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Inclusion of Hemp Winter Retting in a Crop Rotation in Organic Farming

Master`s thesis

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Organic Farming - AGRIME

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Inclusion of Hemp Winter Retting in a Crop Rotation in Organic Farming

Summary

Cannabis sativa or hemp is a multipurpose crop widely used in human history, but abandoned in 20th century, while recently, it is a frequently researched agricultural crop with high potential of applications across many industries. However, its practical applications remain limited. One of the main limitations is the retting process used to separate the fibres for further use. In this study, an alternative method of retting was researched, consisting of leaving the hemp stalks ret standing uncut on the field over winter.

The literature overview was focused on the possible inclusion of winter retting method in crop rotations in organic farming. It reviewed the options for retting methods, environmental benefits of hemp cultivation in general and its benefits for organic farming. From the economical point of view, major possibilities of hemp applications were researched, as well as possible textile uses and the winter retting method. The overview was designed to demonstrate that hemp would be an ideal crop for organic farming crop rotations, but its practical inclusion depends on the economics of further applications. It was suggested in previous studies, that winter retting may be a way to lower the production costs, but the success of this method largely depends on reaching the textile quality of hemp fibre to be profitable for farmer.

Thus, the practical experiment consisted of cultivating a hemp field using the winter retting method and taking samples of hemp stalks over winter. These samples were evaluated and one of them was further processed in order to be tested for its physical qualities. It was observed under microscope, that the resulted fibre had comparable qualities to a fibre used to make actual real hemp/cotton T-shirts. However, when measuring the physical properties using the vibroscope method, the hemp fibres had very good strength, but were lacking the desired fineness for processing on cotton mills. Using the regression analyse, it was suggested, that the elementary fibre would reach the desired quality, but the fibre bundles would need further separation.

The hypothesis, that the winter retted hemp should be included in the crop rotations in organic farming, depending on the reached fibre quality in order to be profitable for farmer, was only proved partially. More research would be needed with more samples and further processing of hemp fibres into yarn and actual T-shirts.

Keywords: agriculture, *Cannabis sativa*, industrial hemp, hemp fibre, spring harvest

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1 Introduction

Today, the world is facing some kind of crisis from almost any direction, but amongst the most debated ones, soil degradation is a serious threat. Every year, around 25 million tons of cotton are produced worldwide for the textile industry. Cultivation of this crop takes up a considerable part of the arable land and leaves it in poor condition, as cotton needs large amounts of agrochemicals, mostly insecticides and pesticides, while it is also extremely water demanding (The World Counts). At the same time, plastic fibres may be causing long term health effects, while it is an unsustainable solution. As a reasonable alternative seems to be hemp fibre, a sustainable material, which can be easily cultivated in organic farming systems, helping to stop the soil degradation. However, its inclusion in crop rotations is very limited.

Besides many other industrial applications, *Cannabis sativa* has historically been used for making textiles. In order to do so, first, the hemp stems need to be retted to break the bonds between hemp fibres, which has been traditionally done by submerging it under water. Then, the fibres need to be separated, spun into yarn, and weaved into hemp fabric, used to make clothes. The most challenging part of this process is the retting, as most technologies are outdated, environmentally unsuitable, or economically unprofitable. Leaving the hemp on the field uncut over the winter is an alternative method, that has not been largely researched yet, but may be a way to decrease the harvest and retting costs, retain the textile fibre quality, while it is an environmentally friendly method.

2 Objectives of the work

The goal of this theses was an evaluation of the hemp winter retting method. Existing literature was studied in order to prove the ecological benefits of hemp standing on the field over winter and its inclusion in crop rotation, while the practical experiment was designed to prove the economical benefits through the hemp fibre quality assessment.

As the winter retting method has not been a topic of frequent research, a considerable part of existing literature was researched in order to prove the environmental benefits of this method and also hemp in general. The importance of this method has also been highlighted by researching other retting methods and applications for hemp materials across different industries, mostly from the economical point of view. The literature overview served as a demonstration that the possible inclusion of hemp winter retting in crop rotations largely depends on the reached quality of the hemp fibre and whether it can reach the textile quality.

The complementary practical research was designed to prove that the winter retted hemp fibre can reach the textile quality; thus, it would be able to generate tempting profits and be included in crop rotations by farmers, allowing hemp to utilize its environmental benefits. In order to do so, a hemp field was cultivated using three different varieties of *Cannabis sativa*. Monthly observations took place and obtained samples were evaluated. The side objectives were to compare the varieties and choose the most suitable one for this method, to measure the yields and to go through to whole process of making a hemp fibre. At last, physical assessments were performed to measure the reached parameters of this fibre. The results were statistically analysed and compared to other studies in order to conclude whether it has reached the textile quality.

The study as a whole was designed to prove the hypothesis that hemp winter retting is a valuable method for organic farming and it should be included in crop rotations.

3 Literature overview

3.1 Hemp winter retting

3.1.1 Introduction to hemp fibre

Hemp (*Cannabis sativa*) was an important agricultural crop in human history, that has been grown for millennia, as Pierre Bouloc (2013) mentions in his book. Besides its well-known medicinal properties, hemp has a wide range of applications, which can be easily divided into categories based on the part of the plant. Seeds are used as bird or human food, for hemp oil or hemp protein production. Before the whale oil use had spread, hemp oil was also a major source of lightning. The stem is then divided into bast fibres, which grow on the outside of the stem and hemp hurd, found in the stem core. Hemp hurd is a source of cellulose, thus it has been and still is used for papermaking, but it can also be used as building material or as animal bedding (Bouloc 2013; European Commission).

