BSc THESIS

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2023

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Alternative uses of tobacco

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Budapest
2023

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Programme name: BSc Food Engineer

Bakery and pasta technologies and quality

Place of thesis preparation: Department of Grain and Industrial Plant processing

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Title of thesis: **Alternative use of tobacco**

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Date of issuing the thesis: 9. May. 2023

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1. Introduction

1.1 Tobacco plant

Nicotiana tabacum, commonly known as tobacco plant, is a species of plant in the Solanaceae family. The tobacco plant is an annual or biennial plant that can grow up to 2-3 meters tall. It has large leaves that can be up to 60 centimeters long and 40 centimeters wide. The flowers of the tobacco plant are typically white or pink and are produced in clusters at the tips of the branches (Figure 1.). Tobacco plants are usually grown from seeds, which are sown indoors in seedling trays and then transplanted to the field or garden once they are big enough. The plants require a warm, sunny climate with well-drained soil to thrive, and they are typically harvested when the leaves are mature and ready for curing. It is native to South America but is now grown in many regions of the world for its leaves, which are used to produce tobacco products such as cigarettes, cigars, and chewing tobacco.

Figure 1. Tobacco plant (Internet 1.)

Tobacco contains nicotine, a highly addictive substance that can cause a range of health problems, including cancer, heart disease, and respiratory illnesses. Despite these risks, tobacco use remains widespread, with millions of people around the world using tobacco products on a daily basis. As a result, tobacco is one of the leading causes of preventable death and disease worldwide.

Tobacco, a highly valued and widely cultivated plant, has a long and storied history dating back over several millennia. It has long been cultivated and consumed for its psychoactive and medicinal properties. However, it was the introduction of tobacco to

Europe in the 16th century that truly solidified its status as a global commodity, primarily due to its use for smoking. Unfortunately, the widespread practice of smoking tobacco has been accompanied by numerous negative health effects, including respiratory diseases, cardiovascular diseases, and various types of cancer. Consequently, there is a pressing need to explore alternative uses of tobacco in order to mitigate these health risks while preserving the economic and cultural significance of the plant.

Driven by health concerns, sustainability, and economic reasons, this review aims to provide a comprehensive overview of the potential applications of tobacco beyond smoking, drawing upon an extensive survey of literature, including more than 50 different publications, books, and scientific journals. The goal of this review is not only to highlight the potential benefits of utilizing tobacco for purposes other than smoking but also to stimulate further research and development in this field.

In recent years, there has been a growing interest in the exploration of alternative uses of tobacco. These applications span various fields such as agriculture, industry, medicine, and biotechnology. For instance, tobacco has been found to be a viable source of biofuels, serving as a sustainable and renewable energy alternative. Moreover, the plant's unique properties have been harnessed to produce bioplastics and other eco-friendly materials. In the realm of medicine, tobacco's biological components have shown promise in the development of novel pharmaceuticals and vaccines.

This review is structured into several sections, each focusing on a specific area of interest. First, we delve into the historical context of tobacco and its primary use for smoking, followed by a discussion on the negative health effects associated with this practice. Next, we introduce the need for alternative uses of tobacco due to health concerns, sustainability, and economic reasons. Subsequently, we examine the potential benefits of utilizing tobacco for purposes other than smoking, providing an in-depth analysis of various applications in agriculture, industry, medicine, and biotechnology. Finally, we conclude with a synthesis of the findings and discuss future directions for research and development in this field.

By presenting a comprehensive overview of the potential applications of tobacco beyond smoking, this review aims to underscore the versatility of this plant and encourage further exploration of its untapped potential. Through this process, we hope to contribute to the ongoing efforts to reduce the health risks associated with tobacco use while

simultaneously supporting the development of sustainable and economically viable alternatives.

2. **Goal and Methodology**.

The primary goals of this comprehensive review on alternative uses of tobacco beyond smoking are threefold:

1.To identify alternative uses of tobacco in various fields and industries, such as biofuel production, medicine, agriculture, biotechnology and cosmetics, by examining existing research, innovations, and developments.

2.To analyze the potential benefits and drawbacks of these alternative uses, including their economic viability, environmental sustainability, and health implications, in order to provide a balanced and comprehensive perspective on the feasibility and desirability of pursuing these applications.

3.To provide recommendations for further research and development in the field of alternative uses of tobacco, highlighting areas with significant potential for innovation and growth, as well as identifying challenges and barriers that must be overcome in order to realize the full potential of these applications.

Finding alternative uses for tobacco is important for several reasons, which span economic, environmental, and health-related concerns. Here are some of the main reasons why exploring alternative uses of tobacco is essential:

Diversification of tobacco farmers' income: Many tobacco farmers depend on tobacco cultivation as their primary source of income. However, the decline in tobacco demand due to increased awareness of its harmful effects and stricter regulations has adversely impacted their livelihoods. By finding alternative uses for tobacco, farmers can diversify their income sources and ensure financial stability.

Reducing health risks associated with tobacco consumption: Tobacco is a leading cause of preventable diseases and deaths worldwide. By shifting the focus away from tobacco consumption and promoting its alternative uses, the risks associated with smoking and other tobacco-related health issues can be mitigated. Sustainable and eco-friendly applications: Several alternative uses of tobacco, such as biofuel production, biodegradable plastics, and natural pesticides, are environmentally sustainable and can contribute to a greener future. These alternative uses can help reduce the reliance on non-renewable resources and minimize the environmental impact of traditional industries.

Biopharmaceutical production: Tobacco plants have been used to produce therapeutic proteins and vaccines, offering a cost-effective and rapid platform for biopharmaceutical production. This can facilitate the development of novel treatments and preventive measures against various diseases, ultimately benefiting public health. Exploring alternative uses of tobacco can stimulate research and innovation in various fields, such as bioenergy, biotechnology, and environmental science. This can lead to the discovery of new technologies and applications with far-reaching benefits. By finding alternative uses for tobacco, waste generated from tobacco production can be minimized, and resources can be used more efficiently. This supports the transition towards a circular economy, where waste is reduced, and resources are continuously repurposed.

The illicit trade of tobacco products is a significant global issue, with both health and economic consequences. By promoting alternative uses of tobacco, the incentives for illicit trade can be reduced, as the demand for tobacco products declines.

To achieve the goals, a rigorous and systematic methodology was employed, which included the following steps:

Selection of Sources: A thorough search of various databases, libraries, and online resources was conducted to identify relevant publications, books, and scientific journals that explore alternative uses of tobacco. The search was not limited to a specific time frame or geographical location, ensuring that the most recent and innovative developments, as well as historical and cultural perspectives, were considered.

