

The application of hemp (*Cannabis sativa* L.) for a green economy: a review

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Abstract: The concern for the issues related to the growing needs of human civilization like resource depletion, pollution, climate changes, and health risk has led to a search for eco-friendly alternatives to environmental problems. Recently, hemp started gaining popularity for its medicinal, nontoxic, greenhouse negative, and biodegradable properties. Originating from the steppes of Central Asia, *Cannabis sativa* L. (hemp) is one of the oldest domesticated plants known to humans. Since 5000–4000 BC, different parts of the plant were used for spinning, weaving, papermaking, the seed for human feed, animal feeds, medicinal, and health purposes. Reports also suggest the use of hemp as an organic additive in the historic earthen plasters of Ellora Caves, India (6th Century). Due to its psychoactive and recreational properties, this environmentally friendly plant lost its importance eventually in the 19th century and its cultivation was made illegal. People, in general, changed their outlook towards the plant and considered it a sign of moral indignation. Recently, food, pharmaceutical, textile, paper, building, energy, and other industries found hemp to be a promising solution for synthetic-based economies. Since then, the cultivation of hemp has been reintroduced, legalized in some countries, and now in recent times, there has been a good reimplementation of the plant in creating a green economy. This review will highlight the application of hemp and display its outstanding qualities in minimizing environmental and health issues. Based on the knowledge gained from various scientific resources; the commercial, industrial, and agricultural potential of the plant will be unveiled to give more push towards the hemp cultivation.

Key words: Eco-friendly, biodegradable, reimplementation, green economy, reintroduced

1. Introduction

For thousands of years, hemp (*Cannabis sativa* L.) has been one of the oldest domestic species of value to humans (Schultes, 1970; Fike, 2016). The genus *Cannabis* originated in Central Asia and then eventually diversified in different regions of the world. The fast growth of the plant in both temperate and tropical climatic conditions and the enrichment of the soil after every crop on cultivation attracted many people to grow it (Singh and Sardesai, 2016). Since then, it has accompanied humans for ages for various purposes. The first evidence of its cultivation is from the Neolithic period (around 4000 BC) and it came from the archaeological findings of pollen grain deposits from the village named Pani-p'o in China (Li, 1974; McKim and Hancock, 2013). Moreover, the hemp macroscopic and microscopic structures were reported in tombs of the Turpan Basin of China (Jiang et al., 2006). The fibers of *Cannabis* plant were characterized in the pots belonging to 10,000 years ago in Taiwan. Hemp was farmed as a major crop since ancient times in China for production of clothing, rope, paper, oil, sails, etc. and was amongst the five most commonly

used grains (Touw, 1981). The use of hemp in ancient cave murals of Ellora dating back from 6th century CE to 11th century CE and in the massive Daulatabad fort for lime plasterwork suggested that the people during those times had a good knowledge of hemp and its use in the construction (Singh and Arbad, 2014; Singh and Sardesai, 2016).

As the plant grew in most climatic conditions, cultivation of hemp was easily possible in many parts of the world. Cultivation of hemp started in western Asia and spread from China to Egypt and then reached Europe between 1000 and 2000 BC. Hemp has an exceptional quality of growing in pesticide- and herbicide-free condition (Bender, 1994; Zuardi, 2006). Acid-free and less deteriorating resistance to rodents, fungus, and many types of weeds makes it a very durable plant for commercial purposes. As this heterogeneous plant is a composite system in itself due to its properties and microstructural complex, with the advancement in science and technology, the plant was transformed into many serviceable products (Brett and Waldron, 1996; Dai and Fan, 2010). Hence, food, pharmaceutical, textile, paper, building, energy, and

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other industries find hemp to be a promising solution for synthetic-based economies (Figure 1). In coming years, it is anticipated that the global market of products made from hemp may increase multiple times and hemp may acquire its reputation again as a promising raw material and leading symbol for sustainable agriculture.

2. History and ethno-botany of plant use

The hemp plant has been distributed globally since ancient times owing to its easily adaptive climatic requirement to grow in both temperate and tropical environments. It does not require much effort for growth and development. Although the plant is described as a potent psychoactive and only cultivated legally, it was a well-known plant in ancient times and was harvested for a number of purposes like rope, clothing, and sails. All the parts of the plant like seeds, flowering heads, and leaves are used for various purposes. Seeds were used for producing oil. For producing oil, seeds were crushed and then were used in lamps or for cooking. The seeds have also been used

as food and medicine in China for 3000 years and even now it is used in kitchens in Nepal (Touw, 1981; Zuardi, 2006). The plant fiber made from the stem has excellent durability and was used for making strongest ropes, pots, net fabrication, paper making, ropes, clothing sails, etc. (Li, 1973; Pringle, 1997; Maisto, Galizio and Connors, 2014). The leaves were used for smoking and enjoyed for its recreational properties. The leaves and flowers had medicinal value and mind-altering properties.

Builders of ships used the ropes made from hemp as they were the strongest and most durable ropes at that time. The fruit of hemp known as achene is a tiny nut covered with a hard shell (Li, 1973; Touw, 1981; Maisto, Galizio and Connors, 2014). It is consumed as food, crushed for making oil for cooking, and is also used as medicine for various herbal formulations (Bouquet, 1950).

The use of hemp by humans is so ancient that its appearance in writings cannot be traced exactly. Its use and consumption are very ancient, even before the appearance of proper writings and archival records.