The hemp fibres are naturally strong, moisture absorbing, antimicrobial and thermoregulating (Zhang et al. 2016). These advantages make the hemp fibre an excellent choice for the textile industry. Humans have known the hemp properties for millennia and they have been using the hemp fibres for textiles for just as long. The oldest records of hemp canvas can be tracked to as far as 6000 B.C. (Walker 1998; Bouloc 2013). In his bachelor's thesis, Schroeder (2019) has researched the oldest tracks of cultivating hemp plants in Europe from 4280 B.C. from the Lake-Verna region in Bulgaria, while Vikings were making hemp fabrics in 200 B.C. and cultivating cannabis even much earlier (Skoglund 2013). Hemp stalks were a world major textile material up until the 19th century, when cotton took over the textile industry. Before then, Hemp fibre had been used for clothing, but more importantly for rope, cordage and sail production. Before the steam boats were invented during the 19th century, each ship would carry up to ninety tons of hemp fibres. Naval forces have used hemp for this purpose even during the second world war in great quantities (Bouloc 2013; Williams 2019). Recently, hemp is regaining its popularity and more research is being done on renewing some of its forgotten uses, including textile applications.

3.1.2 Chemical process of hemp retting

The hemp stem is made out of cellulose, hemi-cellulose, lignin and pectin. In order to successfully produce hemp bast fibres, they need to be separated from the hemp hurd and other components of the stem, including epidermis, shives, or xylem. The fibres and the hurd are made mostly out of cellulose, and they make up most part of the stem. The bast fibres are located in the phloem of the stem and are enclosed and kept together in bundles by lignin and pectin, acting as natural glue. Lignin and pectin can be broken up by various enzymes, mostly pectinase, produced by microorganisms, specifically fungi and bacteria. When the natural glues are removed, the fibres need further mechanical or physical separation (Eynde 2015).

3.1.3 Traditional methods for hemp retting

Traditionally, there were two main methods for removing pectin and lignin from the hemp fibre and they both include retting of the stem by exposing the stems to wet environments with perfect conditions for the growth of specific microorganisms producing ligninase and pectinase enzymes.

During water retting, the oldest method for hemp stem production, hemp stems are submerged into warm water after the harvest and left to ret for five to twenty days, depending on numerous factors as the temperature of water, pH, further processes and others (Jankauskienė et al. 2015). While the water retting process results in high quality fibre, ideal for textile production, it has been proved to be highly energy demanding, but on top of that, Keller et al. (2001) suggest that it leaves the water polluted, full of high oxygen demanding bacteria. The treatment of the polluted water is a costly process and the European Union directives prevent releasing of the polluted water into the environment (European Parliament & Council of the European Union). There were bans on water retting in ponds as early as in the 19th century in France for the odour that the retting stalks were making (Bouloc 2013). Due to the polluted water after the water retting, this method can no longer be used in hemp fibre production, other than research projects.

The other traditional way of processing the hemp fibre is called dew retting. This method consists of cutting the hemp stalks and leaving them to ret on the field for a couple of weeks, based on the weather conditions. For the microbacterial growth and enzyme production, warmer and more humid weather is preferred. This method is more environmentally friendly, as it slowly releases nutrients back in the soil, but it is strongly dependent on the weather conditions and leaves the farmer with lower quality, grey coloured fibre. Both of these methods are also highly labour demanding. (Keller et al. 2001; Lee et al. 2020).

3.1.4 Alternatives to hemp retting

Because the disadvantages of traditional hemp retting methods limit the possibility of their use, other ways to break the lignin and pectin bonds were researched and used for hemp fibre production. Amongst the most spread ones are enzyme and chemical degumming, mechanical decortication or steam explosion method.

The enzyme degumming method is based on cultivating selected fungi or bacteria strains, or their mix, and using the produced enzymes to ret the stems. The enzyme retting process is more effective, yielding higher amounts of finer and stronger fibres, while being more environmentally friendly than the water retting method. However, the disadvantages are a high cost of commercial enzymes and the crucial importance of correct ratio of the pre-mixed enzymes and their correct application, which Lee et al. (2020) argue is not always the case. The incorrect use of enzymes leads to either over or under retting. The unevenness of the diameter of hemp stalks can also lead to unevenly retted fibre.

The chemical degumming uses specific combinations of chemicals to break the pectin and lignin bonds. A commonly used chemical retting method is called alkali degumming, which applies alkali chemicals on the stems for a short period of time, measured in hours, but applying high temperature and intensity. This method results in even finer and cleaner fibre than the enzyme degumming, but can be as easily unevenly or over retted. Rani et al. (2020) find the downside of chemical degumming method in an intensive use of chemicals, which leads to water pollution.

After the hemp stalks are retted and the lignin and pectin no longer hold the fibre bulks together, the fibres need to be further mechanically processed. This process separates the bast fibres from the hemp hurd, while it also separates hemp fibres from each other. This method is called mechanical decortication. For a nontextile fibre production, for example insulation or hemp hurd production, the hemp stems do not need to be pre-retted, which gives the process considerable advantages. This material can only reach lower price and it is not weather dependent, water polluting nor biologically damaged (Hepworth et al. 2000).

