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Hemp for regenerative agriculture, a potential champion for Indian economy: A review

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Abstract
Hemp, often called as the plant of wonders, has bloomed in the field of extensive scientific research over the years, due to the numerous uses it possesses that are contributing to the ecology and economy respectively. Hemp (*Cannabis sativa* L.), also known as industrial hemp, is a plant from the family of Cannabaceae. It can be used in industries of ropes, fibres, food, textiles, as a building material, extracting oil with medicinal properties, paper and many more. Hemp lays an auspicious imprint on ecosystem by encouraging many ecological and biological mechanisms that govern the conservation and evolution of life itself. Hemp plays a vital role in phytoremediation. Hemp is one of the quickest CO2-to-biomass converters due to its rapid growth and development. Hemp has been shown to be an excellent carbon sink, capturing more CO2 per hectare than other commercial crops and even forests. As a result, we can conclude that hemp is extremely significant for environmental and agricultural preservation since it can effectively battle climate change and desertification processes. Thus, considering all the ecological and industrial benefits of hemp, India should significantly shift its focus on this wonder plant which could hike India's agro-economy tremendously. The final scope of this review is to outline the superlative qualities of hemp in rejuvenating the agriculture in India, by serving not only as an industrial crop, but as a multipurpose crop which would boost India's bio-economy and help ameliorate the natural agricultural sources, like soil, whose degradation is a hot topic to focus on in the ongoing era of agriculture.

Keywords: regenerative agriculture, Indian economy, *Cannabis sativa* L

Introduction
Hemp (*Cannabis sativa* L.), also known as industrial hemp, is a plant from the family of Cannabaceae. It has very low THC (tetrahydrocannabinol) levels. As per its estimated numerous different uses, hemp is hailed by many as a plant of explicable wonders. It can be used in industries of ropes, fibres, food, textiles, as a building material, extracting oil with medicinal properties, paper and many more. Industrial hemp is an eco-friendly crop that has biomass crop that grows rapidly with low fertilizer demand and no requirement of pesticides. Hemp can grow on various types of soil and has been proven to tolerate heavy metal (HM) contamination through plant-specific mechanisms (De Vos *et al*., 2022) [1]. The phenotypical structures of hemp can be used efficiently. Very extensive research carried out on this plant over the years had results that show that industrial hemp possesses the potential to change entire industries for the better.
Since hemp is a plant that is not weeded, it creates a microclimate near the inflorescences that is favorable to pollinating insects. Due to the strong emissions of the terpene like essence from its inflorescence, hemp attracts pollinating insects resulting in an increase in plant biodiversity. The crop is also itself a source of biodiversity because its pollen carried by the wind can reach a considerable distance of 3 km (Campiglia *et al*., 2020) [2]. Recent research conducted in the USA has highlighted that hemp, due to its flowering cycle, occurs at a different time compared to other species and also to the abundant pollen produced, favors the nutrition of various species of bees, increasing their biodiversity. As a result, the increase in pollination with other crops in the area leads to the increase in the biodiversity of the entire agroecosystem under study (Flicker *et al*. 2020) [3, 23].
On rewinding to the era of the Swadeshi movement which started in 1905 as part of the Indian independence movement, 'Vocal for Local' was a concept introduced back then which stays alive to date. As part of an economic strategy, it helped develop Indian nationalism at the time and so will it this time. The global industrial hemp market is expected to grow and reach USD 12.01 billion at a compound annual growth rate of 16.2% from 2021 to 2028. Extensive research towards industrial hemp as a more affordable, easy and approachable replacement in the textile industry to synthetic fibers, made from petroleum and cotton (Claudio, 2007) [4], because of the demand for lots of pesticides, water, and land used up in producing fibers from petroleum and cotton (Duque Schumacher *et al*., 2020, Vandepitte *et al*., 2020) [6, 5]. A healthy India can be created by reclaiming our ancient culture and customs and rebranding it to suit modern times by providing richer and sustainable livelihood to the Indian farmers by regenerating our agriculture with the cheapest input costs.