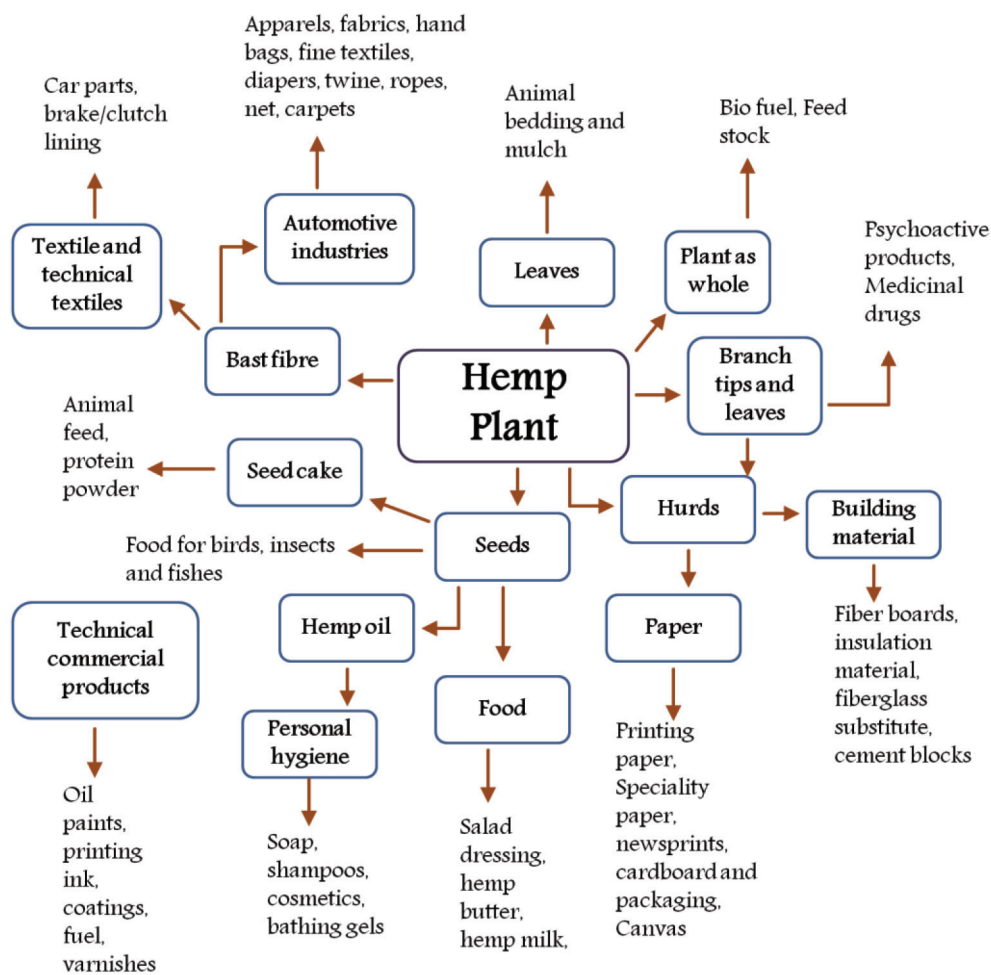


Figure 1. Overview of hemp plant uses.

The records of its use in medicinal formulations were mentioned in the compendium of Chinese medicinal herb book written in 2737 BC by Shen Nung, the emperor of China (Li, 1973; Merlin, 2003). The cultivation and utilization of hemp then spread from China to India for seeds, medicines, fiber, and recreational consumption (Mechoulam, 1986). In India, the plant was integrated into religious aspects and was considered holy. The plant was included among the five most sacred plants of Hinduism and the leaves were smoked during the daily devotional service. For religious purposes, the leaves were thrown into fire to overcome enemies and evil forces (Chopra and Chopra, 1957). There was also a religious belief that the guardian angel thrives within the plant's leaves (Zuardi, 2006). This secret virtue eventually became part of numerous religious rituals in India. In Atharveda, the sacred book of Hinduism plant also holds religious importance and is considered one of the five sacred plants worshipped (Aldrich, 1977). In 'Sushrita' the first record of medicinal uses of *Cannabis* in India was compiled around 1000 BC and also in Indian texts like Tajnighuntu and Rajbulubha *Cannabis* has been listed (Bouquet, 1950; Schultes, 1970). Herodotus, a Greek writer, has mentioned the use of hemp seed; in his culture the seeds were buried ritually for euphoric effects (Zuardi, 2006). Persians and Arabs also mentioned the use of the plant from the 13th to 14th century in the book named "Avicenna's Cannon of Medicine" in Persia, and Al-mayusi and Al-badri in Arabic. In ancient Egypt, during the building of pyramids hemp was used in a special procedure to break stone during construction (Ruman and Klvanova, 2008; Singh and Sardesai, 2016).

Hemp was brought from India to Africa by the Arab traders and it was used by Africans for treating malaria, fever, asthma, and dysentery (Zuardi, 2006). By the 15th century, the utility of plant was famous in South America via traders. Later it reached Brazil, where it was considered as a plant having spiritual importance. The Brazilians used hemp in rituals for celebrating "Catimbo" (Zuardi, 2006). In the 15th century, apart from the traditional uses, the fiber was also used as a net for netting, clothing, and painting canvas. The great artists Master Rembrandt and Van Gogh also used hemp seed oil in the preparations of paint mixes (Ruman and Klvanova, 2008).

William-O-Shaughne, in his published book named "On preparation of Indian hemp or gunjah", states the utility of hemp came into notice and got popularity in the western world by the 18th century for its therapeutic values mostly (Wujastyk, 2002; Zuardi, 2006). Furthermore, by the 19th century, the plant was included in official pharmaceutical repertoire in Europe and USA.

3. Biochemistry

Biochemistry of a plant determines its molecular mechanisms, chemical setup, the chemical processes

involved, and cellular components and their interactions. Like any other plant, *Cannabis sativa* L. consists of the basic plant setup having cellulose polymeric chains aligned by microfibrils. The primary metabolites are very similar in composition and amounts to any other plant. It is the secondary metabolites that are very important to hemp. Cannabinoids are terpenophenolic compounds unique to hemp. They are produced by glandular trichomes that occur on most aerial surfaces of the plant (Nixdorff et al., 1975; Dayanandan and Kaufman, 1976). Out of the total 450 secondary natural chemicals produced, the major contribution belongs to cannabinoids (Andre, Hausman and Guerriero, 2016). More than 90 cannabinoids have been reported so far and the predominant compounds are tetrahydrocannabinolic acid, cannabidiolic acid, and cannabinolic acid followed by cannabidgerolic acid, cannabichromic acid, and cannabinodiolic acid (ElSohly and Slade, 2005; Brenneisen, 2007; Radwan et al., 2008; Fishedick et al., 2010) (Figure 2). These terpenophenolic compounds are unique to *Cannabis* and are mainly produced by glandular trichomes of the plant (Potter et al., 2008; Andre et al., 2016). These cannabinoids are predominantly in the form of carboxylic acids and with time, by drying of harvested plant or by heating, the cannabinoids get decarboxylated. The psychoactive property of the plant is due to a compound named delta-9-tetrahydrocannabinol (THC). Above a threshold level of 0.3% THC, the cultivation of the hemp plant is banned as it induces toxification (Leyva et al., 2011). There is a general inverse relationship between THC and CBD. The drug strains of hemp contain THC and very little or no CBD. On the other hand, fiber and oilseed strains contain very little THC.

The knowledge of the biochemistry of hemp is important because the studies suggest that its importance will increase as a raw material for sustainable development and form a good base for further use and modifications industrially and agriculturally. Studies on derivatives from the *Cannabis* plant are still full of surprises and possibilities, which sustains our fascination with the plant. It is expected that, in the near future, advancements in biochemistry will improve the gene technological studies associated with the plant, help in maintaining cannabinoid levels, manipulate the chemical contents and form a strong base for producing sustainable raw material in the near future for various uses.

