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(Review Article)

Industrial *Cannabis sativa* (Hemp): A multipurpose Revolutionary Crop for Sustainable Agriculture

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Abstract

Industrial *Cannabis sativa* (Hemp) is a multipurpose revolutionary crop widely cultivated for its seeds, which are rich in oil, proteins, carbohydrates, and fibers, as well as in vitamins and minerals. Research from 2024 and early 2025 indicates that industrial hemp (*Cannabis sativa* L.) is a rapidly expanding, sustainable, and multifunctional crop with significant applications in medicine, nutrition, construction, and environmental remediation. The unique properties of the plant make it a highly valuable and sustainable crop. There are more than 25,000 hemp-based products available in markets worldwide. Oil meal, a residual material of hemp seed after expression of hemp oil, is a useful protein-rich material. Industrial hemp farming has the potential to dramatically minimize the amount of carbon impact on the environment and can be cultivated with little or no usage of chemical pesticides or fertilizers. The hemp plant will continue to find new applications due to its unique properties for sporting goods, musical instruments, portable and wearable energy storage devices, semiconductors, nanomaterials, active packaging, bio-composite orthotic devices, and medical applications. Nations should realize the importance of this amazing plant and initiate marketing and growth policies that will be beneficial for both their economies and the environment. This review paper highlights and updates the recent industrial applications of hemp.

Keywords: Bioplastic; Biofuels; Edestin; Hemp; Industrial *Cannabis sativa*; Hemp Protein

1. Introduction

Cannabis sativa L. belongs to the family *Cannabaceae* was used as a medicine before the Christian era in Asia**,** mainly in India**,** China, Bhutan, Nepal, Afghanistan, Pakistan, Egypt, Africa, Iran, Persians and Latin America [1-59]. Hemp (*Cannabis sativa* L.) is an increasingly important multipurpose crop, valued for its industrial, nutritional, and medicinal uses. It is not only a treasure for the industrial sector but also a dignified plant for sustainable farming systems. Industrial *Cannabis sativa* (hemp) has long been used in various civilizations and religions since ancient times to the present day [1-15-78]. Industrial (*Cannabis sativa L.*) (hemp) is widely recognized as a versatile, sustainable, and revolutionary crop with over 25,000 potential applications ranging from construction materials to food, textiles, and biofuels [1-15-78]. The benefits of industrial hemp cultivation will uplift the socio-economic level of the farmers globally and can even add to the GDP per capita of nations to a great extent [1-15-78]. The stalks, seeds, and leaves are converted into various construction materials, textiles, paper, food, furniture, cosmetics, healthcare products, biofertilizers, hempcrete, bio hemp cake, bioplastics, automobile, painting industries, biofuels, and biopesticides, are some of the innovative applications of the plant [1-15-78]. Recent application research of hemp protein in food processing includes plant milk, emulsifiers, fortification of gluten-free bread, plant-based meat production, as well as membrane formation[1-15-78]. The hemp plant will continue to find new applications due to its unique properties for sporting goods, musical instruments, portable and wearable energy storage devices, semiconductors, nanomaterials, active

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packaging, bio-composite orthotic devices, and medical applications [1-65-78]. While fiber and seeds are the main by-products' from industrial hemp, hurds, leaves, and inflorescences, they are considered a waste of low economic value, also described as hemp biomass residue [1-65-76]. The future of the plant strongly depends on market demand for its bio-based products that will help the plant to establish itself as a worthy sustainable crop [1-15-78-85].

Moreover, its high nutritional value is comparable to soy and its unique characteristics in food processing appear to be high-profile in the food industry. Oil meal, a residual material of hemp seed after expression of hemp oil, is a useful protein-rich material [1-78]. Recent application of hemp protein in food processing reveals its unique properties. Especially, in recent studies, its cysteine-rich amino acid composition and high sulfhydryl (-SH)/disulfide (S-S) ratio offer a glimpse of its distinctive features useful in food processing [1-19-78]. As a rapidly growing plant (often reaching maturity in 3-4 months), it offers a sustainable alternative to traditional, resource-intensive materials. Hemp seems one of the most relevant gluten-free crop plants. Its high nutritional value is comparable to soy[1-15-78].