The rich repertoire of *Cannabis sativa.L* in possessing the great extent of phytochemicals, its textile and medicinal uses, its agricultural attributes, its firm fibers, drought and pest resistant qualities, its well-built root system that prevents soil erosion, has made it a reigning area for\ research in the recent years, despite the issues of legalities involved (Russo *et al*., 2008; Skoglund *et al*., 2013) [8, 9]. The final scope of this review is to outline the superlative qualities of hemp in rejuvenating the agriculture in India, by serving not only as an industrial crop, but as a multipurpose crop which would boost India's bio-economy and help ameliorate the natural agricultural sources, like soil, whose degradation is a hot topic to focus on in the ongoing era of agriculture.

Phylogenetic Classification and Distribution

Hemp has been long regarded as one of the most important crops and holds its place among the first domesticated plant species (Berenji *et al*., 2001) [51]. The genus *Cannabis* is alleged to have originated from Central Asia and spread throughout the other continents like Africa, America and Europe via anthropogenic means (Clarke *et al*., 2013) [52]. Taxonomy, a biological categorisation, reveals evolutionary links between taxa based on characteristic similarities. The taxonomy of hemp is given below in Table 1.

Table 1

KINGDOM	***Plantae* (plants)**
SUBKINGDOM	*Tracheobionta* (vascular plants)
SUPERDIVISION	*Spermatophyta* (seed plants)
DIVISION	*Magnoliophyta* (flowering plants)
CLASS	*Magnoliopseda* (dicotyledons)
SUBCLASS	*Hamamelididae*
ORDER	*Urticales*
FAMILY	*Cannabaceae*
GENUS	*Cannabis*
SPECIES	*sativa*
TAXONOMIC AUTHORITY ABBREVIATION	L.

Cannabis sativa L, commonly called as hemp, belongs to the family *Cannabaceae* under the genus *Urticales* as defined by Endlicher in 1837. The genus of hemp is *Cannabis.* Pausanius, a Roman philosopher, described hemp for the first time in the 2nd century BC (Koren *et al*., 2020). Greek botanist Pedacius Dioscorides documented the medicinal value of the herb Kannabis in his work De Materia Medica (3:165). (Nelson, 1996). Although Linnaeus is credited with coining the term Cannabis sativa, it was first used in 1543 by Fuchs in his Kreuterbuch (Fuchs, 2002). Linnaeus (1753) [55], in his comprehensive work *Species Plantarum*, documented various kinds of hemp, which marked the start of a structured approach to hemp categorization. The majority were assigned to the *Cannabis* genus, with *Cannabis sativa* being the exception.

In addition to *Cannabis sativa*, which is characterised as a tall plant with a fibrous stalk, Lamarck (1785) [56] cites *Cannabis indica*, which is a shorter psychoactive plant. The word "indica" relates to its provenance, implying that this taxon's plants are native to India. Cannabis indica was the name given to pharmacological hemp imported from India that was utilised in popular medicine until the early nineteenth century. Serebriakova (1940) [57] created one of the most complete hemp taxonomies, dividing the genus *Cannabis* under two species based on phenotypical traits. As one of the most precise hemp classifications to date, it requires special attention. Tall, poorly-branched plants with big leaves and large grey-brown grain characterise *Cannabis sativa L*. Short, densely branching plants with small leaves and small, glossy, dark-colored grain characterise *Cannabis indica* LAM (Koren *et al*., 2020). The distribution of hemp is given below in Figure 1 by GBIF—the Global Biodiversity Information Facility (2022).