The steam explosion is usually conducted on pre-retted stems, although green stems can also be used with lower quality product. It can also be used before the retting to increase its effectiveness. In the first part, the stems are exposed to high pressure and temperature, which softens the fibre and prepares it for the second step, when the steam is quickly released. The steam that is trapped inside the stems mechanically breaks the fibres from each other, as it finds a way to escape. The effectiveness of steam explosion can vary based on the combination with other methods and the final destination of the product, but it increases the value of fibres meant for the textile production (Riet 2019; Lee et al. 2020).

Some of the methods stated above can be combined in order to reach the desired fibre quality and they usually need further mechanical separation such as beating, scutching or combing, before they can be spun into yarns and woven into hemp fabric. However, the first step of hemp processing poses the biggest challenge, as all the methods have their disadvantages and the hemp industry has not yet proved to be profitable enough to regain its popularity. The hemp textile industry still calls for a method that would be both gentle to the environment, and profitable enough to compete with cotton and men made fibres, meaning that the end product needs to reach a lower price and high quality (Werf & Turunen, 2008; Eynde 2015,).

3.1.5 Winter retting

The scientific literature also mentions an old, almost forgotten method called spring harvest, Finish method, Dry-line-method, or winter retting, which it will be referred as in this review. Winter retting consists of leaving hemp uncut on the field and letting frost do the retting over winter. In 2000, Pasila has published in his research that this retting method drastically lowers financial input and increases yields. The repetition of changing temperatures below and over 0 °C damages the pectin and lignin bonds, allowing the separation of fibres from each other. Moreover, when the early spring comes, the stems are dried enough for future processing. This study suggests, that the stems retted over winter are more easily separated, thus leading to higher yields of the bast fibre. However, Nilsson & Olsson (2008) and Fike (2016) agree that this method could lead to significant biomass losses, depending on the harvesting technique. Ivanovs et al. (2015) also argue, that the sun naturally bleaches the fibres over winter, giving it nice pale color, as opposed to dew or even water retting. On the other side, multiple researches agree that the winter retting leads to a lowered strength of the fibre and the stalks can get easily over-retted (Pasila 2000; Hautala et al. 2004; Ivanovs et al. 2015). Although the lowered strength allows non-specialized combines to harvest the crop. Ecological and financial benefits will be further discussed in separate chapters.

3.2 Ecology of hemp winter retting

3.2.1 Ecological benefits of growing hemp

Beside the industrial potential of processing hemp plants, its cultivation has also many advantages for agriculture and benefits for the environment. Hemp has low watering and fertilization requirements, does not need any herbicides, pesticides or fungicides and breaks the soil with deep roots, while it grows fast and dense, quickly capturing CO^2 and requiring less acreage.

The irrigation requirements differ based on the location, but studies listed by Amaducci et al. (2015) conducted in Europe agree that hemp needs from 500 to 700 mm of precipitation per year for an optimum yield, although most of the studies were conducted in the Mediterranean climate, which is known for drought and high temperatures; thus, the water consumption will be lower in central Europe. Moreover, in 2000, Amaducci et al. have found that the hemp yields were only increased by less than 7 % when irrigation was used in the Northern Italy, which is not a significant difference.

The need for adding nutrients always depends on the soil conditions. In nutrient rich soils, hemp does not need any added fertilizers. Generally, higher nitrogen availability does increase the yields, but it also lowers some of the technical qualities, such as the fibre strength (Amaducci et al. 2015). Up to 200 kg/ha of nitrogen worked in the soil during the sowing increased the biomass yield, seed yield, plant height or the plant composition, says Aubin et al. (2015). The other macro-nutrients, potassium and phosphorus, have a very limited effect on the quantity of the product, although this also depends on the soil conditions, as complete lack of these nutrients will negatively influence the growth. A lack of phosphorus will result in lower resistance against pests, lower strength of the fibres and overall health of the plant. Adesina et al. (2020) adds that a lack of potassium has lower effects than the lack of nitrogen and phosphorus, but it can also negatively impair quality of the fibre.

Nitrogen fertilization will also influence hemp ability to compete with weeds, especially in lower densities. In higher densities, hemp quickly creates a dense canopy that suppresses the weeds and it leaves the soil virtually weed free for the next crop. Due to this fact, hemp does not have a natural resistance against most herbicides; therefore, more ecological approach needs to be used for its cultivation (Piotrowsk & Carus 2011; Kousta et al. 2020).

Each season the hemp field grows, it captures carbon dioxide from the atmosphere. The hemp hurds can then be used as building material in hempcrete and the CO^2 is stored for decades, possibly centuries. In 2017, Jami & Kumar conducted a study, where they find that one cubic meter of hempcrete can capture 307.26 kg of CO^2, meaning that the whole building can capture tons of CO^2 and becoming carbon dioxide negative, as opposed to conventional buildings. This is a true statement even when we take into consideration emissions produced by the transportation of materials and the construction of the building, while hempcrete has many functional and health benefits described later on. Jami & Kumar (2017) and Arrigoni et al. (2017) both agree that due to its properties, hemp is an ideal crop for a sustainable approach in farming.

