Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 13th International Scientific and Practical Conference. Volume 1, 281-287

The Application of Hemp in Bioeconomy

Ērika Teirumnieka
Institute of Energy Systems and Environment
Riga Technical University
Riga, Latvia
Erika.Teirumnieka@rta.lv

Dagnija Blumberga
Institute of Energy Systems and Environment
Riga Technical University
Riga, Latvia
Dagnija.Blumberga@rtu.lv

Edmunds Teirumnieks
Faculty of Engineering
Rezekne Academy of Technologies
Rezekne, Latvia
Edmunds.Teirumnieks@rta.lv

Abstract **- Global trends in the world are currently representing a serious incentive to bring 'green thinking' to life. This is the case of replacing synthetic materials derived from fossil resources with natural-origin, renewable resources. In the automotive industry and other segments of the manufacturing industry, increasing attention is being paid to the use of natural fibers in the manufacturing of composite materials. For example, flax and hemp fiber, as reinforcing material, is starting to widely replace carbon fiber. It is not just an ecological benefit, but also an important product protecting human health, since the amount of emissions that pollute the environment is minimized. Consequently, that lead to reduced intake by human being of harmful substances that would affect its health status. Existing composite materials used in motor vehicles, produced from carbon fibers, are creating very sharp fracture areas in the event of accidents causing human injury, while materials from natural fiber plants in this case are free from sharp edges at the place of fracture. Raw materials derived from hemp processing are used in the automotive, textile industry, construction (hemp concrete, heat insulation material), energy, biofuel production, arts and design, paper production, food, medicine, etc. This paper covers the main types of products derived from hemp.**

Keywords: *bioeconomy, hemp products, hemp use*

I. Introduction

Hemp is a raw material of a number of products with high added value, which increases the value of hemp compared to many other industrial crops. The use of hemp (*Cannabis sativa L.*) shows cross-sectoral links.[1] The diversity of raw materials is the key, since several types of raw materials are obtained in the hemp recycling process:

- hemp seeds,
- bast fiber,
- shives,
- leaves.

The use of hemp depends on the available technologies, their degree of development, and the availability and quality of the raw materials as such. At present, there is a demand for a variety of hemp products on the European market, while there is a shortage of producing enterprises active in the development of products. The fundamental problem is also linked to the small areas of hemp crops in Europe. At present, the largest areas of crops are in France, Romania, Croatia and the Netherlands. This is a limiting factor at the moment, but in the future there are ample growth opportunities. For example, the United States are consistently committed to hemp cultivation and the development of their products, thus playing an important role in the global market. The way to replace fossil raw materials with natural sources also opens up opportunities for hemp to be an important crop for involvement in the fight to improve the ecological situation. Evidence is presented already that many countries around the world, including Latvia, are targeting increased areas of hemp crops.[2, 3]

Historically, hemp has been cultivated very widely in Latvia. Both climatic and agro-technical conditions allow for the cultivation of hemp in industrial quantities. Currently, areas of crops are starting to increase, but there is a shortage of possibilities for further local use of their raw materials. In Latvia hemp raw materials are used in small quantities in the manufacture of food products and construction materials, research in the field of energy – incineration, gasification, biofuel extraction, as well as in the production of composite materials – is taking place.

Online ISSN 2256-070X
https://dx.doi.org/10.17770/etr2021vol1.6966

However, the potential for use of hemp is much wider (Fig. 1).