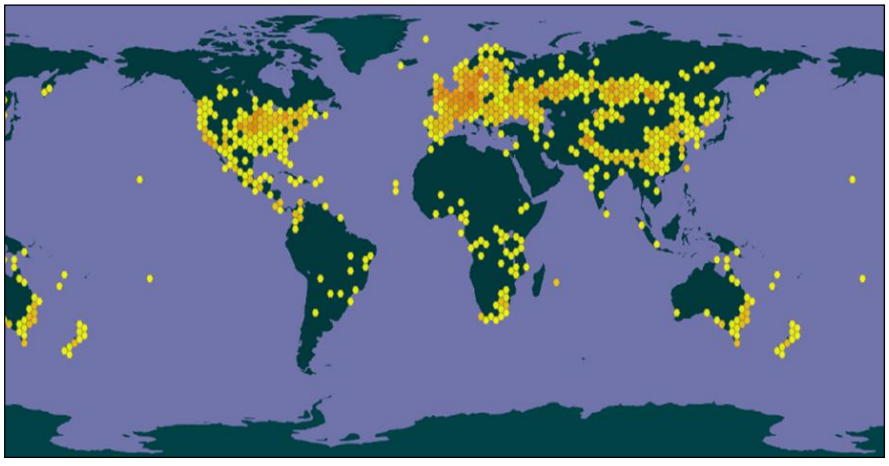


Fig 1: Global Distribution of Hemp.

Perquisites of Hemp- Environment and Agriculture

The perks of cultivation of hemp are unequivocally very compatible with our environment and agriculture considering the loads of properties this plant accounts for. Hemp lays an auspicious imprint on ecosystem by encouraging many ecological and biological mechanisms that govern the conservation and evolution of life itself. According to set limits of sustainable ecological development within which the humans can operate safely, most of the planetary limits have been exceeded which are at a point of no return (Rockstrom *et al*. 2009).

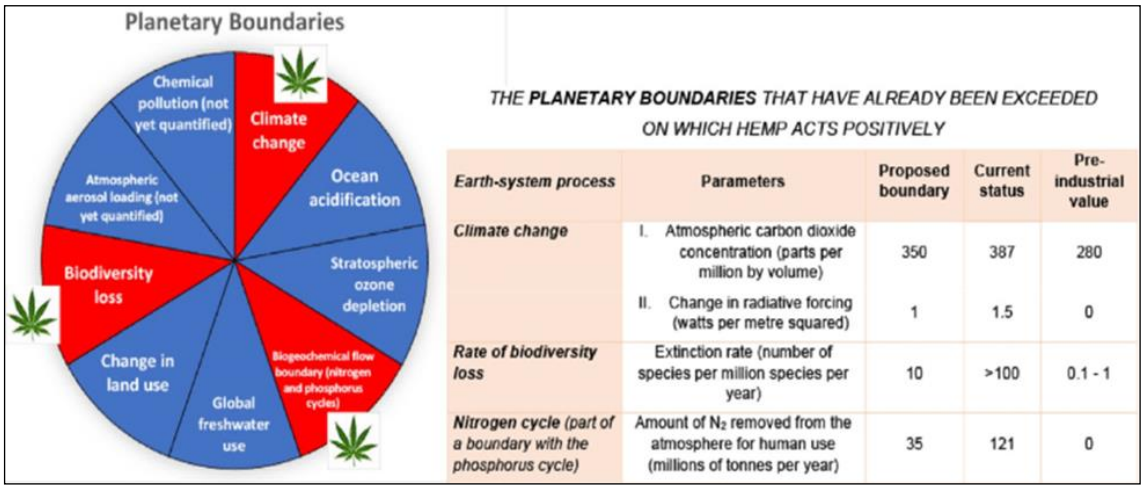
The current CO_2 concentration in the atmosphere is 450 parts per million (ppm) which is more than the pre-industrial limit value of 280 ppm. Now, as hemp is a culture ΔCO_2 negative, it removes more CO_2 from the environment than it emits. Hemp is thus also titled as the "carbon sink" because it can capture more CO_2 as compared to other agricultural species or even forests due to its very rapid growth. If we take an example of other fiber crops like cotton and flax, hemp produces about 8 and 3 times more biomass respectively. Also, the life cycle of hemp is a very rapid one as compared to cotton and flax which have a longer life cycle. The biomass produced by hemp between 8 and 12 tons captured a value of 10 and 15 tons of CO_2 per hectare (Melosini 2017) [12]. The dry matter of the stem sequesters and stores about 80% of the atmospheric carbon, thus, the increase in the dry matter of the stem as in case of hemp, for values of nitrogen between 0 and 120 kg/ha for nitrogen fertilisation, it captures upto 22 tons of CO_2 per hectare. Recent agronomic research also states that hemp exhibits mechanisms that govern its nitrogen nutrition that help in reducing the agricultural greenhouse gases (Tedeschi *et al*., 2020).