3.2.2 Hemp in organic farming

The qualities listed above make hemp a suitable crop for organic farming. To clearly interpret how each of these advantages may help an organic farmer, students from the Royal Agricultural and Veterinary University in Copenhagen have put together a SWOT analysis (Barron et al. 2003).

As strengths, they included no need for synthetic fertilizers and agrochemicals, which avoids pollution and allows the farmer to use local resources, similarly to natural resistance against pests and diseases, which prevent the use of pesticides. Both synthetic fertilizers and other agrochemicals are commonly washed from the fields into ground water causing rapid growth of polluting bacteria and other unwanted harmful side-effects. Organic local fertilizers can be used to grow hemp, reducing the carbon footprint and pollution. Hemp ability to outgrow weeds helps the organic farmer with weed control, as Francis (2009) believes it is one of the most challenging problems in organic farming. Soil breaking roots improve the soil structure, which comes in handy in no-tillage systems, while new crop from a new family does increase biodiversity.

Besides variable yields and lack of public information about hemp as a crop, lengthy retting periods and harvesting difficulties were stated to be the weaknesses of growing hemp. However, these weaknesses do have solutions and the study suggests that hemp is a suitable crop for an organic farming. The possibility of integration hemp into crop rotations is further researched.

3.2.3 Hemp in crop rotations

Thoughtfully designed crop rotations are one of the oldest methods to increase both quantity and quality of the yields and still are of major importance today, especially in organic farming, where some of the conventional techniques are banned. Crop rotations help to manage available levels of nutrients in the soil, mainly nitrogen, through rotating crops with different nutrient uptakes. Different crops also vary in their competitiveness against specific weeds and their resistance against pests and diseases; thus, crop rotations are an effective tool for weed, pest and disease control (Piotrowski & Carus 2011; Kousta 2020).

An Irish study evaluating hemp as an energy crop concludes that hemp cultivation for biomass energy would effectively fit into crop rotation as a break crop (Finnan & Styles 2013). Break crops are designed to break repeated sowing of similar crops, bring diversity and reduce weeds, pests and diseases, mostly in cereal oriented crop rotations. They are also supposed to improve the soil structure and content, they should make and diversify profit and they should not compete with main crops (Finch et al. 2002). One of the ways to break the crop rotation cycle and diversify the income is to grow energy crops. When Finnan & Styles (2013) compared hemp to other biomass energy break crops, hemp surpassed two major ones, sugar beet and oil-seed rape, in terms of environmental impact and biomass yields. In long term, hemp could even compete with perennial energy crops such as willow or Miscanthus, which have a great advantage for they do not need annual sowing, harvest or transportation. Hemp not only diversifies the farmers income, but as a break energy crop, it does not compete with other main crops in the time of their harvest. Moreover, Gorchs et al. (2017) have proved that by breaking the soil with its deep roots, as a break crop in cereal-oriented rotations, hemp increases the winter wheat yield.

Organic farming especially relies on the soil health for its stable production. A team of researchers (Kok et al. 1994) conducted several in-lab, greenhouse and field experiments on hemp interaction with selected pathogens. Laboratory and greenhouse experiments proved that hemp may effectively suppress the spread of handful of harmful nematodes, including pathogenic root-knot*M. chitwoodi,* or fungi, such as pathogenic *V. dahlia*, which is a soil borne disease hard to manage even by strict crop rotations. Hemp meets all the criteria for an ideal break crop except for nutritionally enriching the soil content, which can be argued. Although hemp does not fix nitrogen in the way legumes do and the SWOT analysis conducted by Danish students (Barron et al. 2003) lists high nitrogen uptake as one of the weaknesses, hemp does use up different nutrients than cereals, balancing the nutrient content in the soil. Furthermore, Kraenzel et al. (1998) suggested, that hemp conserves nutrients in the soil through leaving its leaves on the ground and roots bellow it quickly decaying, as opposed to corn or wheat. Up to two thirds of the nutrients can be recovered in the soil if hemp is dew-retted on the field. Even though it is not a recommended practice, hemp can be grown as monoculture for years on the same field with a minimum decrease in yields, which highlights its nutrient recovery abilities. All of this suggests that hemp would be a valuable crop in crop rotations.

3.2.4 Ecological benefits of hemp winter retting

An ideal winter cover crop needs to have similar properties as a breaking crop. The main reason to grow winter cover crops is to prevent the field from being hallow over the winter; thus, decreasing the water or wind erosion, and preventing nitrogen leaching, increasing soil and water quality. Cover crops further increase soil quality through carbon sequestration, weed and pest management. Deep rooted cover crops also mechanically break the soil, increasing its structure quality. Rain drops cannot damage the structure, as biomass protects the soil, while slowing water, so it can be effectively absorbed, minimalizing the runoff and nutrient leaching. Recently, studies including the one performed by Dabney et al. (2001) have also argued that cover crops allow beneficial mycorrhizal fungi to survive winter and help the spring crop grow faster in its early stages. Overall, winter cover crops are an effective tool to increase the quality and quantity of the yield, while it is beneficial for the surrounding environment. Subsidies are often provided to farmers growing cover crops (Ministerstvo zemědělství 2015).