The Latvian Bioeconomy Strategy for the period until 2030 foresees development and implementation of an innovative approach to the efficient and sustainable use of natural resources, thereby developing the national economy, providing high added value, promoting exports and employment, while balancing economic interests with environmental quality assurance, climate change mitigation, climate change risk assessment, adaptation to climate change and the preservation and enhancement of biodiversity. The strategy speaks about increasing the use of biomass, about the fact that a promotion of targeted biomass use in the economy as a whole, including construction, manufacturing (textile, chemical industry, etc.) and energy affects the development of bioeconomy sectors.[4]

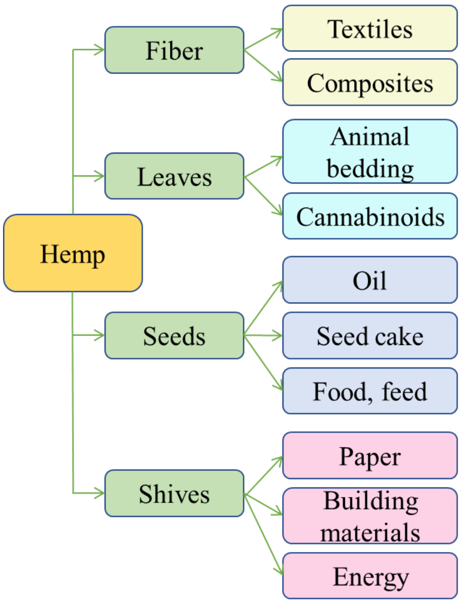

Fig. 1. Use of hemp

Looking from future perspectives, hemp is a crop that is fully in line with the strategy settings and can serve as the main contributor to the volume and use of biomass in Latvia.

Hemp is a widely used, multi-functional crop providing raw materials for their use in the production of both traditional and innovative industrial products [5].

II. HEMP USE: OVERVIEW

Composite materials

Composite materials are man-made materials consisting of at least two different materials/raw materials. Physical properties of composite materials generally differ significantly from those of materials used in them that can be unique.[6] Materials with advanced properties that are cheaper, more environmentally friendly, are required in many sectors, such as automotive, aeronautics (mainly due to the low weight of material for 20-30% of natural fibers when compared to synthetic fibers, fuel efficiency can be improved and transport emissions reduced), in the construction industry, ballistic protective equipment, sports, furniture, packaging industry, biomedical products, etc. Composites with hemp and synthetic binders show the best wear resistance in biological objects at high loads.[7] Plant (hemp, jute, flax, coconut, coir, bamboo, elephant grass, etc.) fibers and animal fibers can provide for such properties, they is provided by lignin and pulp.[8]

Thanks to the European Green Course and the joint global trend towards producing more environmentally friendly materials from renewable natural resources, the number of studies focusing on the use of hemp fibers and epoxy resins in producing composite materials has increased.[9] In addition, topicalities and trends both in the European Union and in Latvia are developing of new nano-materials and smart materials to be used in the production of new products, as well as the replacement of fossil materials with renewable materials. The functional component of composite materials must come from natural local raw materials such as fiber plants, including hemp. Hemp plays a key role in mitigating climate change by attracting CO_2.

Both raw and processed hemp fibers are used to make composite materials.[6] Better mechanical properties are presented by composites with mechanically treated hemp.[10] As well as fibers with different positions influence the mechanical properties of the material (tensile, bending, impact resistance, hardness, density).[11] Also, hemp harvesting technology affects their quality and options for use in composite materials. The characteristics of natural fibers are affected by growth climate conditions — humidity and heat regime.[12] The use of natural fibers in the production of materials significantly reduces the consumption of petroleum products.

The following methods are basically used for the manufacture of composite materials:

- injection forming and
- extrusion - thermoplastic injection forming. [13]

Fiber materials most commonly used in composite manufacturing:

- carbon fiber,
- glass fibers,
- kevlar fiber,
- flax fiber,
- hemp fiber, etc.

At present, those are the composite materials of synthetic fibers that dominate the world, yet more and more synthetic fibers are replaced with natural flax and hemp fibers.

Hemp materials in construction

The construction sector is one of the largest emitters of greenhouse gases, and in addition it also uses high consumption of energy, land and raw materials. Sustainable construction practices include the use of renewable materials and industrial by-products, including hemp in construction.