4. Hemp as a new biocomposite

Composite materials, which are derived from a biological origin, are known as biocomposites. They are formed with one or more phases of reinforcement of natural fibers with organic matrix or biopolymers. The biological components and reinforcements include plant fibers such

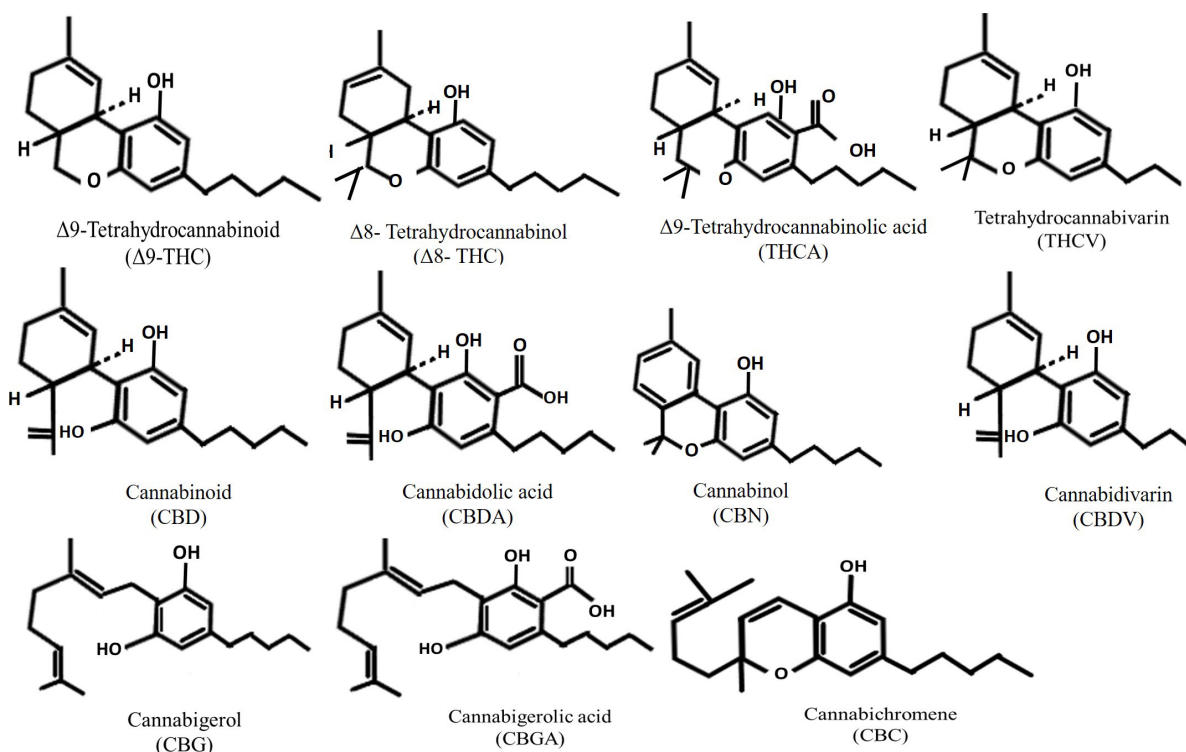


Figure 2. The chemical structure of cannabinoids in the hemp plant.

as cotton flax and hemp or fibers derived from waste paper or by-products from food crops. These materials attract great interest because of their many superior properties and applications.

Hemp has been a raw material for the industry for more than 2000 years. Eventually, as it lost its importance, people only considered it a major mind-altering drug and it lost its industrial value. In the 1990s, it was rediscovered as an important raw material for bio-based products in a sustainable bioeconomy, and the most important application was as a biocomposite (natural fiber reinforced plastic).

Reinforcement of hemp fibers to produce hemp-biocomposites can be a very valuable option to produce sustainable bioproducts (Garcia-Jaldon et al., 1998; Finnan and Styles, 2013; Rehman et al., 2013). Such biocomposites are present in various forms such as films membranes, molding coating particle fibers, and foams. They account for 14.4% of the applications (Carus et al., 2013). The press moulding biocomposites are popular among all the other biocomposites and have a wide spectrum of high-quality applications. Hemp can be reinforced to produce insulation mats and interior panels for cars (Somma, 1923; Schultes, 1970; Schultes et al., 1974; Holbery and Houston, 2006) and expanded starch foams in food packaging sector (Jabeen et al., 2015). Until now, the only really established application of hemp biocomposite has been in automotive

interior parts. Automotive biocomposite consumption is growing and usage in door panel/inserts, trunk liners, spare wheel covers, parcel trays, headliners, and many more products is also gaining popularity.

Hemp biocomposites show good strength, durability, lightweight, and good accidental behavior. The biocomposites made from hemp are popular in Germany, France, and the Czech Republic industries.

5. Hempcrete technology

The mixture of hemp hurds/shiv is combined with lime binder and water to form a concrete-like substance known as hempcrete. The ancient Indians used hemp in the 6th century Ellora caves i.e. almost 1500 years ago by mixing it with clay/lime plaster. This indicates that the ancient Indians were aware of hemp use in construction. In addition, buildings made from hempcrete hundreds of years ago are still standing in France, which indicates the durability of building material (Singh and Sardesai, 2016). Traces of hemp fiber were found by the archaeologists in construction of a bridge dating back to the 6th century AD in southern France. These findings revealed that the hempcrete technology is not new and hemp is used as a biocomposite material for a long time.

In recent times, the construction of buildings and roads in the built environment is in great demand for both the developing and developed countries. The

emissions from fossil fuel combustions and the associated greenhouse gases released in the atmosphere during the construction are principal factors for ruining the current climatic conditions and environmental health. Therefore, there is a need for valid replacements or alternatives which will reduce the carbon footprints of buildings and help in saving our natural resources. Such alternatives will promote the development of sustainable construction materials and replace synthetic-based products.

The inclusion of hemp in the construction would resolve many current environmental issues. The major advantage of using hempcrete in houses and constructions is that it sequesters carbon dioxide from areas of construction and provides greenhouse negative atmosphere to live in. *Cannabis* is said to sequester around 249 kg of carbon dioxide per ton of hemp used. Hempcrete is thermally stable and makes house fire-resistant (Singh and Mamania, 2018). Another important advantage of using *Cannabis* is that it is a good insecticide and insect repellent, so the wood is less prone to damage and has long durability. High insulation power of hemp wall lowers energy consumption costs by half. For example, if the conventional walls have 12–15 R-value, hemp has an R-value of 30 for a 12-inch wide hempcrete wall, which is almost the double¹. The R-value is the measurement of a material's capacity to resist heat flow from one side to the other. Currently, many construction companies are producing hemp plaster under market names like Hempcrete, Canobiote, Canosmose, and Isochanvre². Hempcrete is used for floor slabs and ceiling insulation and as an internal coating for renovating old stone walls. Depending on the purpose, hemp hurds and lime mix concentration changes. Given the potential positive environmental benefits, including the potential for carbon sequestration and the economic benefits to the manufacturing, rural, and construction sectors, further research and investigation into hemp lime as a construction material should be encouraged.