As increased quality of the main crop yields can hardly equal the costs to cover the soil, subsidies are crucial for a widespread practice of this method (Lu et al. 2000). One other way would be to grow a profitable cover crop. Letting the hemp grow into the winter and leaving it ret standing on the field does meet all the criteria stated above to be a good cover crop, while it generates profits. Unfortunately, this topic has not been researched yet and the only literature that touches any ecological side of the winter retting method only mentions, that seeds left on the stalks over winter are consumed by animals (Ivanovs et al. 2000). This suggests that hemp standing on the field over winter might provide shelter and food for wild animals.

From an ecological point of view, hemp is a suitable crop for organic farming, fitting into crop rotations even as break or cover crop, having numerous side benefits for the soil and the environment. However, the success of this method will largely depend on its economic output.

3.3 Economy of hemp winter retting

3.3.1 Possible economical uses of hemp

As already stated, hemp is a variable multi-purpose crop, having many possible uses across different industries, while it has been proved that its cultivation is beneficial for the ecosystem. Although its ecological benefits may result to increased production in long term, in short term, a farmer’s income will still be the most important factor deciding the cultivated area. Farmer’s profits depend on economics of further processing methods. Today, commercial uses of hemp include CBD production and medicinal use, seeds and oil production, housing industry, paper and plastics making or growing for biomass.

In recent years, growing cannabis for flower containing a cannabinoid called cannabidiol, CBD, has been spreading rapidly. CBD has proved to have many positive health effects, while it is a non-psychoactive compound, as opposed to THC. Besides helping with diseases such as epilepsy, Alzheimer's or Parkinson's disease, CBD relieves stress, reduces anxiety, improves sleep and relieves muscle pain. The CBD industry reaches over 2 billion dollars per year in Canada and it still has a potential for further growth (Nichini 2021). On the other side, the laws about its legality are still unclear in most countries and the product itself lacks any legal definition. It has not been yet decided, whether CBD is a food supplement, a novel food, new medicine or narcotics (Hazekamp 2018). Furthermore, it is also argued by Lachenmeier & Walch (2020) that its long-term effects are still unknown, making it unsafe to consume, even though no harmful effects have been observed. In some European countries, a CBD oil cannot contain any level of THC, which is practically impossible to achieve, as even technical registered varieties contain traces of THC. Other countries prohibit any processes involving hemp flowers, making CBD production illegal, while the final product can be legal. For example, Czech Republic legislation only allows hemp production for industrial, technical or horticulture purposes (Parlament České Republiky 1998). Although CBD market seems like a promising industry from the financial point of view, its legal definition and thus its future legislature limitations are uncertain.

Hemp seeds, historically used mostly for animal feed as a by-product of growing hemp for fibre, have recently became a commonly used food source, mostly because of its nutritional value. They are high on proteins, omega 3 and 6 fatty acids and some of the important minerals and vitamins (Farinon et al. 2020). Hemp seeds can be compressed into hemp oil, which is again high in healthy fatty acids. However, an uneven rate of maturity and high shattering resulting in grain loss during the harvest are discussed by Schluttenhofer & Yuan (2017). Furthermore, the legality of the hemp in foods made for human consumption is unclear due to complicated legislature and definition of such products.

Housing in general is one of the most polluting industries. Most focus to minimalize the construction emissions is put on the operational phase of the building and less on the "embodied energy", but both phases are deeply connected. One of the effective ways to decrease the operational phase emissions is increasing insulation thickness, but if the materials for insulation come from polluting sources, the embodied energy increases. It has been suggested by Arrigoni et al. (2017), that the housing industry will need to use more bio-based building materials in the future. Hempcrete is a fitting solution, since it has optimal insulation properties, it is antimicrobial, breathable and when used as hempcrete blocks, it is relatively easy to use. On the other hand, this building material has been forgotten for almost a century and some of the legislature regulations for its use are now missing. In Czech Republic, its use is limited because the authorities do not accept hempcrete as fire resistant material, even though it has been certificated so in other countries with similar regulations (Zvelebilová 2016).

The environmental crises and continual climate change call for more ecologically friendly solutions across all industries. Besides those already mentioned, hemp plants could play a major role in many other solutions. Among these are also hemp paper or bio plastics. However, both of these industrial uses of hemp pose unsolved technological questions and will need more research and investments to be able to spread hemp cultivation into common use (Wretfors et al. 2009; Vieira et al. 2010).

3.3.2 Economical aspects of textile hemp

Although hemp has many possible economic uses with high potential in the future, most of them are not economically interesting at this moment. In a Chinese leading hemp market, the only wide spread commercial uses of hemp are well-being products, such as food, cosmetics and food supplements including CBD, and hemp textile industry (Mirizzi & Jablonski 2020). Throughout the history, the most important reason to grow hemp has been the fibre production. In EU, the most important use of the hemp bast fibre is textile production, argues Ranalli & Venturi (2004). The production for bio composites and other technical uses, where only the raw materials are used cannot compete with prices of imported hemp, because of high labour costs in the EU.

The biggest competitor to hemp textile is cotton, which has replaced it in the first place. However, from the environmental point of view, hemp is a better alternative. It yields thrice more fibre from a hectare than cotton does, while cotton needs chemicals, fertilizers and irrigation for its cultivation. Hemp does not need any of those as already listed above. This means that hemp is not only more environmentally friendly alternative to cotton, but it is also cheaper to produce, when the costs of agricultural activities are compared. When it is taken into account that hemp has bigger yields per hectare, it can be concluded that only one third of the land dedicated to growing textile fibres would be needed worldwide (Schumacher et al. 2020). The total costs of hemp production cannot be objectively compared to those of cotton as the technological advancements are not on the same level (Fortenbery & Bennett 2004; Ranalli & Venturi 2004).

