of 292 nm [51]. Application of hemp nanocellulose in developing biodegradable composite films was demonstrated in different film matrix [51]. Hemp cellulose nanocrystals (CNCs) showed a good compatibility in a PVA film, and the addition of 10% hemp cellulose nanocrystals (CNCs) significantly improved the strength, stiffness, and ultraviolet-blocking effect of PVA film [51]. Likewise, hemp cellulose nanofibrils (CNFs) were miscible with PVA in the composite film [51]. When 10% hemp cellulose nanofibrils (CNFs) were added, the PVA film displayed increased strength, stiffness, and ultraviolet-blocking effect [51]. In addition, hemp cellulose nanofibrils (CNFs), Poly-L-lysine hydrochloride (PLH), and Poly(vinyl alcohol) (PVA) were used to envelop a novel composite film [51]. Liao (2022) [51] reported that the film owned a high transparency, good mechanical performance, UV-blocking effect, and antimicrobial activities against Gram-positive and Gram-negative bacteria [51]. The PVA/CNF/PLH film was biodegradable, sustainable, and had great potential to be used as an antimicrobial packaging to improve food quality and safety [51]. Both CNCs and CNFs showed a good compatibility in the Poly(vinyl alcohol) (PVA) film, and the addition of 10% nanocellulose significantly improved the strength, stiffness, and ultraviolet-blocking effect of PVA film[51]. In addition, hemp CNFs, Poly-L-lysine hydrochloride (PLH), and PVA were used to develop a novel composite film [51]. The film owned a high transparency, good mechanical performance, UV-blocking effect, and antimicrobial activities against several bacteria, including *Salmonella enterica* serotype *Typhimurium*, *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas aeruginosa* [51]. The PVA/CNF/PLH film has great potential to be applied as antimicrobial food packaging [51].

8. Conclusion

Traditional fossil-fuel based plastic production emits massive levels of greenhouse gasses, and the material can take hundreds of years to break down. Consequently, oceans and landmass are infested with plastics. The vast accumulation of end-of-life plastic has put the ecosystem under unprecedented strain. In terms of environmental consciousness, plastic waste has become one of the main global challenges. Industrial *Cannabis sativa* (hemp or fibre), hemp plastic stands out as a viable solution to address the environmental challenges posed by traditional plastics. With a fully biodegradable nature and the ability to replace petroleum-based synthetic plastics in numerous applications, hemp plastic offers hope for a sustainable future. One of the most significant advantages of hemp plastic is its biodegradability. Unlike traditional plastics that contribute to plastic pollution, hemp plastic decomposes fully, minimizing environmental impact. Nanocellulose can be utilized as a biodegradable material for use in bioplastics to improve their mechanical and barrier properties. Therefore, cellulose material is extracted and used for the bioplastic production. Bioplastic preparation includes the hemp based cellulose and mixed with the plastisizers. Hemp cellulose is mixed with plasticizers and plastic additives to enhance the final product properties. The mixture then goes under heat pressure treatment to produce the hemp bioplastic desired. The addition of a natural plasticizer like glycerin to get greater flexibility in finished hemp plastic product. The exact ratios will depend on project and the desired properties of hemp plastic.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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