6. Hemp as food

Utilization of hemp as food is traced back to around 3000 years ago, when the Chinese and Nepalese used it as a major food commodity (Touw, 1981; Zuardi, 2006). However, hemp eventually lost its importance as food while its psychoactive properties received more attention and its cultivation became illegal. As the nutritionists researched hemp, it was revived as a very healthy source of food. The unique nutritional quality is due to the presence of hemp seed protein called edestin. In the entire plant kingdom, hemp has the highest amount of this protein in the seed. It is the richest source of alpha-linoleic acid (ALA) and

represents a very good source of healthy fat, particularly for those who do not consume fish or eggs (Abedi and Sahari, 2014). Hemp seed also contains phytosterols, which help in reducing the amount of cholesterol in the body by removing fat build-up in the arteries. As the nutritional qualities of the hemp seed have become known, many new products have been released in the market. Some of them are hempseed butter, hempseed oil, hemp milk, and hemp flour.

Hemp butter is a pure ground form of hempseed nut similar to almond and peanut butter. As it is made from hemp seeds and the seeds have chlorophyll content, the color of the hemp butter is slightly greenish. It is made at home and also commercially produced. The reviews of hemp butter are quite interesting and the people seem to enjoy it and find it delicious. People use it in smoothies, salad dressings, and also as spread on a sandwich. Edible hempseed oil is also gaining popularity for making smoothies as healthy substitutes. It is used in salad dressings and sauces, or is drizzled on the meals. It could also be taken as a supplement. The oil is packaged in a dark and opaque bottle and needs constant refrigeration. Another upcoming product, the hemp milk has become very popular and it can be made at home by blending the seed nuts with water in 3:1 ratio and then straining it. The milk has exceptional nutritional value with medicinal properties, which can be very helpful for health maintenance³. Hemp flour is also incorporated in baked goods using other processed ingredients. The exposure of hemp as food is a very upcoming addition and people are responding well to it.

7. Medicinal uses of hemp

Medicinal importance of hemp is has been widely known since the very beginning even before the proper documentation. People have been writing the documented experience of hemp for 6000 years. These documentations have been very important for spreading knowledge related to its medicinal use. Around 1000 BC, in medicinal documentation like 'Sushrita', the use of cannabis was first recorded. Moreover, in the Indian literature like *Tajnighuntu* and *Rajbulubha*, hemp has the references for its use in the treatment of various problems related to clearance of phlegm and expelling of flatulence. In addition, these books mention the use of cannabis for sharpness of mind and eloquence increase, as appetite stimulant, in gonorrhoea treatment, and also as a general tonic (Schultes, 1970; Bouloc, 2013).

The physical evidence about the use of hemp was found by an Israeli scientist. He found the residues of the hemp

¹ <https://www.ukhemp.co.uk/articles/hemp-for-construction>

² <https://en.wikipedia.org/wiki/Hempcrete>

³ <https://www.healthline.com/nutrition/hemp-milk#bottom-line>

plant within the body of young women who apparently died during childbirth 1600 years ago (Martin et al., 1993). Apart from Indian medicine, Arabic medicine also used hemp in the medicinal preparations. Hemp was regarded as effective in the treatment of epilepsy. As mentioned in the written records of the Arabic medicinal book named *Al-badri* of 1464 BC, leaves of hemp cured Chamberlin's epileptic son. In the 19th century, Queen Victoria's doctor used hemp to elevate the labor pains and dysmenorrhea (Baker et al., 2003). Also in Egyptian papyri, the use of hemp to ease childbirth is mentioned (Nahas, 1973). Between 117 and 207 AD, Hua T'o, a physician and the founder of Chinese surgery, described and reported the use of hemp as an analgesic when mixed with wine, finding it to be a good anesthetic for patients (Nahas, 1973; Schultes et al., 1974).

All the historical evidence above proves that the medicinal importance of hemp is immense. Hemp can cure many diseases including rabies, epilepsy, anxiety, rheumatism, and even respiratory conditions like bronchitis and asthma (Li, 1974). As mentioned in historical sources, with more refined knowledge and technologies, the plant was used for many purposes, such as analgesic (neuralgia, headache, and toothache), anticonvulsant (epilepsy, tetanus, and rabies), hypnotic, tranquilizer (anxiety, mania, and hysteria). Hemp was also used as an anesthetic, antiinflammatory (rheumatism and other inflammatory diseases), antibiotic (topical use on skin infections, erysipelas, and tuberculosis), antiparasite (internal and external worms), antispasmodic (colic, diarrhea), digestive, appetite stimulant, diuretic, aphrodisiac or anaphrodisiac, antitussive, and expectorant (bronchitis, asthma) (Schultes et al., 1974; Baker et al., 2003; Ruman and Klvanova, 2008; Andre et al., 2016). Harnessing the THC content in hemp was shown to have a significant impact on the stimulation of appetite in patients with cancer and AIDS (Amar, 2006).

The therapeutic potential of hemp led to the opening of new areas in research of hemp as a pharmaceutical product. As pharmaceutical companies became acquainted with the properties of hemp and its exceptional compounds, many formulations were made. In 2003, hemp entered the world of pharmaceuticals and many multinational giant companies shifted their focus on hemp pharmaceutical products. GW pharmaceutical joined hands and made exclusive marketing agreements. Certain medicines are now FDA (Food and Drug Act) approved and are sold in pharmacies. However, in coming years, the usage of these medicines will be more common and they will be easily available in the market.

8. Hemp in the automotive industry

Disposal of old used cars is a major issue in waste management as 25% of vehicle waste by weight includes plastics, fibers, foam, glass, and rubber remains. To protect the environment from the internal combustion engine and for the sake of waste management, the world has finally decided to take measures in the right direction. The inspiration of using hemp in the automobile industry comes from the fibrous hemp dating back to around 1940, when Henry Ford, founder of Ford Motor Co. made hemp-based car plant in 1940 (Peças et al., 2018). Later, with the advancements in technology, automotive industry has shown great interest in using hemp fibers to make materials that can be molded and products that are a good replacement for fiberglass (Marsh, 2003). Moreover, cars made using hemp would easily be buried at the end of their life and would be naturally consumed by bacteria.