Industrial *Cannabis sativa* (hemp) is an eco-friendly and worthwhile crop that complements a sustainable growth system[1-15-78]. Industrial *Cannabis sativa* (hemp), as a diverse plant, can be a revolutionary crop for a better future and for upcoming generations. Industrial hemp farming has the potential to dramatically minimize the amount of carbon impact on the environment and can be cultivated with little or no usage of chemical pesticides or fertilizers[1-15-78]. The U.S. Farm Bills describe hemp as "*Cannabis sativa* L. and any part of that plant, whether growing or not, with a Λ-9 tetrahydrocannabinol (THC) concentration of not more than 0.3 percent on a dry weight basis [1-59]. The low Δ9-tetrahydrocannabinol content of industrial hemp (<0.3%) makes it non-psychoactive, distinguishing it from other *Cannabis* species, namely *C. indica* and *C. ruderalis* [1-60]. Industrial hemp (*Cannabis sativa* L.) is a versatile and sustainable multipurpose plant for agroecology services and a zero-waste circular economy [1-78]. The 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 fibre, seeds and oil [1-58-76]. 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 [1-55].

2. Industrial Applications of Hemp

Industrial hemp is re-emerging as a versatile and sustainable crop with broad applications across the food, fiber, construction, and bio-economy sectors[1-15-78-85]. Hemp is a sustainable plant requiring less water or pesticides in cultivation compared to cotton. It has a short growth period and almost its whole plant body has versatile utility value[1-15-78-85]. Its enduring value and adaptability have made hemp a lucrative crop that stimulates new markets and contributes to global economic growth while providing environmental benefits[1-15-78-85]. Hemp's economic appeal lies in its dual-purpose nature, yielding both agricultural outputs (fibre, seed and oil) and industrial raw materials from a single crop cycle[1-15-78-85]. This multipurpose crop provides growers with a sustainable and profitable alternative crop including cannabinoid production in many regions[1-15-78-85]. Hemp generally requires fewer pesticides and herbicides than conventional grain crops due to its dense canopy and pest tolerance, leading to lower input costs and reduced environmental impact[1-15-78-85]. Hemp seeds and oils, rich in protein, fiber, omega-3 and omega-6 fatty acids, have attained super-food status[1-15-78-85]. They are incorporated into health foods, snacks and dairy alternatives, meeting the needs of health-conscious consumers and supporting sustainable agriculture[1-15-78-85]. Hemp's high cellulose content is ideal for manufacturing biodegradable plastics and composite materials for packaging, automotive parts and consumer goods. These hemp-based products reduce reliance on petrochemicals and help tackle plastic pollution through compostability[1-15-78-85]. Following are the few industrial applications of hemp.

2.1. Functional food

The nutritional value of hemp is attracting attention [1-14-60]. Hemp seed is composed of a white kernel and brown hull. The kernel is rich in protein, unsaturated fatty acid, and dietary fiber [1-52-67]. Hemp shares a unique high-protein, low-carbohydrate nutritional composition with soybean, distinctively different from other representative food materials such as rice and wheat, the protein/carbohydrate (%, w/w) content of which is 7.17/77.55 and 10.6/73.2 respectively[1-54-78]. Hemp and soy are also rich in dietary fiber and unsaturated fatty acids. Hemp oil is popular and the oil meal, a by-product of oil processing, is utilized in many protein-rich foods as well as animal feeds[1-54-78].