Hemp composite materials obtained from hemp shives may be used in the manufacture of frame elements, various door panels, containers, furniture and interior elements. They can be used both as fillers for wall insulation and for filling of door plates. Many studies on prefabricated wood-frame panels look at hemp-insulated wood-frame panels, performing analysis of their thermal conductivity ratio, internal humidity and air exchange. A conclusion is drawn that the use of hemp presents an ecological and construction-compatible solution that is successfully integrated into the thermal insulation of buildings.[14]

Simple mixtures of hemp, water and lime can be used to produce hemp concrete. A concrete from hemp shives (hemp concrete) is obtained by mixing hemp shives with slaked lime (where appropriate additives are added as well) and water, in certain proportions. Hemp concrete is used as a thermal insulation material and a filler in non-bearing structures in wooden pillar buildings, as well as a sound insulation material. It is one of the few materials that can continue to absorb carbon after use in construction, storing more carbon in the atmosphere during the lifetime of the building than it is produced during construction. It is a biocomposite material that can be used as an alternative to concrete and thermal insulation in buildings. Hemp concrete is also recyclable after end of its life-cycle. Hemp concrete is not only ecological but also meets all the requirements of the bearing structures for building construction.[14, 15]

Concrete is the most widely used material in the construction sector, 10 billion tonnes are produced annually and used in a variety of applications. On the other hand, cement-based products are sometimes considered unsustainable because each tonne of cement produced releases approximately one tonne of CO_2 into atmosphere. Hemp concrete is a concept that is becoming more and more popular. It is a new and sustainable building material. Hemp shives are a by-product of the hemp fibers sector. 65-70% of shives come from the total production (mass) of hemp plants. They have light weight and low thermal conductivity, which means they have good thermal insulation capacity due to their high porosity. Lime is a binder heated at 950 °C temperature in a limestone oven, which temperature is by 500 °C lower than the temperature used for the manufacture of cement (1450 °C) and therefore it has a lower impact on the environment. In addition, during the carbonisation process, the majority of CO_2 released as a result of chemical reaction is reabsorbed into the system. The binder is the most important component of each concrete. Hemp concrete is made with a binder on a lime basis. The most common binding substance in hemp concrete is the hydrated or slaked lime ($Ca(OH)_2$). The low compressive strength is probably the most significant lack of hemp concrete. Its maximum compressive strength is 3.5 MPa, while the lowest compressive strength of a traditional concrete is approximately 17 MPa. As a result, hemp concrete cannot be used in bearing structures but may be used for the construction of non-bearing insulating walls. It can also be used to repair old stone and lime structures. Hemp concrete walls are sound-resistant, moisture resistant, resistant to mold and fireproof. The value of hemp concrete R (heat transfer resistance) can range from 0.67 to 1.2 cm, making it an excellent insulator (the higher the R value, the better the insulation). The porosity range of hemp concrete is between 71.1 and 84.3% vol.

Technologically hemp concrete is usually prepared (mixed) and embedded in situ in the construction site, less frequently in the form of plates as prefabricated construction material. It is important to achieve a uniform mass that is both easily applied and homogenous throughout the incorporated volume.

The very important advantage of incorporating the material in situ on the construction site is that there are no stitching seams that would otherwise be individually treated. Avoiding the formation of heat bridges is a benefit, so there is no loss of heat. The finished product is fireproof, with a small density. Consequently, hemp concrete needs not to be supplemented with chemicals harmful to human in order to ensure the level of fireproofness required for the structures.

Depending on the proportion and consistency of the composition of the prepared material, the material incorporated in one run can reach a height of 4 m.

The thermal insulation composite material of the residues (shives) of sapropel and hemp is an absolutely ecological thermal insulation material as well, being also referred to as: sapropel-hemp shive concrete (hereinafter referred to as the “SHS concrete”).[16] The main binders are organogenic lake sediments, sapropel that replaces slaked lime in the present case. SHS uses hemp shives derived from hemp varieties as a filler. Hemp shives are residues resulting from the processing of hemp with a small density. SHS concrete is breathable, so a favourable microclimate in the room is provided. The impact of this material on the environment is very important.

Sapropel derived from lakes is also considered to be a renewable and ecological material, which is not further processed. At the same time, the overgrown lakes are being purified by extracting sapropel.