3.3.3 Economical aspects of hemp winter retting

The financial profit of growing hemp for fibre depends mainly on the costs of the production, influenced by the harvest and decortication techniques, and the market price of the product, stated by its quality.

As stated in the first chapter, the biggest challenge during the processing of hemp is the separation of its fibres. Most of the methods are polluting, economically demanding, or unstable in the resulted quality. Decreasing costs of the production while not increasing ecological load would be a desirable solution. In his dissertation work, Hennele (2000) suggests that the hemp winter retting method can drastically reduce the costs of the production by not needing any specialized machinery for the harvest and not needing any other post-harvest treatments such as decortication or other expensive retting processes. The fact that farmers can use machinery that they already have makes it more probable that they will include hemp into their crop rotations. On the other hand, a large portion of hemp hurd is left on the field during the spring harvest, decreasing profits from the biomass. The seed harvest can take place in autumn in two-step harvest, but it decreases the yields of fibre by as much as 79%, so it can be skipped leading to complete loss of the seed production (Ivanovs et al. 2015).

Even though the winter retting method reduces the costs of the production, it leads to lower yields and lower quality. The main question in the economical assessment is whether the fibres can reach the textile quality and can be sold for a higher price. Ivanovs et al. (2015) state that strength of the fibres can be lowered by 25-52 % when retted over winter. Hautala et al. (2004) in their study, designed to evaluate the strength of hemp winter retted fibres for a composite production, concluded that these hemp fibres are comparably strong as plywood. In 2019, Rinklebe economically evaluated the winter retting method in German conditions. It concluded that this method was not yet economically profitable, but that the overall profitability of growing hemp increases each year. More importantly, it suggests that winter retted hemp fibres do reach the textile quality and that it is a promising method. One of the factors to measure the strength of fibres for the textile use is measuring the median of breaking tenacity of the 2mm long fibres. In a study conducted by Hennele in 2000, this value was measured from 41 to 74 cN/tex for an autumn harvest and 15 to 42 cN/tex for the winter retted fibre. Although the strength was lower in winter retted stems, the results proved to be more uniform. This study suggests that other quality factors such as water absorbency also need to be taken into account, which has been proved to be better in the spring harvested hemp.

Although the research on hemp winter retting method has been very limited, the literature agrees that this method might be an interesting approach to hemp fibre production.

The most important factor influencing the profitability is the fibre quality. Most studies state that the quality of fibre is lowered over the winter, but they also agree that it can still reach the textile quality. The importance of knowing the hemp winter retted fibre quality is crucial for the inclusion of hemp winter retting in a crop rotation in organic farming, while the knowledge of this topic is minimal; thus, more research is needed.

4 Methodology

4.1 Cultivation and processing hemp

4.1.1 Growth site

The hemp used for this experiment was grown at location near village Chrašťice, Central Bohemian Region, Czech Republic, southeast from the city Příbram. The parcel number 5509/2 has 2.69 ha, it is farmed conventionally and there is no danger of erosion. It does not include any protected area. The experiment took place in its northeast corner, where there is a mild northern slope (LPIS). Hemp is the only plant cultivated on this field for over a decade. Basic agrochemical analyse was conducted in 2021 to measure the nutrient levels in the soil.

4.1.2. Agronomy

Three varieties of *Cannabis sativa* were selected based on their ability to produce a quality hemp fibre. Those included Santhica 27, Sylvana and Finola. The hemp field was sown on 22nd April 2020 on 200 m^2 with the sowing rate 120 kg/ha, which was approximately 600 seeds per squared meter. This high sowing rate was chosen based on the literature, which mentions previous experiments proving that higher plant density results in higher bast fibre content in stems and more homogenous growth, resulting in better weed suppression (Werf 1991; Bouloc 2013). The seeds were sowed in rows with the span 12 cm using a sowing machine and filling an extra row in between by hand, leaving the span between the rows 6 cm. Prior to sowing, the soil was cultivated by a stubble cultivator and turned in autumn. No further treatments were performed during the growing season. The hemp was left on the field uncut and untreated over the following winter, when monthly observations took place. During each observation, a random sample of approximately 1 m^2 of each variety was taken for further evaluation and 4 quarter squared meters were used to estimate the yield and the number of plants per 1 m^2.

4.1.3 Weather conditions

According to the Czech Hydrometeorological Institute, the year 2020 in Central Bohemian Region average temperature was 9.9 C°, which was 1,3 C° warmer than the long-term average 8.6 C°, measured from 1981 to 2010. The rainfall reached 629 mm, which was 107 % compared to the long-term average of 587 mm. April was by 1,5 C° warmer, but it only reached 21 mm, which is 62 % of its long-term rainfall average. May was by 2 C° colder and the rainfall has reached the long-term average. The temperatures during June and July somewhat corresponded with the long-term average, but the rainfall was 120 mm in June, 171 % compared to the long-term average and 40 mm in July, 49 % compared to the average. August, September and October were around 1 C° warmer, but with higher rainfall than the average, in October even by 197 %. November and December were dryer than usually, reaching 16 mm, 40 % and 17 mm, 45 %. The average temperature in December was by 2.6 C° higher than the long-term average of -0.1 C°. The average temperature in January 2021 was -0.3 C° and the rainfall was 49 mm, which is 148 % of the long-term average. Overall, the growing season was slightly warmer than usually, with dry April, July, November and December and higher rainfalls during June, August, September, October and January.