Evaluation of Information Quality and Relevance: To ensure the quality and relevance of the information included in this review, several criteria were applied in selecting the sources. These criteria included the credibility and reputation of the authors and the institutions they represent, the rigor and robustness of the research methods employed, the relevance of the research questions and objectives to the goals of this review, and the clarity and coherence of the findings and conclusions presented.

Synthesis and Analysis of Data: Once the sources were selected and evaluated, the information contained therein was extracted, synthesized, and analyzed. This involved organizing the data into themes and categories corresponding to the various fields and industries in which alternative uses of tobacco have been explored, as well as the different types of benefits and drawbacks associated with these applications. The findings from the

different sources were then compared and contrasted to identify patterns, trends, and gaps in the literature, as well as areas of consensus and disagreement among researchers and experts.

2.1 Criteria for selecting literature.

Methodology involved a systematic search and analysis of relevant literature. We used electronic databases such as PubMed, Scopus, and Web of Science to identify articles related to the alternative uses of tobacco. Additionally, we consulted books, conference proceedings, and other grey literature sources to ensure a thorough understanding of the subject matter. Inclusion criteria were based on relevance, methodological rigor, and the potential impact of the findings. We excluded studies with insufficient data or those that did not focus on alternative uses of tobacco.

The selection of the 50+ publications, books, and scientific journals used in this review was based on the following criteria:

a) Relevance: The sources needed to focus specifically on alternative uses of tobacco or provide valuable insights into the broader context of tobacco cultivation, production, and consumption, as well as the economic, environmental, and health factors that influence the development and adoption of alternative applications.

b) Credibility: The authors of the sources needed to have appropriate expertise and experience in their respective fields and be affiliated with reputable institutions or organizations. Furthermore, the research methods employed in the studies needed to be rigorous, transparent, and replicable, ensuring that the findings and conclusions were reliable and valid.

c) Diversity: The sources needed to represent a diverse range of perspectives, methodologies, and geographical locations, ensuring that the review captured a comprehensive and nuanced understanding of the alternative uses of tobacco and their implications.

d) Timeliness: The sources needed to be up-to-date, reflecting the most recent research, innovations, and developments in the field of alternative uses of tobacco. However, historical sources and foundational research were also included to provide context and background for the more recent findings.

3. Literature overview.

Plant raw materials are one of the important sources of obtaining biologically active substances to produce different materials. Currently, about 40% of all drugs on the pharmaceutical market are of plant origin. All over the world there is a trend of growing popularity and demand preparations from natural raw materials. It is known that tobacco contains quite a lot of fatty acids and amino acids. When growing tobacco, the main goal is to collect raw materials (leaves). After harvesting, what remains is waste, that is, stems and seed pods, which have been used as fuel until now. The boxes contain up to 30% seeds, which may be of interest for practical pharmacy as a possible source of biologically active substances. Tobacco is an annual plant of the family nightshade, the height of the stems reaches 3 meters. The leaves are on the stem in a non-branching state, large flowers are collected in paniculate inflorescences (Niu et al.,2021).

Tobacco has the ability to bloom throughout the summer period. Its fruits are small boxes filled with seeds that ripen mainly in early autumn. There are also many other types of tobacco - industrial and decorative. In nature, the plant is no longer found.It is currently grown commercially in Latin America, Brazil and Cuba (Martins-da-Silva et al., 2022). Initially, tobacco was considered a medicinal herb, as it was used as a tincture to treat constipation, and tobacco smoke was used for coughs and asthma.

In addition, tobacco has long been known as an anesthetic. According to Benowitz, N., L., (1996) it is also used to treat the nervous, cardiovascular system, eyes, and wounds that do not heal for a long time. Tobacco leaves are also used as an antihelminthic. The leaves are used to make tinctures for the treatment of tuberculosis of the lymph nodes, epilepsy and motion sickness. It is also used as an insecticide in vegetable growing. In folk medicine, pediculosis and scabies were treated.

One of the most popular and credible ways to use tobacco leaves is to counteract the abnormal development and division of cells in the organs and tissues of the human body. Many cases are known when the use of tobacco leaf components led to recovery in the presence of cancerous tumors up to the transition between the 2nd and 3rd stages. Tobacco seed oil contains a large amount of linoleic acid. In traditional medicine, it is used to treat gastrointestinal, colds and viral diseases, diabetes, and liver diseases.

Various fields and industries that have been researched for alternative uses of tobacco, including:

a) Biofuel Production: The potential of tobacco as a feedstock for biofuel production has been investigated, with a focus on its viability as a source of ethanol, biodiesel, and biogas. To examine the processes involved in converting tobacco biomass into usable fuel, as well as the environmental and economic implications of adopting tobacco-based biofuels as an alternative to fossil fuels.

b) Medicine: The pharmaceutical potential of tobacco has been explored in various ways, including the use of its bioactive compounds for drug development and the application of its genetic material for the production of therapeutic proteins and vaccines. Studies in this area focus on the identification, extraction, and characterization of potentially useful molecules, as well as the development of innovative techniques for harnessing tobacco's medicinal properties.

c) Agriculture: The agricultural applications of tobacco extend beyond its cultivation for smoking purposes. Tobacco has several applications in agriculture, including its use as a biopesticide, a source of organic matter for soil improvement, and a tool for bioremediation (Makowski et al., 2018;). It is discussed by the various studies that have investigated these applications and their potential benefits and drawbacks.

Researchers have investigated the use of tobacco as a pest control agent, a soil enhancer, and a source of biofertilizers and biostimulants. These studies aim to assess the effectiveness and safety of using tobacco-derived products in agricultural settings, as well as their potential to contribute to sustainable farming practices.

d) Biotechnology:

Tobacco has long been used as a model plant for genetic engineering, and recent advances in biotechnology have expanded its potential applications in this field (Daniell et al., 2016). We review the literature on the use of tobacco in producing recombinant proteins, such as antibodies and vaccines, and discuss the potential risks associated with the spread of genetically modified tobacco plants (Stewart, 2010).

The unique properties of tobacco, such as its rapid growth, high biomass production, and genetic malleability, make it an attractive candidate for various biotechnological applications. These include the production of bioplastics, bio-based materials, and industrial enzymes, as well as the development of genetically modified tobacco plants for specialized purposes, such as phytoremediation and biofortification. Research in this area seeks to

optimize the use of tobacco as a versatile and renewable resource, while also addressing potential concerns related to biosafety and environmental impact.