Hemp plays a vital role in phytoremediation. According to government report, 97.85 million hectares (29.7%) of India's total geographical area (TGA) of 328.72 million hectares underwent land degradation in 2018-19. Hemp is acknowledged as a plant that could be used for land reclamation due to its rapid growth and development as compared to other fiber crop species that have high yield (Piotrowski *et al*., 2019). It also possesses the capacity to remediate lands polluted by heavy metals (Janick *et al*., 2002) [14]. The hemp developed for fiber is tall, and its underlying foundations develop profound into the soil around 45-90 cm. This empowers the plant root to infiltrate profound and increment the effectiveness of eliminating far and wide pollution when contrasted with different plants with shallow root framework (Citterio *et al*., 2003) [15, 17]. Hemp has a great capacity for absorbing and storing heavy metals such as lead (Pb), nickel (Ni), and cadmium (Cd) through its roots, allowing the hemp plant to be harvested alongside dangerous substances. Hemp cultivars of all kinds are strong candidates for phytoremediation and have a high tolerance for Cd stress (Linger *et al*., 2002) [16]. Heavy metal accumulations were identified in the highest concentrations in the leaves, according to the same study, albeit they were present throughout the plant. Cu (1530 mg kg1), Cd (151 mg kg1), and Ni (123 mg kg1), respectively, were found in hemp leaves taken from a contaminated heavy metal site in Pakistan. Hemp cultivation also decontaminated the soil around the Chernobyl Nuclear Disaster back in 1986 (Cittero *et al*., 2003) [15].

Hemp is one of the quickest CO2-to-biomass converters due to its rapid growth and development. Hemp has been shown to be an excellent carbon sink, capturing more CO2 per hectare than other commercial crops and even forests. Hemp can absorb 22 tonnes of CO2 per hectare, for example. High biomass crops, such as hemp, can sequester more carbon through photosynthesis and then store it in the plant's body and roots via bio-sequestration. The harvested hemp stem stores the majority of the carbon, with the roots and leaves storing only a little portion. Hemp has the potential to generate at least 13 tonnes of biochar per acre per year (Gunther 2019). Another potential application for hemp biomass is the creation of biochar for soil applications, which could improve carbon absorption and reduce greenhouse gas emissions (Lehmann *et al*., 2006 and Andreae *et al*., 2001).

Due to its high biomass and energy concentration per hectare, hemp has been identified as one of the energy plants (Kraszkiewicz *et al*., 2019) [20]. Hemp plants are even more energy efficient because of their weed-suppressing qualities, reduced pesticide requirements, and soil health-improving capabilities. Hemp's fuel characteristics are comparable to or better than those of other solid biofuels such as cereal straw, wood, and so on. Hemp, for example, has a heat of combustion similar to maize Zea mays (18 MJ/kg), somewhat higher than Jerusalem artichoke Helianthus tuberosus (16.5 MJ/kg), and significantly lower than Miscanthus sp. (19.8 MJ/kg). Hemp biomass, both wet and ensiled, may be converted into biogas and ethanol (Prade *et al*., 2021). Hemp also has a low ash level and emits less sulphur compounds (Kolodziej *et al*., 2012) [22].

Hemp has a beneficial impact on biodiversity loss. The increase in plant biodiversity associated to hemp production is due to the fact that hemp attracts pollinating insects due to the high emission of terpenic essences from its inflorescences. As pollen transported by the wind can travel up to 3 kilometres, the crop is also a source of biodiversity. (Campiglia 2020) [2]. Furthermore, because of its large size and lack of weeding, it generates a microclimate near the inflorescences that is beneficial to pollinating insects. According to a recent study conducted in the United States, hemp has benefited the nourishment of numerous kinds of bees, increasing their diversification, due to its flowering cycle that happens at a different time than other species and the plentiful pollen produced. The biodiversity of the overall agro-ecosystem under study has risen as a result of increased pollination with other crops in the vicinity (Flicker *et al*., 2020) [3, 23]. The beneficial impacts of hemp are shown in Figure.2 given below (Rockström *et al*. 2009) [10].