The hemp woody fibers are used as good substitutes for glass fibers (Garcia-Jaldon et al., 1998). The use of hemp for making car parts is unestablished yet, but slowly as hemp's industrial uses are coming up in better ways, many states and countries across the globe are encouraging the use of hemp in the automobile industries. The bales of raw hemp are turned into fibrous sheets and are later fed into machinery that creates autodoor panels. Flexform Technology and Johnsons controls have come up with a car door liner made up of hemp. The sheets like maps of nonwoven hemp fibers are spread with resin and pressed into the appropriate shape. Hemp Inc. company claims that hemp could make a stronger panel for cars and give a good solution for replacing petroleum-based plastic and fibers⁴.

In 2012, James Meredith, a researcher from Warwick University, UK has published a paper where, he has tested specific energy absorption (SEA) of three natural composites, namely unwoven hemp, woven flax, and woven jute. He concluded that the hemp withstood the greatest SEA proving it can withstand huge pressure relative to its very light mass (Meredith et al., 2012). These studies indicate that hemp can be a viable substitute for fiberglass used in car paneling.

Currently, BMW and Mercedes also make use of hemp composites in high-end models and BMW showcase cars such as i3 electricity car and i8 hybrid supercar as a concept car that has partly been built from hemp plastics. A car named Kestrel was made by Canadian motive Industries using hemp. It weighs around 2500 pounds and is at a very affordable price⁵. The body of the car is entirely hemp made and is completely impact resistant. The impact resistance was proved by passing the bodyshell with a crash test. The panel bounced back into shape, unlike steel. The

⁴ <https://www.hempinc.com/industrial-hemp-retooling-auto-industry/>

⁵ <https://greenerideal.com/news/vehicles/0926-worlds-eco-friendly-car-made-hemp/>

mechanical properties, lightweight and efficiency make it more advantageous than glass fiber.

9. Hemp seed, hemp oil and its nutritional potential

In science and marketing of food, hemp seed and oil are beginning to be recognized very recently. The nutritional composition and culinary versatility are very much in line and trending for its active pharmacological properties. In countries like Canada and China, almost all of the hemp is grown for the production of seed and oil only. The whole seeds, dehulled seeds, and oil from seeds are used for various applications. The whole seeds constitute 73.2% use of total production. It is the cheapest and least processed product. Out of 73.2%, 67.2% is used as animal feed for birds and fish and 5.1% is used as human food (Small, 1979; Paris and Nahas, 1984; Grinspoon, 1993). From the total of 11.7% use of production of dehulled seeds, mainly 9.5% is used for human food and only 2.2% for animal feed. Hemp oil is the most expensive product accounting for a total of 15.7% of total hemp production usage. Out of the 15.7%, 15.4% is used for human food preparations, 0.3% for cosmetics, and 0.3% as animal feed (Leizer et al., 2000).

Whole hemp seeds comprise 20–25% of proteins, 20–30% of carbohydrates, and 10–15% of insoluble fibers (Theimer and Mölleken, 1995). Along with these major nutritional components, these seeds have a very rich array of minerals like phosphorus, potassium, magnesium, sulfur, and calcium, and small amounts of iron and zinc (Jones, 1995; Wirtshafter, 1995; Rodriguez-Leyva and Pierce, 2010). Zinc is an important co-factor required by carotene and carotene is a precursor for Vitamin A (Erasmus, 1993). This means that the oil is a good source of vitamin A in humans and a potentially important contributor to dietary fiber. On top of this hemp seeds contain adequate amounts of vitamin E, B vitamins including folate, and vitamin D3. Hemp seeds are also a good source of iron and chlorophyll. This iron and chlorophyll content makes it a beneficial source of food for making the blood pure, nourished, and detoxified.

The protein content in the hemp seed has a very good digestible balance of all protein uniquely containing all of the 21 known amino acids—including 9 essential amino acids (EAAs) (Osburn, 1992; Jones, 1995; Wirtshafter, 1995). These amino acids are labeled “essential” because the human body cannot produce them on its own. Amino acids carry out many important bodily functions including giving cells their structure and are essential for healing wounds and repairing tissue. The unique protein edestin (65–67%) is the most easily digestible protein and very similar to the human body’s own globular proteins found in blood plasma (Angelo et al., 1968). This protein produces antibodies which are vital to maintaining a healthy immune

system and since this protein closely resembles the globulin in blood plasma, it is very compatible with the human digestive system (Nixdorff et al., 1975). This could explain why there are very few reported food allergies to hemp foods. Edestin protein has also been shown to promote a healthy immune system as well as eliminate stress. Hemp seeds also are free of trypsin and oligosaccharide inhibitors and these inhibitors affect absorption and digestibility of other plant sources of protein (Guillamón et al., 2008).

Hemp oil is mainly produced from whole hemp seed extraction, has a unique composition of easily digestible complete protein in high amount and a rich endowment of oil, providing a favorable ratio of the linoleic acid (LA) (C18:2w6) and α -linoleic acid (LNA) (C18:3w3) as its major omega-6 and omega-3 polyunsaturated fatty acids (PUFA), respectively, required for proper human nutrition, unlike other plants. The ratio of 3:1 (LA to LNA) and this proportion is alleged to be optimal for nutrition and hence comprise the most desirable contents of the oil (Erasmus, 1993; Callaway et al., 1996; Deferne and Pate, 1996). The balanced 3:1 ratio (LA to LNA) prevents excessive ingestion health problems unlike most of other oils. No other single plant source contains the oils essential to life in this perfect ratio as hemp. The optimum ratio of omega-6 and omega-3 polyunsaturated fatty acids (PUFA) promotes the accumulation of metabolic products during ingestion and hinders fatty acid imbalances in metabolic pathway (Simopoulos, 2008).

In addition it has also the significant contribution of γ -linolenic (C18:3w6) acid of potential therapeutic efficacy (Deferne and Pate, 1996). The γ -linolenic acid in hemp oil makes it nutritionally superior like most of the seed oils. This omega-3 PUFA have anticancerous, antiinflammatory, and antithrombin properties. Additionally, it also increases the metabolic and fat burning rates in humans (Erasmus, 1993). There are also other constituents which are contained within the oil such as β -sitosterol, β -amyrin, and methyl salicylate that enhance the nutritious value of hemp seed oil and increases its effectiveness as a functional food and possesses beneficial properties as well (Weil, 1993; Gutiérrez and del Río, 2005). The fat in hemp seed oil is 75–80% polyunsaturated fat (also known as EFAs) and less than 10% saturated fat (Callaway, 2004). The highly polyunsaturated oil has similar uses to those of linseed oil like fuel for lighting, printer ink, and wood preservative. Industrially, the oil also served as a raw material for soaps and detergents (Olschewski, 1995) and as an emollient in body-care products (Rausch, 1995). The right quality management and marketing strategies can enhance the utility and consumption and eventually its business value will increase incrementally in the near future.