4.1.4 Post-harvest treatment

After the harvest, the hemp straws were dried under the room temperature around 21 C° and taken to the AGRITEC Šumperk for a mechanical decortication. For this purpose, a small mechanical decorticator CMT-200M was used. The samples were weighted before and after the decortication process to obtain the average fibre to hurd ratio. Based on the naked-eye observation of the samples and the field, the most promising hemp variety and sample was chosen for further processing. To separate the fibre bundles into smaller fragment, the steam explosion method was chosen mainly for its economical benefits, as the fibre does not need drying afterwards and the fibres are evenly distributed. This process was performed in Arnhem, Netherlands by StexFibers BV. company.

4.2 Measuring physical properties of the fibre

After the steam explosion treatment, the sample was sent to the Technical University of Liberec, for a hemp fibre quality assessment.

4.2.1 Microscoping

First, the hemp fibre sample processed by steam explosion was observed under a scanning electron microscope TESCAN VEGA3 under several magnifications ranging from 100x to 2000x. To evaluate the results, a sample of water retted hemp fibre processed by the alkali degumming method was obtained, so they could be compared. The fineness (*t*) was derived using the cross section of the stem and the following equation $t=s\rho = \pi d^2\rho/4$, where *s* is the area of the cross section, d is an equivalent fibre diameter and ρ is density. The equivalent fibre diameter is defined as a circle of the same area as the area of the cross section.

4.2.2 Measuring the fineness using the Micronaire method

The fineness was measured using the Micronaire SDL 019A Shirley developments LTD, which was primarily constructed to measure the fineness of cotton fibre. The fineness of the fibers is determined on the basis of the resistance of fiber against air pressure. To measure non-cotton samples, the device only uses the constant air pressure. 5 grams of the sample is compressed by a cylindrical piston, air passes through the sample and the airflow is measured. The fineness is then derived using the formula $t=Q/(K\Delta p)$, where Q is the volume of the passed air, Δp is the change in the air pressure, K is the function of the mass, density and length of the fibers and the air viscosity. The Micronaire device measures the fineness of the sample in Micronaire units, but they can be converted into dtex using the following formula: $t[dtex]=t[mic]/2{,}54$ (Dančíková 2018).

4.2.3 Measuring the fineness, strength and elongation using vibroscope method

Random bundles of fibres were separated from the sample and measured using the Lenzing Vibrodyn vibroscope. The vibroscope measured the fineness in dtex and it recorded the tension working curves to derive the strength, elongation at break and the module of elasticity. These measurements were conducted on twenty samples.

4.2.4 Statistical analyse

From the vibroscope results, average values of fineness, absolute and relative strength, tension and modules and 95% confidence intervals of their mean values were calculated. Based on these values, histograms were made with the observed value on the x-axis and the relative frequency on the y-axis. As the sample strength is expected to be dependent on the number of elementary fibres in the tested fibre bundles, in other words the fineness of the sample, the regression analyse was performed to prove the null hypothesis that the regression coefficient equals to zero; thus, there is no regression between the fineness and the absolute strength. The regression curve was then graphically visualised and further analysed in the software STATISTICA.

5 Results

Results from the agrochemical soil tests have shown some nutrient disbalances. The soil reaction was slightly acidic, while phosphorus was at low levels, as well as potassium. On the other hand, magnesium levels were stated as very high (Figure 1).

The yield of four quarter squared meters averaged at 740 grams of dried hemp stalks per 1 m^2, roughly converted to the yield of 7,4 tons per hectare and 340 single stalks per 1 m^2, which shows that 57 % of sewed seeds have reached the harvest time. This measurement was only done for the whole field, as there were great inconsistencies in growth based on the part of the field, not the variety; thus, comparing the yields of the varieties would be highly dependent on the choice of the samples and misleading, although Finola clearly showed lower growth.

According to the Figure 2, the average total yield of hemp fibre was 27,34 % of the total mass, which makes it around 2 tons of total fibre per hectare. There were not any tendencies based on the month of the harvest, but there were major differences in total average yields based on the variety, where Sylvana had almost twice as much total fibre yield compared to Finola.

However, yield was only a complementary factor, as fibre quality was the most important value for the follow-up experiment. Only one sample was chosen for this purpose and it was chosen based on the sensory evaluation. Not as evident from the Figure 3, Santhica (lower part of the picture) had superior qualities in sense of softness, fineness, and colour, which were the most desired qualities. These qualities were highest represented in Santhica harvested in December, as the fibre was already broken down, but it was not over retted.

When comparing the water retted fibre cottonised in an alkali bath (Figure 4) with the winter retted fibre from the steam explosion (Figure 5) under microscope, it can be certainly concluded that the winter retted fibre was broken up into smaller fragments while the water retted fibres were kept in unbroken bundles. Although, it cannot be stated whether the smallest fragments were single elementary fibres or two or more fibres kept together.

Using the Micronaire method, the sample of winter retted fibre was detected to have the fineness of 1,32 dtex. When using the formula to derive the fineness from the cross section of the stem, the result was 1,31 dtex. However, more statistically reliable data were obtained by the measurements on the vibroscope, as 20 samples were evaluated.