The major protein in hemp kernel is **edestin**, accounting for around 70% of hemp protein. Edestin is a hexamer of identical subunits and belongs to the globulin family [1-57, 77, 78]. Each subunit consists of the acidic (−34 kDa) and the basic (18–20 kDa) chains [1-58-78]. An original single protein is cleaved into these two chains post-translationally at the Asn-Gly site [1-57, 77, 78]. As solubility in water and content of free SHs increases by sonication or pH adjustment of the edestin solution, control of the protein structure/function may be possible in food processing [1-60]. Despite its less solubility, edestin is known for its high digestibility [1-61,62]. The second major hemp protein is albumin, which has fewer disulfide bonds compared to edestin (globulin), thus having a flexible structure with higher protein solubility and foaming capacity [1-59-78]. Another noteworthy protein is rich in Met and Cys, and 20 mole % of the total amino acids of the contain sulphur[1-59-78].

Increasing demand for plant-based milk has enlarged its industry due to lactose intolerance, cow's milk allergy, and vegan lifestyles [1-75]. Hemp milk, with its highly nutritional value and low allergenicity, looks to be an attractive alternative to dairy, soy, and nut milks[1-75]. Comparison of milk products in the market reveals hemp milk as a better source of minerals than other dairy and plant milks. Hemp milk does not taste that different but has a "nuttier" flavor in comparison to soy or rice milk [1-77]. High pressure homogenization following pH adjustment realized non-thermally processed hemp milk, which is remarkably stable, showing negligible phase separation in storage for 3 days at 4 ◦C [1-78].

Stabilization of emulsion-based colloidal structures by food ingredients has attracted attention in the food and pharmaceutical, as well as cosmetic, industries [1-78]. In the Pickering emulsion, solid particles are adsorbed onto the interface between the two distinct phases, such as oil and water, and inhibit emulsion droplets from coalescence. Stabilizing the oil/water boundary by plant-based materials such as proteins and organelles is useful in exploring emulsion systems in developing new foods [1-78]. Examples include egg-free mayonnaise, barley-based non-dairy milk, probiotic encapsulation, as well as additive-free, gluten-free rice bread [1-78]. However, these bio-based emulsions tend to be unstable due to gravity-induced separation (creaming/sedimentation), flocculation, and coalescence. Hemp protein is considered a novel emulsifier in food systems[1-78].

Due to the world-wide prevalence of celiac disease and wheat allergy, demand for gluten-free foods, especially for bread, is increasing [1-73-78]. However, most gluten-free breads are starch-based and thus generally low-protein and high-carbohydrate[1-73-78]. Therefore, researchers are trying to improve the nutritional value of gluten-free breads by fortification of nutrients [1-73-78]. Hemp is one of the ideal food materials because of its high protein content, low content of saturated fats, and high content of unsaturated fatty acids such as omega 3 and omega 6 [1-73-78]. Addition of hemp protein concentrate significantly improved the nutritional value of the starch-based gluten-free bread [1-73-78]. It also changed the rheological characteristics of the gluten-free dough and reinforced the structure. Moreover, sensory acceptance on color and flavor was confirmed for the bread[1-73-78]. Limited amylopectin recrystallization as well as limited hardening of the crumb were observed during storage[1-73-78].

Demand for high quality vegan meat made of plant materials is increasing based on the shortage of animal stock due to the global increase of human population, as well as in view of animal welfare. Hemp cake, a residual material of oil expression from the hemp seed, has long been utilized for livestock feeds [1-73-78]. It is a highly nutritive as well as sustainable feed stuff for cows [102], quails [103], cockerels, pigs , and broilers. Now, research is in progress to utilize hemp protein "directly" as a material for plant meat[1-73-78]. The outer shell is made of the mixture of soy/hemp proteins which are linked with intermolecular disulfide bonds. Dietary fiber, isolated from the protein complex, is located in the bottom of the ball[1-73-78]. Thus, the ball has a low center of gravity and behaves like a "roly-poly" wiggle ball. In this case, hemp protein, rich in free SHs, is considered to work as a SHs donor, as egg white protein worked as a donor of free SHs in the bread made of egg white/soy protein isolate [1-73-78].