Buildings built from SHS concrete have a much smaller environmental impact than conventional ones: lower energy consumption for getting raw materials, virtually no construction waste and having modern thermal insulation properties.

SHS concrete can be applied in parts of all building enclosing structures. This material may be used in the heat insulation of floors, walls, coverings and lofts of the building. The concrete composition of SHS is made of: hemp shives, sapropel and water mixture in proportion

1:2:1. SHS concrete can be used in the construction of framework buildings as well as in the structures of self-bearing walls. Given the relatively low compressive strength of SHS concrete, it should be better used as a self-bearing wall insulation material. First, a wooden frame of the building and a roof structure with coverings shall be formed. Such work technology also allows jobs to be performed during raining. On the other hand, moulds are installed for creating walls, SHS concrete is gradually filled layer by layer, with a good compression. A variety of cyclic-operated mobile concrete mixers can be used to mix SHS concrete. If the construction volumes are high, the spraying technique may be used by means of special pumps. When the material is sufficiently hardened, the walls shall be demoulded.

After complete drying of the material, interior finishing of the wall is performed. By increasing the amount of binders (hemp shives, sapropel and water mixture in proportion 1:2.5:0.5), finished wall blocks may also be formed, but they will require special moulds and block drying may delay the construction process.

In order to improve fire safety of the SHS concrete, addition of borax is recommended (up to 7%), which prevents fire from entering the building – as the temperature rises, borax releases water, the material becomes fireproof and simultaneously protects the building wooden structures.

It is recommended that construction lime or sand (up to 8%) be added in order to protect SHS concrete against rodents and insects.

Not only thermal but also acoustic properties of SHS concrete are good that differ significantly from other concretes. Working with such material does not pose a risk to the environment and human health.

It is recommended that SHS concrete is used in wooden frame buildings having no more than 2 floors. The density of SHS concrete is ranging from 140 to 170 $kg \cdot m^{-3}$. The average thermal conductivity of the material λ is 0.0552 $W \cdot (m \cdot K)^{-1}$.

Energy production

Traditional fossil fuels have a negative impact on the environment by polluting the environment during their production and use, thereby contributing to climate change. Hemp biofuels can be considered as an effective alternative to fuels in order to reduce dependency on fossil fuels and to mitigate environmental impacts. Nowadays, a variety of energy products can be produced from hemp, such as granules or briquettes for heat production, biomass for electricity or vehicle fuel. The high total biomass of hemp and the increase in biomass demonstrate the capacity to use solar energy and to attract CO_2 for photosynthesis, thereby increasing the potential for cannabis to be used as a renewable energy resource. The amount of cellulose and hemicellulose is higher than in any other crop, and is therefore suitable for the production of biofuels.

Hemp produces a sufficiently high quantity of oil per hectare. Hemp-derived oil is to be used in the production of biodiesel. Hemp biodiesel can compete with the price of retail diesel. In Malaysia, this fuel is already widely used and increase of its use is expected.

The uses of hemp biomass may be grouped according to their harvesting times: hemp harvested as green plants in the autumn, if intended for biogas, or as dry plants harvested mainly in the spring, provided that it is intended for production of solid biofuels. [17]

The production of heat and electricity cogeneration uses bales of hemp harvested in spring, which can be burned. In this case, hemp acts as a supplement to other fuels. For the production of solid biofuels, the crops should be harvested in spring, when the moisture content in biomass is below 30%. In the production of heat and electricity cogeneration it is assumed that hemp is cut and folded, then pressed, usually in large square bales (2.4 m × 1.2 m × 1.3 m). For intermediate storage, bales may be wrapped in polymer film, which is an economic storage option and which does not require as much investment as permanent storage in buildings.