*THE **PLANETARY BOUNDARIES** THAT HAVE ALREADY BEEN EXCEEDED ON WHICH HEMP ACTS POSITIVELY*

Earth-system process	Parameters	Proposed boundary	Current status	Pre-industrial value
Climate change	I. Atmospheric carbon dioxide concentration (parts per million by volume)	350	387	280
	II. Change in radiative forcing (watts per metre squared)	1	1.5	0
Rate of biodiversity loss	Extinction rate (number of species per million species per year)	10	>100	0.1 - 1
Nitrogen cycle (part of a boundary with the phosphorus cycle)	Amount of N_2 removed from the atmosphere for human use (millions of tonnes per year)	35	121	0

Fig 2: Beneficial Impacts of Hemp.

As a result, we can conclude that hemp is extremely significant for environmental and agricultural preservation since it can effectively battle climate change and desertification processes. For these reasons, hemp has the potential to play a significant role in agriculture in the near future, and to be an active player in the green economy, particularly in the current green transition, because the agro-industrial sectors that it can activate are already naturally "green oriented" (Sorrentino *et al*. 2019) [24].

Contemporary Uses of Industrial Hemp

Agriculture, textiles, recycling, automotive, furniture, food and drinks, paper, construction materials, and personal care are among the nine submarkets of the global hemp market. Hemp can be produced for fibre, seed, or as a two-in-one crop. The harvested goods are the stalk and seed. The stalk has short woody fibres called hurds in the core and long bast fibres on the outside. Hemp seed/grains are round and smooth, measuring one-eighth to one-fourth of an inch in length.

Fabrics and textiles, yarns and spun fibres, paper, carpeting, home furnishings, building and insulation materials, vehicle parts, and composites are all made with hemp fibres. Animal bedding, material inputs, papermaking, and oil absorbents all use hurds. Hemp seed and oilcake are used in a variety of meals and beverages (e.g., salad and cooking oils, and hemp dairy substitutes) and can be utilised as a protein source for humans and animals. Soap, shampoo, lotions, bath gels, and cosmetics all contain oil from crushed hemp seeds. Hemp is also employed in nutritional supplements, medications, and medicinal and therapeutic items.

It's found in a variety of composite materials. As a building material, hempcrete which is a mixture of hemp hurds and lime products, is being employed. Hemp is also used in the automotive and aviation industries as a lightweight insulating material and in hemp polymers and related composites as a fibreglass substitute. Hemp is also being touted as a biodiesel feedstock and a cover crop. The modern features of hemp are shown in Figure 3 mentioned below.