Hemp seeds are high-protein, low-carbohydrate, and rich in dietary fiber and unsaturated fatty acids. After expression of oil from the seeds, the residual mass is a useful protein-rich material for food processing[1-73-78]. Moreover, hemp seed protein has distinctive characteristics suitable for developing new foods such as an emulsifier, plant-based meat, and gas-retaining membrane[1-73-78]. The cysteine-rich protein feature realizes unique disulfide-mediated interactions with protein from other sources and is thus expected to facilitate development of new food materials[1-73-78]. Meanwhile, hemp protein is reported to be less soluble, and a higher temperature is needed for processing compared to other plant protein [1-78]. Therefore, suitable reaction conditions should be investigated for future application in the food industry[1-73-78]. Hemp seeds and the protein are expected to be promising food materials in the food industry[1-73-78].

2.2. Supercapacitors

Bowornthommatadsana et al., (2025) [64] and Klangvijit et al., (2025) [65] reviewed that for renewable electrical energy applications that require many rapid charge/discharge cycles, such as regenerative braking, supercapacitors are considered one of the most promising energy storage devices due to their higher power density compared to batteries[64, 65]. Activated carbon (AC), in particular, has been extensively utilized as electrode material in the field of supercapacitors[64, 65]. Hemp is used in supercapacitors by transforming its fibrous, woody waste (bast/hurd) into highly conductive, porous graphene-like carbon nanosheets [64, 65].

2.3. Crop Rotation

Nath (2022) [78] reviewed that the main motive behind crop rotation is to reduce the incidence of pests, diseases, and weeds that are difficult to control by pesticide application [78]. The introduction of hemp in crop rotation will not only improve soil health but also bring pest populations under control [78]. Crop rotation, according to reports, enhances soil organic matter and organic carbon [1-78]. The hemp plant also influences the soil structure by its deep root system [78]. The root system penetrates deep into the soil providing aeration, while simultaneously building soil aggregate sand preventing soil erosion [78]. Hemp is a treasure not only for the industrial sector but also a dignified plant for sustainable farming systems [78].

Industrial fiber hemp (*Cannabis sativa* L.) is an annual crop that requires minimal agricultural inputs and has a high potential to improve soil organic matter (SOM) accumulation in sandy soils, including soil fertility and yields [80]. Hemp cultivation, due to rapid growth and high biomass production, in addition to its deep-seated and entrenched roots, has vast potential in carbon (C) sequestration and nitrogen (N) accumulation[78-80]. Industrial hemp can also be successfully cultivated in the crop rotation system as a preceding crop in particularly followed by wheat and winter cereal to ensure SOM, thus SOC retention in sandy agricultural soils, which is often found to be scarce in sandy soils [80]. Hemp has a lower and more efficient water consumption compared to other bioenergy crops like maize, which is an essential strategy enabling resilience to water and heat stress in sandy soils during the growth period[80].

2.4. Phytoremediation

emp effectively improves the health and quality of the soil [1-78]. One of the important properties of hemp is phytoremediation, which refers to the ability of the plant to remove unwanted and harmful contaminants from air, soil, and water [1-78]. Heavy metals, such as cadmium, lead, and nickel, are absorbed by the plant, thereby reducing the effect of toxic metals in the soil as well as on human health [1-3-78]. Hemp, being a fast-growing crop, can absorb more contaminants and toxic metals in a shorter period, thereby rendering the soil contaminant-free at a faster rate [1-78]. Moreover, hemp has the ability to flourish in contaminated soils where other crops might not thrive [1-78].

2.5. Carbon foot print

Industrial hemp (*Cannabis sativa* L.) is a promising feedstock for low-carbon construction materials because of its carbon sequestration capacity, fast-growing cycles, and technical functionality comparable to traditional materials [63]. One of the study by Rivas-Aybar et al., (2023) [63] highlighted the ISO 14040:2006 LCA methodology to calculate the carbon footprint (CF) (expressed as CO_2 eq emissions) of hemp-based boards developed in Western Australia (WA), composed of hemp hurds and a bio-based binder [63]. Some examples of hemp's durability include its use for military sheets, mummification, canvases for artists, and cordage, due to it being impervious to insects and rodents without the use of any pesticide treatments [63]. Industrial fiber hemp exhibits superiority over other crops because of its notable drought tolerance[80]. The plants expansive root network, which proves favorable during drought periods, allows penetration into deep soil layers in pursuit of water and nutrients. Hemp has been identified as a sustainable source to overtake conventional practices, and its multiple products and derivatives are recognized and align well with the bio-circular economy model [80].