The other type of solid biofuel is represented by briquettes. Hemp is also harvested in spring for the production of briquettes. The hemp is further crushed in an approximately 20 mm long fraction. Further processing includes pressing in briquettes, packaging and transport to local trading sites and customers. Briquettes are usually burned in small-scale domestic boilers for heating purposes (thermal efficiency up to 80%). In recent years, technological developments have also made intensive efforts to produce hemp shive pellets. The main problem for this product is the presence of fiber in total mass, which limits the production of high-quality pellets.

Hemp is usually harvested in the autumn for the production of biogas. Hemp may also be crushed in a fraction of approximately 20 mm in length for the production of biogas. In a biogas reactor, hemp produces biogas and nutrient-rich digestate in an oxygen-free environment.

In the production of biodiesel, the process up to non-processed biogas is the same as in the production of biogas for combustion. But instead of burning biogas, it is processed to biodiesel.

Hemp biomass is 14-15 t/ha, 70-75% of which are hemp shives (also dependent on variety). This means that around 10-11 t/ha of raw material can be used for energy purposes. For hemp biomass, properties such as calorific value, ash content, ash melting temperature, are dependent on the harvesting season. Hemp harvested in spring and winter has shown to have a higher calorific value of 19.1 MJ/kg than hemp harvested in autumn – 18.4 MJ/kg[18].

In order to use hemp biomass for thermochemical treatment, it is important to know its calorific value, ash melting temperature, emissions in the exhaust gas and ash content. It is desirable that its ash has a high melting temperature and should remain in a solid phase in the oven.

Fig. 2 displays the stages of producing energy from hemp biomass for the production of various products.[17]

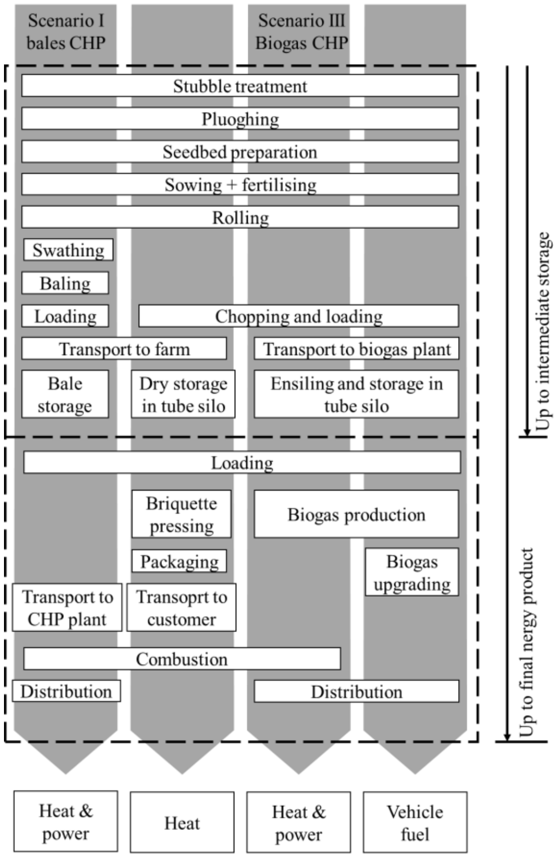

Fig. 2. Stages of the production of hemp biomass energy [17]

The content of volatile substances for hemp biomass is approximately 69%, which is comparatively high. Calorific value or the highest combustion heat with an average value of 18 MJ/kg and a low ash content of 2,5%. The calorific value is slightly lower, possibly affected by higher humidity values for hemp pelles. The values of the parameters evaluated for hemp pellets are among the best among other biofuels used in heating, while the high content of volatile organic compounds can improve the efficiency of energy transformation.[19, 20]