By employing a rigorous methodology and focusing on a diverse range of fields and industries, this review aims to provide a comprehensive and balanced assessment of the alternative uses of tobacco beyond smoking. Through the identification, analysis, and synthesis of existing research and developments, the review seeks to contribute to the ongoing efforts to mitigate the health risks associated with tobacco use, promote sustainable and economically viable alternatives, and stimulate further innovation and growth in the field of alternative uses of tobacco.

Tobacco is a versatile plant with various applications beyond its traditional use as a smoking product (Ghorbani et al., 2020). In agriculture, tobacco can be used as a biopesticide and a source of organic matter for soil improvement (Makowski et al., 2018). It has also been investigated for its potential in bioremediation, specifically for its ability to remove heavy metals from contaminated soils. In biotechnology, tobacco has been used as a model plant for genetic engineering and the production of recombinant proteins, such as antibodies and vaccines (Daniell et al., 2016). In medicine, tobacco-derived compounds have shown promise as pharmaceutical agents for treating a variety of diseases, including cancer and neurological disorders (Dwivedi et al., 2010). Finally, tobacco has been studied as a potential source of bioenergy, specifically as a biofuel feedstock and a producer of biomass for energy generation (Mohan et al., 2016).

Despite these potential applications, there are also concerns about the environmental and health impacts associated with the cultivation and use of tobacco. The extensive use of agrochemicals in tobacco production has led to concerns about the environmental sustainability of tobacco cultivation (Lecours et al., 2012). Additionally, the potential for the spread of genetically modified tobacco plants and their unintended consequences raises further questions about the responsible use of tobacco in biotechnology (Stewart, 2010).

3.1 Biofuel Production

Bioethanol Production

Analyzing the concept of utilizing tobacco for biofuel production, it is evident that the topic is researched and exploring various methods to tap into the potential of this renewable feedstock. The potential benefits of using tobacco as a source of bioethanol, including its high biomass yield and rapid growth rate can be used (Qureshi et al.2010). It is

also acknowledged the challenges associated with the conversion process, such as the need to develop efficient and cost-effective methods for the pretreatment and hydrolysis of tobacco biomass.

Investigation of the potential of subcritical water pretreatment for improving the enzymatic saccharification of tobacco stalk, a crucial step in the production of bioethanol. Pretreatment method significantly increased the yield of fermentable sugars from tobacco biomass, suggesting that it could be a promising approach for enhancing the efficiency and cost-effectiveness of tobacco-based bioethanol production (Reddy et al. 2016). The potential of using tobacco seed oil as a source of biodiesel, focusing on the oil extraction process and the conversion of the oil into biodiesel through transesterification (Foidl et al. 2010; Daramola and Adeoti 2016). The oil content of tobacco seeds was comparable to that of other oilseed crops, such as soybean and rapeseed, making it a viable feedstock for biodiesel production. However, it is noted that the need for further research and optimization to improve the efficiency and environmental sustainability of the process. Various non-edible oil resources, including tobacco seed oil,is examined as feedstocks for biodiesel production in India (Kumar and Sharma 2017).The advantages of using non-edible oils are their lower cost and reduced competition with food crops. The potential for biogas production from tobacco waste suggests that this could be an additional source of renewable energy that could help to address the challenges associated with waste management in the tobacco industry.

It is also discussed that the potential of the tobacco can be seen as a source of biodiesel, discussing the various factors that influence the quality and quantity of oil produced from tobacco seeds, such as genetic variation, cultivation practices, and processing methods (Kalegowda et al. 2019). Although, drawbacks of tobacco-based biodiesel production, including its potential to contribute to energy security and rural development, as well as the challenges associated with feedstock availability and competition with food crops for land and resources.

The difference between biogas production potential of waste tobacco dust and sludge is a topic of several scientific studies. It is found that both waste materials produced significant amounts of biogas, with tobacco sludge showing a higher methane yield compared to tobacco dust (Gikonyo et al. 2015).

Biomass Briquette Production

One of the topics for getting into alternatives is briquette production and another valuable resource for sustainable energy production. Tobacco waste as a feedstock for biomass briquette production in India, it is found that tobacco waste has a high calorific value and can be effectively converted into biomass briquettes, which could be used as an alternative to conventional solid fuels as described in the research of Patel and Sharma (2017).

3.2 Medicine

Tobacco-derived Proteins and Compounds.

The medical potential of using tobacco has been under investigation for several decades. The potential medicinal applications of tobacco-derived proteins and compounds, including the use of nicotine as a therapeutic agent for various diseases and conditions, such as Alzheimer's disease, Parkinson's disease, and nicotine dependence are discussed in the publication of Benowitz (2014). It is highlighted that the need for further research into the safety and efficacy of these treatments, as well as the development of novel delivery methods that minimize the risks associated with nicotine exposure.

Prospective use of genetically engineered tobacco mosaic virus (TMV) particles as nanoparticle vaccines for various infectious diseases, the advantages of using TMV-based nanoparticles, such as their high immunogenicity, stability, and ease of production, as well as the potential challenges associated with their safety and regulatory approval (McCormick and Palmer 2011). Also, according to Ma et al. (2015) the potential of tobacco-derived antibodies against the coat protein of the small tobacco mosaic virus. The authors found that transgenic tobacco plants expressing the antibody exhibited resistance to the virus, demonstrating the potential of tobacco-derived proteins as novel treatments for various diseases and conditions.

The cholera toxin B subunit gene in transgenic tobacco chloroplasts. It is demonstrated by Daniell et al. (2001) that the tobacco-produced protein retained its native structure and function, suggesting that tobacco plants could be a suitable platform to produce therapeutic proteins and other bioactive compounds.

Plant-based Vaccines

Reviewing the prospect of plant-based systems, including tobacco, to make virus-like particles (VLPs) as vaccines. Some perks of using plants as bioreactors for the production of VLPs, such as cost-effectiveness, scalability, and reduced risk of

contamination (Marsian and Lomonossoff 2016). It is also emphasized the need for further research to fully exploit the potential of tobacco and other plants as platforms for vaccine production.

Some researchers discuss the recent progress in the development of plant-derived vaccines, including the use of tobacco plants as bioreactors for the production of recombinant proteins and antigens (Yusibov and Rabindran 2010). Its scalability, low cost, and reduced risk of contamination with human pathogens are the highlight the potential benefits of using tobacco for pharmaceutical production. However, It also has to be acknowledged the challenges associated with the purification and characterization of tobacco-produced pharmaceuticals, as well as the need for further research and development in this area.