10. Hemp use in papermaking

In the 12th and 13th century, the idea of making paper from hemp came from China to Europe and later spread to the other countries. This means that the use of hemp as paper or for paper production is not new. In early times, hemp paper was made from used ropes, sails clothes, fishing nets, and rags. Until the 19th century, 75–80% of the total world paper production was from hemp fiber processing. Hemp paper was widely and primarily used. Hemp use as paper was so popular that the Declaration of Independence and the US Constitution were written on it, and later copied on the parchment (Dąbrowski and Jadwiga, 1991). Many great novels like 'Alice in Wonderland' by Lewis Carroll were printed on hemp paper (Dąbrowski and Jadwiga, 1991)

Globally, 89% of the world paper production comes from the wood and only 11% comes from nonwoody plant fiber (Edyta et al., 2015). In the whole world, only 23 paper mills use hemp fiber for paper production (Edyta et al., 2015). These countries include the USA, UK, France, Spain, Turkey, and Eastern Europe. Papers produced in these mills are of excellent quality and durability. High-quality specialty papers for writing and printing, archival papers, security papers, filter papers for technical and scientific analysis, insulating papers, greaseproof papers, coffee filter, tea bags, handmade papers, biblical papers, and various specialty art papers are the types of papers made from hemp currently produced across the globe (Bouloc, 2013).

Hemp is a unique plant for making paper. The plant consists of 20% fibers and 80% bast that are composed of around 50–77% cellulose (Edyta et al., 2015). The fibers are the strongest natural fiber in the world and the amount and content of cellulose is a perfect raw material for paper production (Lower, 1937; Edyta et al., 2015). The paper made from hemp contains three times more cellulose and in quantitative terms from a hectare of hemp land, a quadruple amount of paper can be produced (West, 1921).

There are several advantages of hemp paper that make it more unique. It is very durable and do not turn yellow with age (Conrad, 1994). It does not require bleaching and can be whitened, if at all turned yellow, by using hydrogen peroxide. Hence, paper made from hemp does not have toxic content like chlorine or dioxin as opposed to paper made from wood. The chemical processing during paper making is minimum and less toxic compared to normal wood pulp paper. The greatest advantage of hemp-made paper is its recycling power. Compared to the normal pulpwood paper that can be recycled thrice, hemp-made paper can be recycled around 7–8 times (Edyta et al., 2015).

In the current scenario, hemp in papermaking has still a long way to go as wood pulp is primarily utilized in papermaking. The pressure of paper demand is such that the trees are cut at a speed of three times as compared to the growth rate. This will lead to more expensive paper production and reforestation will receive more attention. Such situations will lead to use of high-quality hemp as raw material even more after the creation and implementation of the special technology considering the production of this pulp. This will lead to a balance in production and consumption, lessening the pressure on forests.

11. Textiles

Hemp has been a premier fiber for ages. The fiber has been popular and in demand since historic times for its uniqueness and durability. Sailors relied on hemp for its strength to hold their ships and sails. According to the documentation, Christopher Columbus sailed to America using ship rigged with hemp. The archaeological findings of 8000 BC tombs revealed that the textile material made from hemp was used in the tombs⁶. The American flag first sewed was made from hemp by Besty Ross (Fryxell et al., 2001).

The major advantage of using textile made from hemp is its exceptional sustainability. Every time synthetic fibers are washed, microfibers are drained into the ocean, damaging the marine wildlife. The synthetic fibers will remain in the landfills for around 300 years even when disposed of. In spite of being biodegradable, cotton fabric contaminates the decomposition sites as many chemicals are used throughout the production process. Hemp, on the other hand, is a natural fiber that will decompose within a month. Moreover, since it is chemical-free in nature and has a natural dye ability, it can be processed almost chemical-free or with very little use of chemicals. It can be even composted in the backyard of a house very easily.

Hemp textile is extremely versatile and blends with other fibers easily such that it incorporates desirable qualities of both the textiles. It provides softness, warmth, cool feel, and an exceptional superior durability unlike any other material. Comfort along with durability is the main feature of hemp. The fabric gets softer gradually with use. It is naturally resistant to molds and ultraviolet light. Being porous in nature, it is water- and sweat-absorbent, and breaths easily in summer. Moreover, the air trapped in the fiber is warmed by the body and hence makes garments naturally warm in cooler climates. In addition, the dye used in hemp will retain its color better than in cotton.

The advantages of hemp are so immense that it can eventually gain more popularity than cotton, linen, and polyester in the coming years. Countless types of products made from hemp textile like the apparels,

⁶ <http://rediscoverhemp.com/hemp-fabric-among-the-most-sustainable-textiles-in-existence/>

shoes, accessories, home furnishing, etc. will rule the market for its excellent potential and sustainability. The quality of having soft elasticity like cotton and smooth texture like silk will make hemp more popular in fashion design. Along with sustainable benefits and minimum ecological footprints, the plant has extremely beneficial natural advantages that can carry over the textile market to multiple levels up.

12. Cosmetic products

The cosmetic products made from hemp are holding a very important share in the market in recent days. The success in the hemp industry in terms of emerging trends in the herbal product comes from the essential qualities the plant has in serving the consumer a healthy skin. Hemp cosmetics are coming up with a strong base to grow as an alternative for consumers who have embraced herbal products. Since hemp is rich in hydrating omega-3, omega-6, and omega-9 fatty acid, it helps to heal skin inflammation, balance acne, regulate natural oils, and soothe the skin (Vogl et al., 2004; Sapino et al., 2005). The clean mild and earthy scent of the hemp products attracts the consumers.

Cannabidiol (CBD) is the main compound in the hemp that has antioxidant and antiaging properties that are important in the cosmetic industry. CBD also works with the human endocannabinoid system and promotes skin repair and rejuvenation. The body produces endocannabinoid named anandamide which promotes the production of sebum. Sebum is responsible for increasing oiliness in skin and blocks skin pores, thus providing a good substrate for the bacterial growth and ultimately acne (Oláh et al., 2014). The use of cannabinol extract exerts sebostatic and antiinflammatory effects on human sebocytes (Oláh et al., 2014). CBD also protects the skin from environmental damage such as overexposure to sunlight.

Cosmetic experts suggest that hemp-based cosmetics form a good pollution barrier to the skin and also help to soothe muscles. These qualities make it an ideal addition to skin care products. A product named plus CBD oil is currently getting a lot of popularity and is ranked amongst the top 10 best-selling hemp-based cosmetics. Another product named CBD skin salve has also gained notable reviews because of its standards and principles. The product made from hemp is organic and are very safe for even the most sensitive skins. Apart from hemp products, the hemp compounds are also mixed as additives in shampoos, hair sprays, soap, conditioners, lip balms, hand creams, lipsticks, and deodorants. This means that hemp is not only a stand-alone cosmetic ingredient but also an additive, which in a way widens its addressable market.