Manufacture of textiles

Bast fiber, or hemp fiber, has been used for a long time in the manufacture of fabrics. It is compared to both cotton and flax fabrics. When the hemp fabrics are compared to the cotton products, the fact is highlighted by that there is much less water needed to cultivate it, even three times less water compared to the cultivation of cotton. For getting 1 kg of cotton fibers, 10 thousand litres of water is needed, but hemp fibers require less than three thousand litres of water. In an area of equal size, hemp can yield by 220% more than cotton.[21] Hemp fibers are sustainable substitutes for cotton fibers.[22] Hemp fiber consists of cellulose, pectin and waxes. Pectin is found in the middle lamellae of cells. It glues together the elemental fibers, by creating bunches. Lignin contains cellulose and contributes to the hardness and breaking capacity of fibers. The content of additional substances (other than cellulose) in hemp fibers is much higher than in cotton. This means that hemp needs different treatment. The higher the amount of cellulose in hemp fibers, the higher the quality of fiber.[23] The thermal properties of hemp depend on whether it is non-woven or woven. When used as a fabric, hemp has the same characteristics as other bast fibers, they have relatively good heat sustainability but also excellent breathability. The thermal properties of hemp fibers are higher when investigating the use of non-woven hemp fibers.[24]

Hemp fabrics are also widely used in design, development of design elements or structures. At the University of Colorado,[25] hemp fiber fabrics were tested and compared to 100% cotton fabrics. The main aim of the research was to determine whether 100% hemp fabric could be replaced in the upholstering of 100% cotton fabrics. Differences in colour resistance to water, light and smocking, as well as dirt removal, wear resistance and the probability of an inflammation were compared. In a number of indicators, the hemp fabrics even overcame the cotton fabrics:

- 100% hemp and 100% cotton fabrics have no difference in colour resilience to smocking, the results were depending on the fabric finishing and choice of color.
- 100% hemp and 100% cotton fabrics present the same performance in removing dirt because the persistence was satisfactory, it is recommended that hemp furniture has to be treated with dirt-repellent coatings.
- The flammability of 100% hemp and 100% cotton fabrics does not differ. Both cotton and hemp fabrics have a high risk of inflammation, and the material needs to be treated with anti-burning coating in order to mitigate that risk.
- According to the specifications of the American Society for Testing and Materials (ASTM), 100% hemp and 100% cotton fabrics do not differ in rupture resistance. Both hemp and cotton fabrics meet the standards of ASTM specifications.
- 100% hemp and 100% cotton fabrics have no difference in rupture resistance. Both hemp and cotton fabrics comply with the minimum ASTM specification for 7 upholstery fabric. The minimum conditions for the ASTM specification were met for both cotton and hemp materials. Hemp fabrics with twill weave or modified weave were more resistant than the plain weave fabrics and significantly exceeded minimum requirements.
- 100% hemp and 100% cotton fabrics have differences in colour resistance to light. Following tests, it was concluded that hemp

fabrics was recommended to be used for indoor furniture because the colour was not sufficiently persistent to light impact.
- For 100% hemp and 100% cotton fabrics, colour resistance to water varies. In the tests carried out, the resistance of hemp fabrics to water received better assessment than that for the cotton fabrics.

Hemp fabrics have an advantage over synthetic materials on the market, and this is their ability to biodegradation.

Paper

Hemp paper has several advantages when compared with paper made of wood. Within four months hemp fiber grows until it is harvested, while wood needs a period of 20 years. The hemp paper is also more natural-friendly for the reason that fewer chemicals are used in the production process. Currently, hemp paper is less demanded due to its costs, because wood paper production is cheaper. However, with the development of hemp cultivation, leading to large amounts of processing, this will also reduce the cost of producing hemp paper. It should be noted that the hemp fiber material can be recycled up to eight times, which is only three times for the pulp paper. The technical specifications also meet the required strength requirements for paper and are similar to that of wood paper. The fact that hemp paper with technical characteristics does not lag behind wood-derived papers may be used in perspective as a substitute for it.

The production of hemp fiber paper does not differ significantly from the normal paper production process. After mixing the mass, the production process is going through a similar cycle. Hemp bast fibers are used in the manufacture of paper. The hemp fiber material is characterised by better strength and requires the use of hydrogen peroxide in its bleaching process, which is more naturally friendly than the chemicals currently used in the bleaching process for wood paper. Bleaching of material is performed in order to remove the residual lignin, which results in providing better quality, white and softer paper[26].