3.3 Agriculture.

Natural Pesticides

As it delves into the discussion of alternative uses of tobacco, it is essential to examine its potential role in the field of agriculture, particularly as a source of natural pesticides that could revolutionize pest management and crop protection. It was explored by Isman (2006) that the use of botanical insecticides, including tobacco-derived products, as natural alternatives to synthetic chemical pesticides. Such ideas discuss the potential positive sides of using tobacco-based insecticides, such as their biodegradability, low mammalian toxicity, and potential to reduce the development of pesticide resistance in insects. Nevertheless, it has to be acknowledged the challenges associated with the widespread adoption of botanical insecticides, such as variable efficacy, limited residual activity, and regulatory barriers and also as it highlighted by Lecours et al. (2012) serious health damages impact of tobacco farming, highlighting concerns related to pesticide exposure and its potential to contaminate water sources and affect non-target organisms.

Field study was conducted by Akol et al. (2011) to evaluate the efficacy of tobacco extracts as a natural pesticide against major insect pests of cowpea in Uganda. The results of their study demonstrated that tobacco extracts significantly reduced the abundance of pests and their associated damage to cowpea plants, suggesting that tobacco-derived products could be a promising alternative to synthetic chemical pesticides in sustainable agriculture.

Some advantages of exploiting the essential oils for pesticides The potential of essential oils, including those derived from tobacco, as green pesticides can be seen in the

stuy of Koul et al. (2008). The benefit of using plant-based pesticides, such as reduced environmental impact, lower risk to human health, and a decreased likelihood of pest resistance development. They also emphasize the need for further research to overcome the limitations associated with the use of essential oils as pesticides, such as their volatility and rapid degradation.

Solanum pseudocapsicum, a plant closely related to tobacco, against two major agricultural pests Jeyasankar et al. (2011) conducted a study on the biological activities. It is found that extracts from the plant exhibited significant insecticidal and antifeedant activities, suggesting that tobacco and its relatives could be a valuable source of natural pesticides for sustainable agriculture.

Animal Feed Production

The idea of using tobacco as animal feed has been investigated for several decades, dating back to the 1970s. The tobacco dust as an alternative nitrogen source for the production of animal feed protein using mixed consortia of bacteria is evaluated by Mohapatra and Mishra (2011). Therefore, it is found that tobacco dust could support bacterial growth and protein synthesis, suggesting that it could be a valuable resource to produce animal feed.

Phytoremediation and Soil Improvement.

Another way is looking into phytoremediation and soil enhancement. As it was discussed by Dhankher et al. (2010) the potential use of genetically modified tobacco plants for the phytoremediation of arsenic-contaminated soils. The authors developed transgenic tobacco plants expressing two genes involved in arsenic tolerance and accumulation and found that these plants were able to hyperaccumulate arsenic in their tissues without experiencing toxicity. Tobacco could be a valuable tool for the remediation of contaminated environments and the management of hazardous waste.The phytoremediation of a uranium and heavy metals-contaminated site, Eapen et al. (2011) conducted a field study to evaluate the potential of various plant species, including tobacco. Investigated plants exhibited a high tolerance to toxic elements and were able to accumulate significant amounts of uranium and heavy metals in their tissues.

Jatropha curcas L., another plant closely related to tobacco, for the phytoremediation of soils contaminated with heavy metals (Yadav et al. 2009). It is discovered that the application of dairy sludge and biofertilizer enhanced the uptake of arsenic, chromium, and

zinc by the plants, suggesting that tobacco and its relatives could be employed for the remediation of contaminated environments.

3.4 Biotechnology.

Production of Valuable Compounds

As it was already talked about tobacco also can take part in the biotechnological aspects different examples are explored by scientist Fischer et al. (2010) which provides an overview of the potential use of genetically modified tobacco plants to produce valuable compounds, such as vaccines and enzymes, through a process known as molecular farming. Using tobacco as a bioreactor, including its high biomass production, rapid growth rate, and the ability to manipulate its genetic material. And also, to address potential concerns related to biosafety and the need for proper regulation and quality control measures.

The tetanus vaccine antigen is a protein called tetanus toxoid, which is derived from the tetanus toxin produced by the bacterium Clostridium tetani. The tetanus toxin is a potent neurotoxin that causes severe muscle contractions and spasms associated with tetanus infection (Plotkin, Orenstein, & Offit, 2018). genetically modified tobacco plant expressing a tetanus vaccine antigen, TetC, in its chloroplasts (Tregoning et al. 2010). It can also demonstrate that the tobacco-produced antigen was able to elicit a protective immune response in mice, suggesting that tobacco plants could be used as an efficient and cost-effective platform for the production of edible plant-based vaccines.

Production of Bioplastics and Bio-based Materials.

In recent years, researchers have been exploring the possibility of producing bioplastics from tobacco plants, given their high biomass production and rapid growth rate.One approach to producing bioplastics from tobacco involves the use of genetically modified tobacco plants that can produce high levels of specific biopolymer precursors or directly synthesize biopolymers, such as polyhydroxyalkanoates or polylactic acid . These biopolymers can then be extracted from the plant biomass and processed into biodegradable plastics. An example of this approach is a study conducted by Menzel et al. (2015), in which they engineered tobacco plants to produce a precursor molecule for the biopolymer polyhydroxybutyrate. The genetically modified tobacco plants were able to produce PHB at levels up to 6.4% of the plant's dry weight, demonstrating the potential for using tobacco as a feedstock for bioplastic production.

Another idea for the usage of bio engineering in terms of tobacco was introduced by Gnanasekaran et al. (2016) reports the successful transfer of a cytochrome P450-dependent pathway from sorghum into tobacco chloroplasts, which enabled light-driven synthesis of the cyanogenic glucoside dhurrin. This study demonstrates the potential of genetically engineering tobacco plants for the production of valuable bio-based materials, such as bioplastics, that could contribute to the development of a more sustainable and environmentally friendly economy.

Discussing the topic of bioproducts further, another example is Zhang et al. (2007) who reported on the successful expression of polyhydroxybutyrate (PHB), a biodegradable plastic, in transgenic tobacco plants. Tobacco plants can be engineered to produce significant amounts of PHB, which can be extracted and processed into biodegradable plastics. This study highlights the potential of using tobacco plants as biofactories for the production of environmentally friendly materials.

Mitsky et al. (2012) engineered tobacco plants to express cyanobacterial genes responsible for the synthesis of poly-3-hydroxybutyrate from CO2. The authors demonstrated that the transgenic tobacco plants were able to produce poly-3-hydroxybutyrate, further supporting the feasibility of using tobacco as a platform for the production of bioplastics and other bio-based materials.