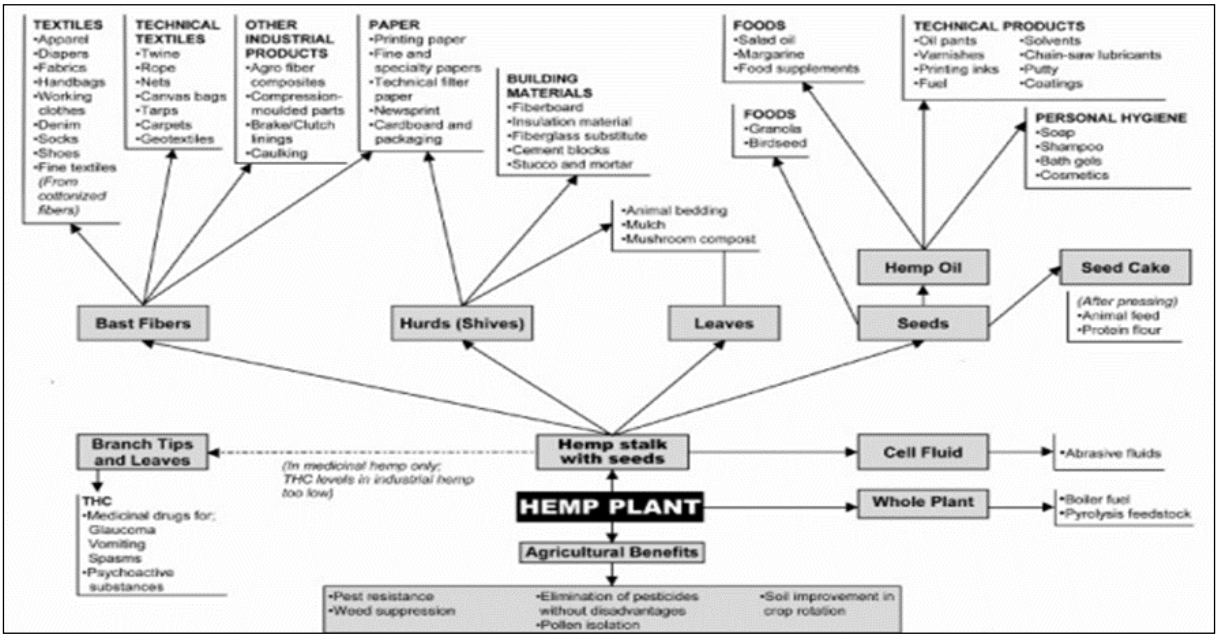


Fig 3: Modern Uses of Hemp

Hemp- Textile and Fiber

Hemp has been used for clothing for thousands of years. The majority of textile fibre demands are currently met by synthetic fibres and cotton. Fiber hemp could be a viable alternative to cotton and synthetic fibres as a textile raw material (Westerhuis 2016) [25]. Hemp is three times stronger than cotton in terms of tensile strength. Industrial hemp clothing has a number of advantages. They're antimicrobial (antibacterial), anti-static, and they keep you warm (Brady 2003) [26].

Lignocellulosic biomass from plants is a plentiful renewable resource that may be used to make biopolymers, textiles, chemicals, and electricity (Guerriero *et al*., 2014, 2015, 2016) [27, 28, 29, 32]. Trees are vital for providing wood, but fast-growing herbaceous species, such as textile hemp (with a THC level of 0.3 percent; Weiblen *et al*., 2015) [s], may supply large amounts of biomass in a short amount of time. The stem of this fibre crop has both cellulosic and woody fibres: the core is lignified, while the cortex contains bast fibres, which are long cellulose-rich fibres (Guerriero *et al*., 2013) [31].

Hemp stems are an interesting model for studying secondary cell wall biosynthesis, particularly the molecular mechanisms driving the deposition of cortical gelatinous bast fibres and core woody fibres, due to their varied cell wall composition. Because of their great absorption capacity and ability to create a concrete-like material, cannabis woody fibres (also known as "hurds" or "shivs") are used for animal bedding (Andre *et al*., 2016) [32].

In the biocomposite industry, hemp bast fibres are utilised to replace glass fibres. Hemp bast fibres are very popular in the automobile industry for making bioplastics since they are tougher and lighter than polypropylene plastic. Hemp bast fibres have been described as antibacterial (Hao *et al*., 2014; Khan *et al*., 2015) [33, 34], and they have been used to make an antibacterial finishing agent (Bao *et al*., 2014), surgical devices (Gu, 2006) [35], and textiles (Cassano *et al*., 2013) [36]. This feature is linked to the chemical composition of hemp bast fibres, which have been found to include both free and esterified sterols and triterpenes, including -sitosterol and -amyrin (Gutiérrez & del Ro, 2005) [37]. These substances are recognised to have antibacterial action (Kiprono *et al*., 2000; Ibrahim, 2012) [38, 38].