2.6. Hempcrete

Malabadi et al., (2023) [8] and Yusuf et al., (2025) [59] reviewed that the construction sector, responsible for nearly 40% of global energy demand and 30% of energy-based CO_2 emissions, is seeking eco-friendly, sustainable, carbon-negative materials to replace carbon-positive materials [8, 59]. Malabadi et al., (2023) [8] reported that hemp-lime composite, a composite made from mineral binder and plant-based aggregates, has gained attention as a natural building material [8, 59]. There are various ways in which hemp is being used to add value in the construction industry[8, 59]. The most common is hempcrete, which is produced by mixing hemp hurds with a lime-based binder and water [8, 59]. The mixture is typically formed into blocks and panels for insulation or infilling walls or cast in place [1-59]. Hempcrete, being highly porous and hydrophilic, can absorb up to 270% water after a few minutes and 400% water of its weight after 48 h immersion [8, 59]. It is more permeable than other construction materials and can work as a moisture buffering material due to its fast moisture transport and retention ability and high permeability[8, 59]. Malabadi et al., (2023) [8] and Yusuf et al., (2025) [59] confirmed that hempcrete has proven acceptable for non-load-bearing insulation in walls, floors, and roofs [1-59] Hempcrete, a lighter, hygrothermal, and acoustic filling material, can be a better choice due to its carbon sinking properties and shorter regrowth cycle compared to traditional concrete walls [1-**8**-59].

2.7. Thermal Insulation

Yusuf et al., (2025) reviewed that [59] hemp-based insulation materials have gained attention for their sustainable properties and performance in thermal and acoustic applications [57-61]. According to Yusuf et al., (2025) [59] comprehensive studies explored the efficacy of hemp fibre as an insulation material in textile-based construction applications [57-61]. Fiedler et al., (2025) [58] reviewed that the thermal insulation contributes significantly to the building's embodied carbon, the carbon dioxide emissions associated with material manufacture and building construction [57-61].

2.8. Cosmetics

Essential oils obtained from hemp seeds have a high value in the market[1-8-78]. Hemp oil with its natural ingredients can emerge as an alternative to petroleum-based cosmetics and other skincare products[1-8-78]. Cosmetic items from hemp include hand soap, shower cream, lip balm, face cream, foot cream, and many more[1-8-78]. The therapeutic effects present in these oil-based products and other benefits attract consumers who have a sensitive well-being and are environmentally concerned [1-8-78].

2.9. Beverages

Hemp drinks are the next big thing for the nutrient trade[1-8-78]. The higher part of the hemp is harvested, collected, and cold-pressed to obtain the hemp juice. The cold-pressing method helps in retaining the natural flavor, color, and active ingredients of the plant[1-8-78]. Hemp juice is considered an excellent organic food that is drug-free. Hemp milk is another product that can be obtained from hemp seeds. This can be an alternative for vegans around the world[1-8-78]. Hemp tea prepared from the leaves or flowers is devoid of any psychoactive effect, which makes it a quality product with therapeutic and soothing properties[1-8-78].

2.10. Hemp paper

Hemp paper has the potential to substitute for trees in terms of paper production, thereby stabilizing the effects of deforestation[1-8-78]. Hemp paper possesses higher strength, length, and fineness compared to conventional wood paper[1-8-78]. Moreover, the plant grows at a faster rate which implies more production of paper within a smaller period as compared to trees, which take years to grow[1-8-78]. Apart from that, the quality of paper obtained from hemp is better and more durable than that produced from trees [1-8-78].