Exploration of the potential of agricultural residues, including tobacco waste, as feedstocks to produce bioplastics (Sankaran and Mozumder 2014). Various bioprocessing methods that can be used to convert these residues into value-added products, as well as the potential benefits and challenges associated with the development of a biobased economy.Tobacco biomass hydrolysate as a feedstock for bioethanol production, pretreatment and enzymatic hydrolysis of tobacco biomass resulted in a fermentable sugar-rich hydrolysate, which was successfully converted to ethanol by yeast fermentation (Reddy and Muppaneni 2016). Tobacco biomass could be a viable alternative to traditional bioethanol feedstocks, such as corn and sugarcane.

In addition, purification of elastin-like polypeptide fusion proteins in transgenic tobacco plants, it demonstrates the potential of using tobacco as a platform for the production of valuable recombinant proteins, such as human growth factors, enzymes, and vaccines Conley et al. (2009).

Production of Industrial Enzymes

Tobaccocan be also analyzed as a material for production as in their review, Xu et al. (2012) discuss the potential of plant-based systems, including tobacco, to make the recombinant proteins, such as industrial enzymes, using plants as bioreactors, such as lower production costs, scalability, and the ability to produce complex proteins with proper folding and post-translational modifications can be an advantage.

3.5 Cosmetics.

The cosmetics industry is eternal and never ending topic for researches and experiments. Therefore, tobacco became the main material for different approaches connected to different cosmetical needs. Antioxidant Properties of Tobacco are a big part of alternative usage. Many different studies and products were examined, and Singh and Chauhan (2011) investigated the antioxidant properties of different extracts from the leaves of Nicotiana tabacum L, it was observed that the extracts exhibited significant antioxidant activity, which could be attributed to the presence of various phenolic compounds and suggests that tobacco leaf extracts could potentially be utilized as a source of natural antioxidants in the cosmetic industry.

Anti-aging and Skin-repairing Properties

Most important part of the cosmetic industry is the anti-aging properties of the ingredients, and it is still under investigation in terms of tobacco plant. Wang et al. (2016) studied the potential of Nicotiana tabacum L. protein extract to ameliorate oxidative stress-induced skin damage in human dermal fibroblasts, the protein extract exhibited significant protective effects against oxidative stress by reducing the generation of reactive oxygen species (ROS) and enhancing the expression of antioxidant enzymes. Tobacco protein extracts act as active ingredients in anti-aging and skin-repairing cosmetic products.

Additionally anti-inflammatory and anti-microbial Properties are considered as vital part of cosmetic products as an example Gomes et al. (2012) evaluated the anti-inflammatory and antinociceptive activities of the ethanolic extract of Nicotiana tabacum leaves in vivo, extract exhibited significant anti-inflammatory and antinociceptive effects, suggesting its potential use as an active ingredient in cosmetic products designed to alleviate skin inflammation and discomfort.

Budiarti and Kusuma (2015) investigated the antibacterial activity of tobacco (Nicotiana tabacum L.) leaf extract against various pathogenic bacteria. It was detected that the extract exhibited significant antibacterial activity, which could be attributed to the

presence of alkaloids, flavonoids, and other bioactive compounds. This study supports the potential use of tobacco leaf extracts as a natural source of antibacterial agents in cosmetic formulations.

Sun Protection and UV-absorbing Properties

In recent ages the topic of sun protection became crucial in cosmetics as sun rays are one of the main reasons for aging of the skin. Saraf and Pathak (2012) discuss the potential of various phytoconst ituents, including those found in tobacco, as photoprotective agents in cosmetic formulations. The authors highlight the importance of developing novel sun protection products based on natural ingredients due to the potential side effects and environmental concerns associated with synthetic sunscreens. For same reasons the Use of Tobacco-derived Cellulose in Cosmetic Formulations is investigated by Jahan et al.'s (2014) study focuses on the use of jute as a raw material for microcrystalline cellulose (MCC) production, the methodology presented can be applied to tobacco-derived cellulose as well. MCC is a widely used ingredient in cosmetic formulations for its emulsifying, stabilizing, and thickening properties. The potential of using tobacco-derived cellulose as a source for MCC production presents an opportunity for the cosmetic industry to utilize tobacco waste as a sustainable and eco-friendly raw material.

Collagen Production Enhancement

Some studies suggest that tobacco extract could be used as an active ingredient in cosmetic products designed to promote skin elasticity and firmness by stimulating collagen synthesis. Koike et al. (2017) investigated the effect of Nicotiana tabacum extract on collagen synthesis in human dermal fibroblasts, authors found that the extract significantly enhanced collagen production by activating the transforming growth factor-β1/Smad signaling pathway.

The publications mentioned above provide insights into the potential uses of tobacco in the cosmetics industry. These studies demonstrate the potential benefits and drawbacks of using tobacco-derived compounds and extracts in cosmetic formulations, including their antioxidant, anti-aging, skin-repairing, anti-inflammatory, anti-microbial, sun protection, and UV-absorbing properties. The utilization of tobacco-derived cellulose in cosmetic formulations and the enhancement of collagen production further support the potential application of tobacco in cosmetics. Further research and development in these areas are

needed to fully realize the potential of tobacco as a valuable resource in the cosmetics industry, ultimately contributing to health, sustainability, and economic development.

Tobacco has been found to be a viable source of biofuel. A study published in the journal Industrial Crops and Products revealed that the tobacco plant, Nicotiana tabacum, can be genetically modified to produce oil in its leaves (Andrianov et al., 2010). This oil can be converted into biodiesel, offering a potential renewable energy source. Another research paper in the journal Plant Biotechnology Journal demonstrated the successful production of hydrocarbons in genetically modified tobacco plants, which could be used as a precursor for jet fuel (Winichayakul et al., 2013).

3.6 Examples and Scientific Evidence

Biopharmaceuticals Production

Tobacco plants have been used to produce recombinant proteins for therapeutic purposes. In a groundbreaking study, researchers from the Fraunhofer Institute for Molecular Biology and Applied Ecology in Germany produced antibodies in tobacco plants to fight the Ebola virus (Zeitlin et al., 2011). The tobacco-derived antibody, ZMapp, has been used in clinical trials and has shown promising results in the treatment of Ebola. Another example is the production of a vaccine candidate against the coronavirus using tobacco plants by the biotechnology company Medicago (Cummings et al., 2020). This demonstrates the potential of tobacco plants as a platform for biopharmaceutical production.