Hemp Plastic

Despite relatively high levels of hemp growing in recent years, the majority of plastic is still derived from petroleum-based chemicals. Today, we manufacture a lot of plastics - more than one tonne for every person on the planet. In fact, we manufacture roughly as much plastic as the total mass of all individuals alive today. Petroleum consumption is hazardous to the environment because of the harsh methods employed in its extraction and the amount of waste produced throughout the refinement process. Hemp plastics should replace petrochemical-based plastics for several reasons. These are its lack of toxicity, chemical inertness, easier recyclability, fewer manufacturing hazards and lower use of natural resources. Hemp plastics may also be more durable than their fossil fuel-based counterparts. They can be five times stiffer and over twice as strong as polypropylene. Unlike glass fibers, they pose no risks to health of manufacturers and cause no stress and strain on screws and moulds. Their superlative flexibility also contributes to their durability, as they can bend without breaking (Benhaim 2020).

The usage of hemp plastics will lessen the hazardous burden on the environment and on humans. Plastics derived from fossil fuels contain endocrine-disrupting chemicals (EDCs), which can have a negative influence on health and childhood development. If children are exposed to EDCs in the womb, even low dosages may raise the risk of chronic disease and result in permanently impaired organ function. Bisphenol A (BPA) was discovered in 92.6 percent of urine samples from 2,517 children and adults in the United States. Although BPA is often found in plastics and synthetic resins, increased knowledge of its dangers has resulted in certain phaseouts in recent years. 4-tertiary-octylphenol (tOP), another component identified in these goods, was discovered in 57.4 percent of urine samples (Calafat *et al*., 2004) [40].

The use of industrial hemp to replace petrochemicals in plastics and traditional building materials, at least partially, could play a key role in the combating climate change. The advantages of employing hemp in plastics may be found at every level of manufacturing, from its farming methods and petroleum substitution to the absence of hazardous contaminants and long-term carbon sequestration in perpetual constructions.

Hemp- Medicine and Pharma Industry

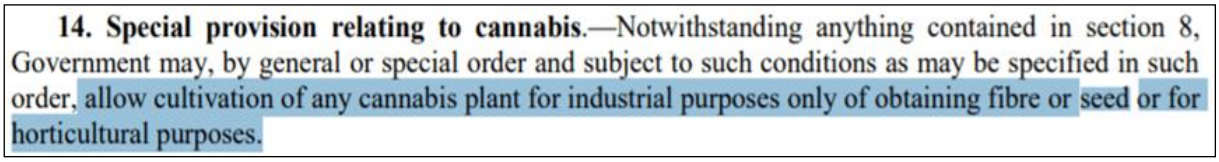
Hemp can prodigiously serve for the medicine and pharma industry due to the compounds it possesses. Cannabidiol (CBD) is a chemical present in hemp which has been proven to serve beneficially in the diseases and disorders associated with humans. CBD has been helpful in relieving and treating the chemotherapy side effects. It has been useful for treating nausea, pain, and it also stimulates appetite in cancer patients ((Davis 2016; Javid *et al*. 2016) [41, 42]. Epidiolex is the first prescription medicine that contains CBD, that has been approved by the US Food and Drug Agency, that is used in treating rare and difficult to control epilepsy (Holland 2020) [43]. It also prevents the growth of breast cancer cells (Shrivastava *et al*., 2011) [44] and it can also prevent prostate cancer (Sharma *et al*. 2018) [45].

The majority of cannabinoids' biological effects are dependent on their interactions with the endocannabinoid system in humans. Two G protein-coupled cannabinoid receptors, CB1 and CB2, as well as two endogenous ligands, anandamide and 2-arachidonylglycerol, comprise the endocannabinoid system. Endocannabinoids are hypothesised to control or regulate a wide range of physiological processes, including appetite, pain perception, cognition, memory, inflammation, insulin sensitivity, and fat and energy metabolism (De Petrocellis *et al*., 2011;