III CONCLUSION

1. Hemp has historically been cultivated in Latvia for getting both seeds and fiber. The current, bioeconomy-focused situation, allows for the development of hemp cultivation in Latvia.
2. Creating new materials (biocomposites) by means of hemp is a perspective one, due to the fact that materials with better (but not against all synthetic materials) characteristics, more environmentally friendly and based on local raw materials are produced. This reduces the dependency on external raw material chains.
3. In view of the growing global demand for energy and more ambitious climate objectives, the use of biomass (hemp) for incineration will be even more important than it has been before. As wood remains scarcer due to growing demand for wood and energy consumption, interest in the use of alternative solid biofuels in energy is increasing. Pelleting or briquetting of hemp raw materials is the best way to optimize the value of solid biomass fuels. Pellets have advantages such as high energy density, uniform physical properties, easy handling and efficient transportation. However, in order to manufacture hemp pellets, additional research should be carried out in the manufacture of specific equipment.
4. Although, in the short term, the cultivation and use of hemp for energy production can facilitate the challenges posed by the energy crisis, a more sustainable solution in the long term, both economically and environmentally, would be necessary to devise solutions that would allow hemp to be processed in order to produce products with high added value.
5. Hemp is a very prospective raw material in a variety of construction materials. At present, the most up-to-date is hemp concrete and the use of hemp in the development of heat insulation materials.
6. The limiting factor for the wider use of hemp is their limited cultivation in Latvia and Europe. As areas of the hemp crops and their harvest levels are increasing, technologies for the production of hemp products and their industrial use are also expected to develop rapidly.

ACKNOWLEDGMENT

Rural Support Service project "Innovative solutions for the treatment and processing of industrial hemp". No. 18-00-A01612-000026.

NACIONĀLAIS ATTĪSTĪBAS PLĀNS 2020 EIROPAS SAVIENĪBA EIROPA INVESTĒ LAUKU APVIDOS Eiropas Lauksaimniecības fonds lauku attīstībai

Atbalsta Zemkopības ministrija un Lauku atbalsta dienests

REFERENCES

[1] T. Karche and M. R. Singh, "The application of hemp (Cannabis sativa L.) for a green economy: a review," *Turk J Botany*, vol. 43, no. 6, pp. 710–723, Jan. 2019, doi: 10.3906/bot-1907-15

[2] Michael Carus, "European hemp industry: cultivation, processing and applications for fibres, shivs, seeds and flowers," vol. 1994, no. March, pp. 1–9, 2017, [Online]. Available: https://eiha.org/media/2016/05/16-05-17-European-Hemp-Industry-2013.pdf

[3] J. Thurmond and J. Horner, "Comparative Analysis of the Industrial Hemp Industry," 2019

[4] Latvian Bioeconomy Strategy 2030

[5] S.Amaducci, D.Scordia, F.H.Liuc, Q.Zhang, H.Guo, G.Testa, S.L.Cosentino, "Key cultivation techniques for hemp in Europe and China", *Industrial Crops and Products*, Volume 68, June 2015, Pages 2-16

[6] N. Murugu Nachippan, M. Alphonse, V. K. Bupesh Raja, S. Shasidhar, G. Varun Teja, and R. Harinath Reddy, "Experimental investigation of hemp fiber hybrid composite material for automotive application," *Mater Today Proc*, vol. 44, pp. 3666–3672, Jan. 2021

[7] D. de Fazio, L. Boccarusso, and M. Durante, "Tribological Behaviour of Hemp, Glass and Carbon Fibre Composites," *Biotribology*, vol. 21, p. 100113, Mar. 2020

[8] B.V. Subrahmanyam, Y. Abshalomu, D. Mojeswararao, and S.B.R. Devireddy, "Experimental investigation of physical and mechanical behaviour of broom grass root and glass fiber reiforced hybrid composites," *Mater Today Proc*, vol. 46, pp. 3193–3197, Jan. 2021