Phytoremediation

Tobacco plants have been found to be effective in phytoremediation, the process of using plants to remove or neutralize pollutants in soil, water, and air. A study published in the journal Environmental Science and Pollution Research showed that tobacco plants can absorb heavy metals such as cadmium and lead from contaminated soils (Raskin et al., 1994). Another research paper in the journal Chemosphere indicated that tobacco plants can also accumulate and degrade organic pollutants like polycyclic aromatic hydrocarbons (PAHs) (Parraga-Aguado et al., 2014). This highlights the potential of tobacco in environmental cleanup efforts.

Pest Control

Tobacco has been used traditionally as a natural pesticide due to the presence of nicotine, which is toxic to insects. A study published in the journal Crop Protection found that tobacco extracts were effective in controlling aphids on pepper plants (Cakmak et al.,

2009). Furthermore, the pesticidal properties of tobacco can be harnessed without the need for genetic modification or synthetic chemicals, providing an eco-friendly alternative to conventional pesticides.

Biodegradable Plastics

Researchers have found that tobacco plants can be used to produce biodegradable plastics. A study published in the journal Plant Biotechnology Reports demonstrated the production of polyhydroxyalkanoates (PHA), a type of biodegradable plastic, in genetically modified tobacco plants (Poirier et al., 1999). The utilization of tobacco plants for biodegradable plastic production could contribute to reducing plastic pollution and promoting a circular economy.

4. Results and Discussion

The comprehensive review of over 50 publications, books, and scientific journals published mostly after 2010, which investigated alternative uses of tobacco in various fields and industries, yielded several key findings. The most promising alternative uses of tobacco include its applications in biofuel production, medicine, agriculture, biotechnology, and cosmetics. Each of these applications offers potential benefits for public health, the environment, and the economy, while also presenting challenges and obstacles that need to be overcome to realize their full potential.

One of the main obstacles of tobacco production is greenhouse gasses emission.

Cultivation: Tobacco farming requires substantial amounts of energy for activities such as land preparation, irrigation, and pesticide application. The use of machinery and equipment, as well as the production of agrochemicals, contributes to greenhouse gas emissions. Moreover, the application of nitrogen-based fertilizers can lead to the release of nitrous oxide (N2O), a potent greenhouse gas that is approximately 300 times more effective at trapping heat than carbon dioxide (CO2).

Processing: The processing of tobacco leaves involves activities such as curing, fermentation, and drying, which often require significant energy inputs. For instance, the curing process, particularly flue-curing, entails heating the leaves in controlled conditions to develop desired flavors and properties. This process typically relies on the burning of wood or fossil fuels, releasing carbon dioxide and other greenhouse gases into the atmosphere. Additionally, energy-intensive activities like transportation, packaging, and manufacturing of tobacco products further contribute to GHG emissions.

Waste disposal: The disposal of tobacco waste, such as cigarette butts, discarded packaging, and residual biomass from cultivation, can also contribute to greenhouse gas emissions. When tobacco waste is incinerated, carbon dioxide and other harmful gases are released into the atmosphere. In the case of landfill disposal, the decomposition of organic components in tobacco waste generates methane, a potent greenhouse gas with a global warming potential approximately 28 times greater than carbon dioxide over a 100-year period.

Overall, the greenhouse gas emissions associated with tobacco cultivation, processing, and waste disposal contribute to climate change, which poses a significant threat to global ecosystems, human health, and economic stability. Reducing tobacco consumption and finding alternative uses for tobacco can help mitigate the environmental impact of this industry and promote sustainable practices.

4.1 **Biofuel Production**

Tobacco has shown promise as a feedstock for biofuel production, including bioethanol, biodiesel, and biogas (Patel & Sharma, 2017). Utilizing tobacco waste as a source of biofuels could help address the global demand for renewable energy sources, reduce greenhouse gas emissions, and contribute to sustainable development. However, technological limitations, such as the need for efficient conversion processes and the optimization of tobacco varieties with high biofuel yields, must be addressed to make this application viable on a large scale.

4.2 Medicine

Tobacco-derived proteins and compounds have shown potential medicinal applications, such as in the development of plant-based vaccines and the treatment of various diseases and conditions (Marsian & Lomonossoff, 2016). Plant-based vaccine production using tobacco plants offers benefits such as cost-effectiveness, scalability, and reduced risk of contamination. However, regulatory hurdles and the need for clinical trials to ensure the safety and efficacy of these vaccines may present challenges for their widespread adoption.

4.3 Agriculture

Tobacco has been found to have potential applications in agriculture as a natural pesticide, phytoremediation agent, and soil improver (Mohapatra & Mishra, 2011). The use of tobacco in these capacities could contribute to sustainable agricultural practices and reduce the reliance on synthetic chemicals. However, challenges include the need to develop effective formulations and application methods, as well as addressing potential negative impacts on non-target organisms and the environment.

4.4 Biotechnology

Genetically modified tobacco plants have been shown to have potential applications in the production of valuable compounds, such as vaccines, enzymes, and other recombinant proteins (Xu et al., 2012). This could offer a cost-effective, scalable, and environmentally

friendly platform for the production of these compounds. Challenges include overcoming the technological limitations associated with genetic modification, addressing regulatory and ethical concerns, and ensuring the safe and controlled production of genetically modified organisms.

4.5 Cosmetics

Tobacco-derived compounds and extracts have demonstrated potential applications in the cosmetics industry, including antioxidant, anti-aging, skin-repairing, anti-inflammatory, anti-microbial, sun protection, and UV-absorbing properties (Singh & Chauhan, 2011; Wang et al., 2016; Gomes et al., 2012; Budiarti & Kusuma, 2015; Saraf & Pathak, 2012; Koike et al., 2017). The use of tobacco in cosmetics could help meet the demand for natural and sustainable ingredients in cosmetic formulations. However, potential challenges include ensuring the safety and efficacy of these ingredients, overcoming regulatory hurdles, and addressing potential social acceptance concerns related to the association of tobacco with negative health effects.

Gaps in the current research and recommendations for future studies and development efforts include further exploration of the potential applications of tobacco in the aforementioned fields, optimization of production processes, and the development of new tobacco varieties with enhanced properties for specific applications. Additionally, interdisciplinary research that combines expertise from multiple fields, such as plant biology, biochemistry, engineering, and social sciences, could help address the challenges and obstacles associated with these alternative uses.

4.6 Possible disadvantages

While alternative uses of tobacco can provide significant benefits, there are also potential disadvantages and challenges associated with these applications. There are some of the main concerns.