13. Essential oils

According to the reports by Ministry of Hemp, people tend to confuse essential oils with the hemp oil. Hemp essential oil is derived from upper leaves and the flowers of the plant. The essential oil is pale yellow to light green in color with a highly concentrated therapeutic aroma. The aroma of hemp is of considerable commercial value if rightly extracted. It takes around 50 pounds of hemp to produce one ounce of hemp essential oil.

Hemp essential oil has been used since ancient times. The warm sweet scent of the oil played an important part in the life of Christians. It was used as an ingredient in the holy anointing along with the mix of myrrh, cassia, sweet cinnamon, and olive oil. Egyptians also used hemp and other essential oils for medicinal and spiritual purposes. During the 11th century, steam distillation became a common practice and essential oils were not only used for medicinal purposes, but also for attaining high frequency of spirituality throughout the world.

In hemp, the aroma of the essential oil originates from the volatile monoterpenes and sesquiterpenes (Lehmann, 1995). In total, 58 monoterpenes and 38 sesquiterpenes have been identified (Turner et al., 1980). Studies suggest that mixing of monoterpenes and sesquiterpene received maximum commercial appraisals compared to each individually, in hemp essential oil. The essential oils like linoleic (LA) and linolenic (LNA) acid have very beneficial advantages to humans like providing luster in skin, and healthy hair and eyes. The skin gets good moisture and antiinflammatory support keeps the skin soft and supple and allows the skin to absorb other active ingredients such as antioxidants. Additionally, an essential oil also acts as a protectant showing repellent effect against many insects (McPartland, 1997). The essential oil gives aroma to hemp commercial products like cosmetics, soaps, shampoos, creams, oils, perfumes, and also foodstuffs.

14. Plastics

According to research published in 2017, only 9% of the total plastic manufactured is recycled and 79% ends up in the landfills and natural environment (Geyer et al., 2017). If the same situation continues, and the plastic waste gets piled up, by 2050 there will be an accumulation of over 12 billion metric tons of plastic polluting the environment. Researchers from the University of Tasmania and UK Royal Society for protection of birds found that 38 million pieces of plastic waste on Henderson Island has polluted coral island in South Pacific. The oceans are in worse conditions as the microplastics pollute water and are often eaten by marine life. According to the reports from National Geographic, the Great Pacific Garbage Patch has been really in a very bad condition and the ocean is full of

millions of these tiny microplastics as much as 1.9 million per square mile⁷.

Plastics have very harmful and devastating effects on the environment, as they are petroleum-based compounds. The waste produced as by-products during the process of plastic making is harmful to our land, water, and wildlife. Since there are so many harmful effects, eco-friendly approaches are necessary for the plastics so as to reduce the acceleration of climate changes and environmental risks. These efforts of creating clean and green alternatives will eventually reduce the negative footprint on the planet.

Hemp-based plastics provide a real solution to maintaining the functionality of plastics while minimizing our ecological footprint. These bioplastics are affordable, naturally made from natural fiber composite that can be used to replace oil-based materials. The hemp bioplastic is made from the stalks of the plant as the stalk provides high cellulose count required for making plastics. The hemp cellulose content (65–70%) is the highest compared to wood (40%), flax (65–75%), and cotton (up to 90%). The stalks provide both durability and strength to plastics⁸. The main properties of hemp that make it exceptional are the low cultivation input and favorable growing characteristics. High CO₂ absorbing power from the atmosphere, low pesticide requirements, fertilizers, and water compared to the other bioplastic sources make hemp a more superior resource for bioplastic than cotton and wood.

Currently, different grades of hemp bioplastics are made by infusing the hemp fibers. Standard plastic reinforced with hemp fibers made up of 30–40% of hemp and 100% hemp plastics are currently manufactured. These hemp bioplastics are 5 times stiffer and 2.5 times stronger than polypropylene. This infusion of the fiber makes it less polluted, more durable, and biodegradable. Companies like Kanesis and Zoefform highlight the use of hemp in the production of bioplastics.

Automotive industries use the maximum proportion of hemp plastic for manufacturing plastic panels in foreign cars. Industrial hemp will be in the spotlight as bobsledding and other concrete sledding runs are reinforced with hemp fiber during the 2022 Winter Olympic Games in China⁹. Along with the automotive industries, packaging and building industries are also using hemp bioplastics. The restorative and regenerative qualities of hemp ease out complications related to recycling, composting and all the other waste management strategies.

Although there are so many advantages, things like label, ink additives, colorants, and coatings during the process makes the recycling a little complicated. These

complications create a positive effect by motivating and creating more opportunities for research and development in the areas of waste management and waste recovery systems in the hemp industry.

15. Hemp in production of biofuel

After 150 years of drilling and fracking, fossil fuel is nearing its limit and search for a viable replacement is the need of the hour. Researchers are currently unlocking the greener path to renewable fuels which can provide a valuable resource as well as repair environmental damage in the process. Traditional fuel sources harm the environment by releasing polluted air during fossil fuel processing and harm the troposphere, indirectly depleting ozone. This depletion has led to environmental issues, climate changes, and global warming.

Use of hemp in making biofuels dates back to 1941, by Henry Ford. He was the first to create a vehicle that used hemp biofuel. His model named Tin Lizzie ran either on gasoline or on hemp-based fuel¹⁰. However, as the crude oil was discovered, in the 20th century his idea of creating sustainable plant-based automobile got blurred with time.

As the fossil-based fuels are on the verge depletion, people have again started their search for a sustainable alternative that can resolve all the current problems. Hemp-based biofuels are considered one of the most effective tools for reducing the dependency on oil imports and for reducing greenhouse emissions. Biofuels will decrease the dependency on fossil fuel and contribute to a clean environment.

The hemp plant has high density and rapid growth; this makes it suitable for the biofuel crop. The digestible cellulose and hemicellulose concentration is higher in hemp fiber than any other energy crop. Moreover, the ratio of digestible sugars to lignin is higher in hemp than in other similar yielding biofuel crops. Biofuels from hemp seed oil exhibit superior fuel quality with exception kinetic viscosity and oxidation stability parameters that can be resolved with the introduction of chemical additives like antioxidants. They are sustainable and low-emission replacements for petroleum-based fuels¹¹.