2.11. Bioplastic

Biodegradable plastics made from plants such as hemp[1-30-78]. Hemp is making a strong comeback and is emerging as one of the fastest expanding agricultural and industrial markets[1-18-78]. The demand for hemp-based wellness and skin care products is the main factor behind the growth of the market globally. However, the legislative structure and its regulations for the use of industrial hemp are expected to hinder market growth [1-20-78].

2.12. Hemp-Based Microfluidics

Microfluidic analytical devices have a wide range of applications in point-of-care diagnosis, clinical tests, food safety measurements, and environmental protection [62]. Temirel et al., (2021) [62] reviewed that considering the advantages and drawbacks, hemp is a promising choice for biofuel production, oil extraction, the fabrication of interiors of automobiles, and biomedical applications, such as paper-based and polymeric microfluidic devices [62].

2.13. Horticulture

Hemp shives are used for mulching in horticultural orchards as well as gardens[1-8-78]. The mulch helps in maintaining soil moisture conditions, minimizing soil erosion, moderating soil temperatures, and suppressing weed growth [1-8-78]. As a result, it eliminates the need for weedicides and prevents seed germination of unwanted plants. Apart from that, hemp mulch protects against harsh and fluctuating weather conditions by acting as an insulating layer[1-8-78].

2.14. Biopesticides

Hemp essential oil shave emerged as a powerful tool for controlling insect pests[1-8-78]. Some researchers have claimed that the essential oils act as effective control tools against *Aedes albopictus*, also known as the tiger mosquito or forest mosquito, and *Physella acuta*, an air-breathing freshwater snail [1-8-78, 86]. Thus, biopesticides can be obtained from industrial hemp which in turn may reduce the dependence on synthetic pesticides to some extent[1-8-78]. This will not only help to affect the target pest but also safeguard natural enemies and other beneficial organisms[1-8-78].

Most importantly, hemp-based biopesticides are of minimal risk to human health as well as the soil and environment[1-8-78-87].

2.15. Painting Industry

One of the study by Aksoy et al., (2025) [71] developed and evaluated eco-friendly, high-performance road marking paints formulated with alkyd resins synthesized from hemp seed oil [71]. The study by Aksoy et al., (2025) [71] showed that hemp oil-based alkyd resins are effective sustainable binders for road marking paints, providing comparable or superior performance to conventional petrochemical systems[71].

2.16. Probiotic

Nissen et al., (2021) [75] reviewed that foods formulated with hemp (*Cannabis sativa* subsp. *sativa*) are being increasingly accepted by consumers, and the global sector is expected to generate almost USD 5 billion by 2026 with a CAGR (compound annual growth rate) of around 6.2% between 2019 and 2026 [75]. *Lacticaseibacillus rhamnosus*, *Lactiplantibacillus plantarum*, and *Limosilactobacillus fermentum* harbor different alpha-glucosidases that make them ideal to ferment plant-based stuffs; besides, strains of these species are considered probiotics, such as *Lacticaseibacillus rhamnosus* GG (LGG), *Lactiplantibacillus plantarum* K10 [12], and *Limosilactobacillus fermentum* ME-3 [1-59, 75]. The fermentation process proposed by Nissen et al., (2021) [75] was able to reduce unpleasant VOCs, whilst at the same time keeping the healthy ones, and it also improved nutritional quality, depending on time and bacterial starters [75].

2.17. Solar Panels

Researchers at the University of Ottawa, Canada [70] reported that organic electronics where the active material is carbon-based – are making possible diverse new technologies ranging from sensors for monitoring cannabinoid levels in cannabis plants to lightweight, bendable solar panels [70]. A benefit of using hemp (*Cannabis sativa* L) in construction is its ability to sequester carbon dioxide during plant growth, thereby providing the potential to create carbon-negative materials [68, 69]. This study Aybar et al (2024) [69] reported an application of an eco-efficiency framework to explore options for improving the environmental and economic performance of non-load-bearing hemp-based construction boards at the production stage in Australia [69].