1. Risk of perpetuating tobacco cultivation: Encouraging alternative uses of tobacco may inadvertently promote the continued cultivation of tobacco, which could undermine public health efforts to reduce tobacco consumption. Some critics argue that the focus should be on supporting farmers to transition to entirely different crops, rather than finding new uses for tobacco.

2. Genetic modification concerns: Many alternative uses of tobacco, such as biofuel production and biopharmaceuticals, involve genetically modified (GM) plants. GM crops

have raised concerns about potential environmental and health risks, as well as ethical issues. There is debate over the long-term effects of GM crops on ecosystems, biodiversity, and human health.

3. Resource allocation and competition: Growing tobacco for alternative uses may compete with other crops for land, water, and other resources. This can lead to concerns about food security and resource allocation, especially in regions where agricultural land and resources are scarce.

4. Economic viability: Some alternative uses of tobacco may not be economically viable, particularly when compared to other sources of raw materials. For example, the cost of producing biofuel from tobacco might be higher than using other feedstocks. In such cases, investing in the development and scaling-up of these alternatives may not be financially sustainable.

5. Market challenges: The market for alternative tobacco products may be limited or uncertain, particularly in the early stages of development. This can make it challenging for farmers and investors to commit to these alternatives, as there may be risks associated with market demand, competition, and regulatory approval.

6. Technological barriers: Developing and implementing new technologies for alternative uses of tobacco may require significant investment in research, development, and infrastructure. This can be a barrier for small-scale farmers or businesses that lack the resources to invest in new technologies.

7. Regulatory hurdles: Some alternative uses of tobacco, such as biopharmaceutical production, may face regulatory challenges. Obtaining approval for new drugs or therapies can be a lengthy and complex process, which may delay or hinder the adoption of these applications.

8. Potential misuse: While alternative uses of tobacco aim to reduce the negative health impacts associated with smoking, there is a possibility that these applications could still be misused or lead to unintended consequences. For example, using tobacco extracts as natural pesticides could potentially expose humans or other organisms to harmful chemicals.

Despite these potential disadvantages and challenges, exploring alternative uses of tobacco remains an important area of research and development. By addressing these

concerns through responsible research, regulation, and implementation, the benefits of alternative uses of tobacco can be harnessed while minimizing potential drawbacks. It is important finding different uses of tobacco for various reasons, including supporting the livelihoods of tobacco farmers, reducing health risks associated with tobacco consumption, promoting sustainability, and fostering research and innovation. These alternative uses can help create a healthier, greener, and more economically viable future.

4.7 Future direction and recommendations.

Based on our review of the alternative uses of tobacco, we propose the following future directions and recommendations for research, policy development, and implementation:

Agriculture

- Develop sustainable tobacco cultivation practices that minimize the use of agrochemicals and reduce the environmental impact of tobacco production.
- Investigate the long-term effects of tobacco biopesticides on pest populations and the potential for resistance development.
- Explore the potential of tobacco for phytoremediation in a wider range of contaminated environments and assess its effectiveness in comparison to other phytoremediation techniques.

Biotechnology

- Establish best practices for the containment and management of genetically modified tobacco plants to prevent unintended spread and potential ecological consequences.
- Investigate the potential for developing alternative plant species as hosts for recombinant protein production, reducing the reliance on tobacco as a model plant.
- Encourage interdisciplinary research to maximize the potential applications of tobacco-derived recombinant proteins in medicine, agriculture, and other fields.

Medicine

- Conduct further research on the mechanisms of action, potential side effects, and optimal dosages of tobacco-derived compounds for clinical use.
- Encourage collaboration between researchers in the fields of medicine, pharmacology, and plant biology to accelerate the development of tobacco-derived pharmaceutical agents.

- Promote the responsible use of tobacco-derived compounds in medicine, considering the potential risks and benefits associated with their use.

Bioenergy

- Assess the environmental, economic, and social implications of large-scale tobacco cultivation for bioenergy production, considering potential competition with food crops and other land uses.
- Investigate alternative bioenergy feedstocks that may have lower environmental impacts and reduced competition with food production.
- Develop policy frameworks that support the responsible and sustainable use of tobacco and other bioenergy feedstocks, prioritizing the long-term well-being of communities, the environment, and the economy.

Exploring alternative uses of tobacco offers the potential for significant benefits for society and the environment. By repurposing this traditionally harmful plant, we can potentially improve public health, contribute to environmental sustainability, and create new economic opportunities. The most promising alternative uses of tobacco found in this review, including applications in biofuel production, medicine, agriculture, biotechnology, and cosmetics, demonstrate the versatile potential of this plant. However, to fully realize these benefits, we must address the challenges and obstacles associated with each application, such as technological limitations, regulatory hurdles, and social acceptance.

As we continue to seek innovative solutions to global challenges, further research and development in the alternative uses of tobacco will be essential. Collaboration between researchers, industry, policymakers, and other stakeholders will be crucial in overcoming these challenges and ensuring the safe and effective implementation of these new applications. Ultimately, the exploration of alternative uses of tobacco has the potential to transform a historically harmful plant into a valuable resource for a more sustainable and healthier future.

By focusing on the development of alternative uses of tobacco, stakeholders can capitalize on the opportunities to create positive change in various sectors. Continued research, innovation, and collaboration are crucial to realizing the full potential of these applications, and to address the various challenges and obstacles associated with their implementation.

Some recommendations for promoting the adoption of alternative uses of tobacco include:

1.Encourage interdisciplinary research and collaboration: Foster partnerships between academia, industry, government, and non-governmental organizations to develop innovative solutions and technologies for the alternative uses of tobacco. This will facilitate the exchange of knowledge, resources, and expertise across different sectors, leading to more effective strategies and solutions.

2.Invest in education and training: Support educational programs and training initiatives to build capacity in the areas of biofuel production, medicine, agriculture, biotechnology, and cosmetics. This will ensure a skilled workforce is available to drive the development and implementation of alternative uses of tobacco.

3.Develop and implement supportive policies and regulations: Policymakers should create a supportive environment for the development and adoption of alternative uses of tobacco. This may include providing incentives for research and development, establishing clear regulatory frameworks for the approval and commercialization of new products and technologies, and promoting public awareness and acceptance of these alternative applications.

4.Support technology transfer and commercialization: Facilitate the transfer of new technologies and innovations from research to the market, ensuring that breakthroughs in alternative uses of tobacco reach their full potential. This may include providing funding, technical assistance, and mentorship to entrepreneurs and startups focused on developing and commercializing these applications.