Di Marzo and Piscitelli, 2015) [46, 47]. CBD has been found in *in vitro* and animal studies to have anti-anxiety, anti-nausea, anti-arthritic, anti-psychotic, anti-inflammatory, and immunomodulatory characteristics (Burstein, 2015) [48]. CBD is a significant cannabinoid that has exhibited therapeutic potential in preclinical models of central nervous system diseases such as epilepsy, neurodegenerative diseases, schizophrenia, multiple sclerosis, affective disorders, and central modulation of eating behaviour (Hill *et al*., 2012) [49].
Researches have shown that CBD also poses benefits on human skin, treats pain and inflammation and acts as an analgesic to promote wound healing. A discovery made in human trials is that topical administration of CBD reduced skin lesions in the course of psoriasis, by reducing Psoriasis Area Severity Index, atopic eczema, and tissue scarring. It also increased skin moisture and elasticity. Similarly, CBD affects psoriasis in cultured human epidermal keratinocytes (Wilkinson *et al*., 2007) [50]. Therefore, the legalisation of industrial hemp in India could lead to a massive upgradation in the Indian medicine and pharma industry by helping in the treatment of the diseases and disorders related to the human health which would sequentially elevate the Indian economy.

Hemp- A rescue to post COVID shock in India

The COVID-19 outbreak has sent a stumbling economy into a full-fledged downturn. Good monsoons may have softened extreme agricultural suffering, but the inflow of migrants from metropolitan regions has made a lot of people reliant on meagre returns from agriculture. Many traditional solutions fix one problem while exacerbating another - the most prominent example is the seeming balance between economic expansion and environmental protection. To get past this faulty dualism, we need creativity, which is where we need to bring in hemp.
The "Narcotic Drugs and Psychotropic substances Act of 1985" has outlawed hemp in India. India has been making gradual inroads into the industry, but the 1985 Act has hampered progress. The ministry of Uttarakhand took the initial steps in 2016, when it legalised the permitted cultivation of hemp with THC levels below 0.3 percent. It took advantage of a provision in the NDPS law that allowed hemp to be grown for both industrial and agricultural purposes. The Indian Industrial Hemp Association (IIHA), founded by Mr. Rohit Sharma, a non-profit organisation dedicated to the industrial application of hemp, received a licence from the Uttarakhand government allowing it to cultivate hemp.


14. Special provision relating to cannabis.—Notwithstanding anything contained in section 8, Government may, by general or special order and subject to such conditions as may be specified in such order, allow cultivation of any cannabis plant for industrial purposes only of obtaining fibre or seed or for horticultural purposes.

Section 14, Chapter III of the 1985 NDPS Act

Fig 4

Governments are fighting fires on far too many fronts, with an economy that is battling to generate jobs, an agricultural sector that has been in turmoil for decades, a climate problem that is overwhelmingly affecting people, and government revenue collection sliding to dangerously low levels. Therefore, considering all the ecological and industrial benefits of hemp, India should significantly shift its focus on this wonder plant which could hike India's agro-economy tremendously.

Conclusion and Future Prospects

Hemp has been in a long controversy for its legalisation in India despite the advantageous baggage it brings along that needs to be explored and brought into use. This review suggests that hemp would definitely prove to be a liberator in the times of the climate emergency that we are facing. The land reclamation can be achieved propitiously by the cultivation of industrial hemp. Redirection towards using hemp plastics would prove to be a boom for our environment. The shock that the Indian agriculture and economy faced due to the ongoing pandemic of COVID-19 urges for the use of sustainable resources and to reduce our dependence on petrochemicals to save our environment which can be successfully achieved by the cultivation of hemp, a multipurpose crop. Hemp production necessitates meticulous attention to detail, and factors such as land preparation, type of soil, day duration, planting rates, dates, and harvesting dates are all influenced by the hemp cultivar used. Hemp cultivars grown for fibre, oil, seed, and CBD demand specific fertilisation, and most recent fertilization research have focused on hemp cultivated for fibre. Crop rotation, cover cropping, mulching, and manure application are all examples of operational managerial strategies that can be applied to hemp farming to enhance health of the soil. Hemp is a promising new multipurpose crop that provides not only economical but also environmental and soil health benefits via phytoremediation, biosequestration, and bioenergy generation. In order to achieve maximum capability of this high-potential multi-purpose crop, further studies on appropriate agricultural production practises for greater productivity and sustainability is needed.

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