2.18. Carbon Materials

Yusuf et al., (2025) [59] reviewed that the need for high-performance carbon materials for applications in energy storage, composite fibers, adsorbents for water purification, and heavy metals removal has increased in recent times [56- 59-70] Carbon-based materials include biochar, biomass carbon, activated carbon, carbon fibers, and carbon nanotubes [56-59-70]. Hemp carbon materials have also been widely used as an adsorbent to remove hazardous metals [56-59-70]. Hemp-derived activated carbon performed better than flax and sisal-derived activated carbon [56-59-70].

2.19. The automotive industry

Yusuf et al., (2025) [59] reviewed that the automotive industry earnestly began to adopt the use of natural fibers in the late 20th century as environmental consciousness grew and regulations began to be tightened around material recyclability and sustainability [1-70]. This change became more pronounced around the 1990s when the major automakers like BMW, Mercedes-Benz, and Audi started to incorporate natural fibers like hemp, kenaf, and flax into their vehicle interiors [59]. Hemp-based composites are used in various automotive parts, especially in non-structural and semi-structural applications[59]. The most common use is in interior panels like door trims, dashboards, seat backs, and trunk liners, where producers can take full advantage of hemp's low density, acoustic properties, and tactile feel, all of which provide functional and esthetic benefits [59].

2.20. Emulsifiers

Abbel et al., (2024) [72] reviewed that applying coatings of paraffins and other synthetic waxes is a common approach to impart hydrophobic properties to fibres and thus control their surface characteristics [72] . One of the study by Abbel et al., (2024) [72] reported the coating of hemp fibres with waxes extracted from pine bark as an exemplar application [72]. Two bio-based emulsifiers were used to prepare wax emulsions suitable for a dry blending process [72]. While successful deposition was demonstrated for all tested formulations, coating homogeneity varied for different emulsifiers [72].

2.21. Biofuels

Hemp oil is used as a biofuel. Biofuels made from hemp-like bioethanol and biodiesel have the potential to replace the utilization of traditional or fossil fuels. Biofuels made from hemp will inherit the usage and emerge as renewable alternatives [1-7-55, 77, 78].

3. Conclusion

Industrial *Cannabis sativa* (Hemp) is an annual plant that has applications in the food, beverage industry, hemp probiotic milk, functional food, hemp based energy drinks, hemp seeds as food additives, biodiesel, bioethanol, hemp oil as medicine, CBD for heart attack, CBD antiviral activities against Nipah virus, dengue virus, monkeypox, Lumpy skin viral disease, cancer, cardio vascular diseases, thermal insulators, the textile industry, biochar, hempcrete, biofertilzers, biopesticide, bioplastic, thin films for food packaging, hemp based-nanoparticles, hemp in painting, hemp in 3D printing biocomposites, carbon electrodes for supercapacitors, hemp paper in microfluidics, hemp made solar panels, hemp based carbon foot print, hemp in automobile industry, paper industry, hemp based semiconductors, cosmetic products, garden products, bio-oils, biofibers, paper fabrication, the refinement of water and sewage, nutritional supplements, reinforcing composites, plastics, and phytoremediation (i.e., removing heavy metals from contaminated soil by cultivating plants). Commercial applications in textiles, biocomposites, packaging, and, most importantly, advanced areas such as hemp-based carbon materials (Biochar) for storing energy, biomedical materials, and smart biomaterials**.** Industrial hemp production has seen significant growth globally, driven by its versatility and sustainability potential, though it generates substantial waste, which presents both challenges and opportunities**.** The stalks, seeds, and leaves are converted into various construction materials, textiles, paper, food, furniture, cosmetics, healthcare products, etc. Nutraceutical- and health-product-based markets are about to grow in the coming years, owing to the increasing awareness about health among end-users. Bioplastics, biofuels, and biopesticides are some of the innovative applications of the hemp plant, which is the subject of research and debate at present time.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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