Hemp can provide mainly two types of fuels; the hemp biodiesel (made from the oil of pressed hemp seed) and hemp ethanol/methanol (made from the fermented stalk). The hemp biodiesel is produced by trans-esterification. In organic chemistry, trans-esterification is a process that exchanges the organic group R of an ester with organic group R of an alcohol. Moreover, by the processes of

⁷ <https://www.nationalgeographic.org/encyclopedia/great-pacific-garbage-patch/>

⁸ <https://sensiseeds.com/en/blog/hemp-plastics-made/>

⁹ <https://www.hempbizjournal.com/hemp-fiber-additive-winter-olympics/>

¹⁰ <https://www.cannabistech.com/articles/driving-toward-a-greener-future-with-hemp-biofuels/>

¹¹ <https://cannasystems.ca/single-column/joomla-content/616-bio-fuels>

gasification, acid hydrolysis, and enzyme utilization, hemp can be used to make both ethanol and methanol.

Hemp B20 blend is the biodiesel blend and it provides better thermal efficiency, lower specific fuel consumption, and reduced CO₂ emissions (Gill et al., 2011). The biodiesel is a carbon neutral replacement to diesel. Hempanol or hempoline is the fuel made through a process called cellulolysis that ferments and distills the hemp to extract ethanol¹². The biofuels made from hemp have many advantages. Being a carbon neutral resource, plant ingests carbon dioxide more quickly than the trees. Moreover, the emissions from the hemp biofuels are reabsorbed through the process of photosynthesis in plants. Thus, in addition to pulling toxins from soil, the hemp plant can essentially scrub carbon dioxide from the air we breathe.

16. Innovative domains

As the hemp industry grows, more advanced technology will be required to keep up with consumer demands. As it is a renewable and sustainable resource for a wide variety of consumers and industrial products, it is reemerging in various innovative ways. Searching for innovative domains means to obtain maximum profit from the crop for various applications. Industrial hemp has poised to be a new 'cash crop' with extensive market opportunities. As the technology progresses, many innovative uses of hemp fiber and hurd have come up and these include the production of carbon nanosheets, plastics, 3D-printer filaments, oil absorbent materials, and construction concrete (Gray et al., 2016).

One of the innovative ideas of hemp use is the supercapacitors made from hemp. Supercapacitors are energy storage devices that are long-lasting. These supercapacitors are used in braking systems of electric vehicles, powering of computers and supercharging or cordless gadgets. Hemp-made batteries can aid the development of faster, smaller, and cheaper supercapacitors. The top-performing supercapacitors are usually made by using graphene. The researchers from National Institute for Nanotechnology found that hempseed supercapacitors are more efficient and outperform graphene in energy storage by nearly 200%.

With the aim to produce industrial products from natural raw materials, hemp plastics are used for producing a 3D-printer filament made entirely from the waste of hemp production. HBP filaments are favorable because of their positive eco-footprint and favorable weight/volume ratio. A company named HempBioPlastic (HBP) has shown hemp plastic to be more efficient and more aesthetically pleasing than other bioplastics on the market. HBP has shown to be 20% lighter and 30% stronger than PLA – the most common plastic used in 3D-printing filaments.

Through 3D printing popularization, consumers are now armed with the ability to manufacture objects in the comfort of their own home. As we search for sustainable solutions to plastic, the potential to do this with a 100% natural and eco-friendly by-product is very timely.

An innovative product named vaporizer pen, which allows patients to discreetly inhale a controlled dose of hemp, has been introduced. This controls the amount of toxicity level that harms the body by smoking. Other innovative upcoming products made from hemp include ink, mulch, tofu, carpet, fireboard, nail polish, jeans, surfboards, diapers, hemp eyewear bags, canvas, and sneakers.

Many companies aim at incorporating hemp (specifically CBD compound) into various topical products and food available in markets today. This has led to increased demand for hemp production and extraction. With this in mind, machinery for raw hemp processing has been developed by Canadian Greenfield Technologies. This machinery separates hemp into its leaves, fibers, and hurds. Another important innovation in this is the development of a continuous countercurrent reactor technology. This technology has been patented by PureHemp technologies and it converts raw hemp into pulp lignin, sugars, flowers, and seed oil.

In Cologne, Germany, in ISM 2019, a sweet and snack trade fair, hemp-derived products gained reputation and popularity among the consumers. A company named Roelli Roelli, run by a Swiss family has made chewing gums and lozenges using hemp derivatives. These derivatives are benefited after consumption by improving the mood and relieving anxiety, insomnia, and joint muscle ache¹³. Hemp bars that are delicious and healthy sources of nutrition have been introduced in the market.

As people are getting more and more concerned about their health, they are more inclined towards healthy eating habits. Hemp protein powders are innovated products that have complete sources of protein and fibers containing antioxidants, healthy fats, minerals, and fibers. These protein powders are becoming well-known for their nutritional quality and for being a good substitute for egg and soy (Callaway, 2004). Hemp proteins are 91–98% digestible due to the presence of edestin and albumin protein that breaks down food easily as compared to the animal proteins which are less digestible (Hoffman and Falvo, 2004; House et al., 2010). As the fiber content is high, they can be beneficial for blood sugar issues, make healthy gut bacteria, and reduce the risk of bowel cancer et al., 2010). Hence, the protein powders are blooming in the market and are catching eyes as a good substitute of proteins for feeling fuller, healthier, and stronger.

¹² <https://www.hempgazette.com/industrial-hemp/biofuel-hemp-energy/>

¹³ <https://www.foodingredientsfirst.com/news/the-futures-looking-green-hemp-innovation-thrives-at-ism-in-cologne.html>

The studies at Ajanta and Ellora caves have brought to notice another important innovative application of hemp. The Ellora caves showed no insect activity in the paintings compared to Ajanta, where 25% of the paintings had been lost due to insect activity. Studies revealed that the combination of *Cannabis sativa* in mud/lime mortar saved the precious cave murals from insect destruction. This led to the new idea of mixing hemp in the compatible materials prepared for replastering work during the conservation of heritage.

Hemp eyewear utilizes leading-edge sustainable technology and traditional artisanal techniques to manufacture glasses. The eco eyewear is handcrafted and made from hemp and flax fibers. As they are made from hemp, the glasses are strong, lightweight, vegan, and recyclable, and even the packaging is sustainable.

A soil protector mat made from industrial hemp contains seed and nourishment. If this soil protector mat is put over grass during festivals, it protects the grass and ensures short recovery time if the grass is damaged a little. It will also reseed the grass and help in the regrowth process. The mat is prepared such that if it remains where it is even after the celebration is over it will be absorbed by the soil over time.

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17. Conclusion

To conclude, the applications of hemp for the green economy have a very bright future ahead as hemp proves a boon to humankind. Such innumerable applications mentioned in the view of commercial, industrial, and agricultural potential, hemp plant will be given more push for its cultivation and utilization. Along with proper planning for future growth operations and clarity of the purpose, many applications of hemp can be taken a level up for both creating a green environment and good profit. A solid vision and clear plan will pave a way towards discovering new technologies, ideas. Innovations in hemp will increase the production and use of this sustainable material for minimizing environmental and health issues.

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