[9] M. P. Ribeiro *et al.*, "Mechanical, thermal and ballistic performance of epoxy composites reinforced with Cannabis sativa hemp fabric," *Journal of Materials Research and Technology*, vol. 12, pp. 221–233, May 2021

[10] T. Väisänen, P. Batello, R. Lappalainen, and L. Tomppo, "Modification of hemp fibers (Cannabis Sativa L.) for composite applications," *Ind Crops Prod*, vol. 111, pp. 422–429, Jan. 2018

[11] C. Sowmya, V. Ramesh, and D. Karibasavaraja, "An Experimental Investigation of New Hybrid Composite Material using Hemp and Jute Fibres and Its Mechanical Properties through Finite Element Method"," *Mater Today Proc*, vol. 5, no. 5, pp. 13309–13320, Jan. 2018

[12] J. Müssig, S. Amaducci, A. Bourmaud, J. Beaugrand, and D. U. Shah, "Transdisciplinary top-down review of hemp fibre composites: From an advanced product design to crop variety selection," *Composites Part C: Open Access*, vol. 2, p. 100010, Oct. 2020

[13] R. Siva, S. Sundar Reddy Nemali, S. Kishore Kunchapu, K. Gokul, and T. Arun Kumar, "Comparison of Mechanical Properties and Water Absorption Test on Injection Molding and Extrusion - Injection Molding Thermoplastic Hemp Fiber Composite," *Mater Today Proc*, vol. 47, pp. 4382–4386, Jan. 2021

[14] R. G. Martinez, "Hygrothermal Assessment of a Prefabricated Timber-frame Construction Based in Hemp | Enhanced Reader," *Procedia Environ Sci*, vol. 38, pp. 729–736, 2017

[15] E. Awwad, M. Mabsout, B. Hamad, M. T. Farran, and H. Khatib, "Studies on fiber-reinforced concrete using industrial hemp fibers," 2012

[16] LV patent No 14869, Concrete containing sapropel and hemp sheaves for insulation of buildings, 2014, inventors – S.Pleikšnis, Ē.Teirumnieka. Patentee – Rēzeknes augstskola

[17] T. Prade, S. E. Svensson, and J. E. Mattsson, "Energy balances for biogas and solid biofuel production from industrial hemp," *Biomass Bioenergy*, vol. 40, pp. 36–52, May 2012

[18] M. Baldini, C. Ferfuia, F. Zuliani, and F. Danuso, "Suitability assessment of different hemp (Cannabis sativa L.) varieties to the cultivation environment," *Ind Crops Prod*, vol. 143, p. 111860, Jan. 2020

[19] D. R. Nhuchhen and P. Abdul Salam, "Estimation of higher heating value of biomass from proximate analysis: A new approach," *Fuel*, vol. 99, pp. 55–63, Sep. 2012

[20] M. H. Eisenbies, T. A. Volk, and A. Patel, "Changes in feedstock quality in willow chip piles created in winter from a commercial scale harvest," *Biomass Bioenergy*, vol. 86, pp. 180–190, Mar. 2016

[21] J. Averink, "Global water footprint of industrial hemp textile"

[22] A. G. Duque Schumacher, S. Pequito, and J. Pazour, "Industrial hemp fiber: A sustainable and economical alternative to cotton," *J Clean Prod*, vol. 268, p. 122180, Sep. 2020

[23] H. Sankari, "Towards bast fibre production in finland: stem and fibre yields and mechanical fibre properties of selected fibre hemp and linseed genotypes"

[24] M. Novaković, D. M. Popović, N. Mladenović, G. B. Poparić, and S. B. Stanković, "Development of comfortable and eco-friendly cellulose based textiles with improved sustainability," *J Clean Prod*, vol. 267, p. 122154, Sep. 2020

[25] D. de Miranda, "An evaluation of hemp fiber for furnishing applications" Master thesis, 2011

[26] S. Bilgen, "Structure and environmental impact of global energy consumption," *Renewable and Sustainable Energy Reviews*, vol. 38, pp. 890–902, Oct. 2014