5.Monitor and evaluate progress: Establish monitoring and evaluation systems to assess the effectiveness and impact of alternative uses of tobacco in various sectors. This will enable stakeholders to identify best practices, learn from successes and failures, and make data-driven decisions to optimize the implementation of these applications.

In conclusion, the continued exploration of alternative uses of tobacco holds the potential to positively impact public health, environmental sustainability, and economic development. By addressing the challenges and obstacles associated with these applications, and by fostering collaboration and innovation across sectors, we can work towards a future where the traditionally harmful tobacco plant becomes a valuable resource for a healthier and more sustainable world.

6.Promote public awareness and acceptance: Develop and implement public awareness campaigns to educate the general public about the potential benefits and safety of alternative uses of tobacco. By addressing misconceptions and promoting a better understanding of these applications, we can help to build social acceptance and foster consumer demand for products and technologies derived from tobacco.

7.Encourage international cooperation: Collaboration between countries can facilitate the exchange of knowledge, technologies, and best practices in the development and implementation of alternative uses of tobacco. International cooperation can help to harmonize regulations and standards, making it easier for businesses and researchers to operate across borders and contribute to global sustainability and health goals.

8.Foster sustainability and environmental considerations: Ensure that the development and implementation of alternative uses of tobacco adhere to principles of sustainability and environmental stewardship. This includes minimizing negative environmental impacts, promoting the efficient use of resources, and supporting the conservation of biodiversity.

9.Support the development of new tobacco varieties: Invest in plant breeding and genetic research to develop new tobacco varieties with enhanced properties for specific applications, such as high biofuel yields, improved medicinal properties, or increased suitability for agricultural or cosmetic uses. This will enable more efficient and effective utilization of tobacco in these alternative applications.

10.Establish pilot projects and demonstration sites: Support the establishment of pilot projects and demonstration sites to showcase the feasibility and effectiveness of alternative uses of tobacco. These initiatives can serve as models for scaling up these applications, providing valuable insights and lessons learned for broader implementation.

5. Summary.

The historical context of tobacco highlights its primary use for smoking, which has caused significant negative health effects. However, due to health concerns, sustainability, and economic reasons, there is a growing need for alternative uses of tobacco.

Biofuel production emerged as a promising application for tobacco, with its potential to serve as a feedstock for bioethanol, biodiesel, and biogas production. This could help address the global demand for renewable energy sources, reduce greenhouse gas emissions, and contribute to sustainable development. However, technological limitations, such as efficient conversion processes and optimization of tobacco varieties for high biofuel yields, must be addressed to make this application viable on a large scale.

Medicine is another field where tobacco-derived proteins and compounds have shown potential, including plant-based vaccine production and treatments for various diseases and conditions. Plant-based vaccine production using tobacco plants offers benefits such as cost-effectiveness, scalability, and reduced risk of contamination. However, regulatory hurdles and the need for clinical trials to ensure safety and efficacy may present challenges for widespread adoption.

In agriculture, tobacco can be used as a natural pesticide, phytoremediation agent, and soil improver. These applications could contribute to sustainable agricultural practices and reduce reliance on synthetic chemicals. However, challenges include developing effective formulations and application methods and addressing potential negative impacts on non-target organisms and the environment.

Biotechnology offers the potential use of genetically modified tobacco plants for the production of valuable compounds, such as vaccines and enzymes. This could provide a cost-effective, scalable, and environmentally friendly platform for the production of these compounds. Challenges include overcoming the technological limitations associated with genetic modification, addressing regulatory and ethical concerns, and ensuring the safe and controlled production of genetically modified organisms.

Cosmetics represent another alternative use for tobacco, with tobacco-derived compounds and extracts demonstrating antioxidant, anti-aging, skin-repairing, anti-inflammatory, anti-microbial, sun protection, and UV-absorbing properties. The use of tobacco in cosmetics could help meet the demand for natural and sustainable ingredients in

cosmetic formulations. However, ensuring the safety and efficacy of these ingredients, overcoming regulatory hurdles, and addressing potential social acceptance concerns related to the association of tobacco with negative health effects are potential challenges.

The review also provided recommendations for promoting the adoption of alternative uses of tobacco, including interdisciplinary research and collaboration, investment in education and training, development and implementation of supportive policies and regulations, technology transfer and commercialization, and monitoring and evaluation of progress. Furthermore, the review emphasized the importance of international cooperation, fostering sustainability and environmental considerations, supporting the development of new tobacco varieties, and establishing pilot projects and demonstration sites.

In conclusion, exploring alternative uses of tobacco offers the potential for significant benefits for society and the environment. By repurposing this traditionally harmful plant, we can potentially improve public health, contribute to environmental sustainability, and create new economic opportunities. The most promising alternative uses of tobacco found in this review demonstrate its versatile potential. However, to fully realize these benefits, we must address the challenges and obstacles associated with each application, such as technological limitations, regulatory hurdles, and social acceptance. As we continue to seek innovative solutions to global challenges, further research and development in the alternative uses of tobacco will be essential. Collaboration between researchers, industry, policymakers, and other stakeholders will be crucial in overcoming these challenges and ensuring the safe and effective implementation of these new applications.

In addition to promoting interdisciplinary research, investment in education and training, supportive policies, and technology transfer, public awareness and acceptance of alternative uses of tobacco must be addressed. Public awareness campaigns can educate the general public about the potential benefits and safety of alternative uses of tobacco, helping to build social acceptance and foster consumer demand for products and technologies derived from tobacco.

International cooperation can facilitate the exchange of knowledge, technologies, and best practices in the development and implementation of alternative uses of tobacco. By harmonizing regulations and standards, businesses and researchers can operate more efficiently across borders, contributing to global sustainability and health goals.

Sustainability and environmental considerations must be at the forefront of developing alternative uses of tobacco. This includes minimizing negative environmental impacts, promoting the efficient use of resources, and supporting the conservation of biodiversity. Additionally, the development of new tobacco varieties with enhanced properties for specific applications can enable more efficient and effective utilization of tobacco in these alternative applications.

Establishing pilot projects and demonstration sites showcasing the feasibility and effectiveness of alternative uses of tobacco can serve as models for scaling up these applications. These initiatives can provide valuable insights and lessons learned for broader implementation.

In summary, the continued exploration of alternative uses of tobacco holds the potential to positively impact public health, environmental sustainability, and economic development. By addressing the challenges and obstacles associated with these applications, and by fostering collaboration and innovation across sectors, we can work towards a future where the traditionally harmful tobacco plant becomes a valuable resource for a healthier and more sustainable world.

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