The mean fineness, at 14,86 dtex, was close to its median value, suggesting that the extreme values were minimal (Figure 6). According to the histogram of fineness values, most samples ranged between 10 and 20 dtex (Figure 7). The mean elongation at break was 3,35 % and most values ranged from 2 to 4,5 % (Figure 8). Most values of the modulus of elasticity scored at 1000 to 2000 cN/tex, while it averaged at 1428,25 cN/tex (Figure 9). The absolute strength values were inconsistent, but a prediction was made that they might be dependent on the fineness of the samples. Looking at the scatter chart (Figure 10), some relation between the absolute strength and the fineness was observed, but there were few extreme values. Using the regression analyse (Figure 11), the null hypothesis was declined and this corelation was proved with the corelation value 0,451224, meaning that the absolute strength is dependent on the fineness of the fibre. Although, the F value is close to zero, the standard error is high and only 20,3 % of the values were statistically explained, meaning that the statistical significance is existent, but low. It was also derived that as the fineness increased by 1 dtex, the absolute strength increased by 3,375 cN. Evaluating the graph of the residuals (Figure 12), a small unevenness of the residual values were observed. At last, the P-P plot was visualised (Figure 13). The values had some deviations from the expected values, but their distribution respected the expected line, even the external values. An uneven distribution might have been observed, but more data would be needed to clearly see such trend. Even though the statistical significance of the correlation between the fineness and the absolute strength was low, the observed corelation did make sense from the physics point of view. Thus, the relative strength was included in the data set and its histogram (Figure 14) showed the distributed values. The values were scattered over a considerable range, but they were closer together than the absolute strength values and their mean and median were also close, as suggested by the regression analyse.

6 Discussion

As the textile industry needs a sustainable alternative to cotton or plastic fibre, searching for such source of material is a relevant issue. Hemp fibres could represent a material that is environmentally friendly, but its fibre needs to reach the textile quality in order to be profitable for farmers. This quality is mostly influenced by the retting process, decortication and other post-harvest treatments. There are both historical and modern techniques for processing hemp fibres, but most of them have major drawbacks limiting their widespread use. The winter retting method is an alternative with minimal research, but it has a potential to reach the textile quality fibre and be profitable for the farmer, while it has numerous ecological benefits. If the textile quality was met, it would make sense for farmers, especially organic farmers, to include the hemp winter retting method into their crop rotations.

Although this research was focused on the inclusion of hemp in organic farming rotation, the complementing experiment was conducted on a field under the conventional management. On the other hand, no fertilizers or other agrochemicals were used during this study. Other curiosity is that hemp is the only plant grown on this field for years. This practice denies the basic principle of organic farming and has left almost none phosphorus in the soil, but the hemp is still growing, suggesting that even such monoculture of hemp does not degrade the soil as fast as other crops would do.

A high sowing rate was chosen for this experiment in order to grow denser field and thinner stalks, resulting in higher fibre content in the stems and softer fibre for the decortication. 600 seeds per m^2 were sowed, but only 340 mature plants were harvested. In his study, Werf (1991) reviews experiments, where 80-90 kg/hectare were sowed in Hungary, as opposed to our 120 kg/hectare, but they have reached over 300 plants per m^2, while in Denmark, they sowed 100 kg/hectare and obtained 360 plants per m^2 at harvest. This shows, that our seeding rate might have been too high, as lower seeding rate would have the same effect with lower costs.

As the density was so high, it was not clear how much could our hemp yield. Although the yield of the dried matter was rather lower, it was comparable to existing studies, which observed yields ranging from 3 to 13 tons of dry matter per hectare (Werf 1991).

The content of bast fibres in the stems ranges from 20 to 40 % (Stevulova et al. 2014). Our samples of the variety Sylvana reached high content of bast fibres, while Santhica and

Finola scored lower. However, this could be explained by the insufficient length of the samples for the decorticator machine. As the latter two varieties had samples with shorter stems, they were being pulled inside the decorticator and separated along with the hurd. At the same time, the yield of short fibres was only estimated from the tow weight at 40 %, but it could have differed. It is important to keep in mind, that yield was not a main objective of this research and its measurements were mostly only indicative, as well as comparing the varieties. Although our samples were harvested each month over winter in order to find the best harvest date, in reality, the farmers would have hard time follow this recommended date due to harsh winter weather. The crop needs to be dry with no snow, while the soil needs to be frozen, so the tractor would not have any problems. It was found out that the December harvest was most promising. At the end of January, the fibres started separating from the stems on the field and they were getting over retted. This means that the hemp winter retting method would partially lose its benefit of covering the soil over winter and preventing the erosion.

The sample for the following processes and assessments was picked based on the colour and softness. The assumption was made that the most white-ish and softest fibre would be fine enough, but not over retted, so the end product would be softer and stronger. This was proved under the microscope, where it was observed that the fibre was broken up into much smaller fragments than the compared cottonised sample. This cottonised sample was from a fibre used to make actual T-shirts for a Czech design brand, so it has been proved by experience of customers that it has the required softness. However, one could object that these small fragments could have been obtained by the steam explosion. In order to prove this, more research would have to be conducted. The steam explosion methodology is missing in this work. One of the reasons is that the know-how of this technology is protected. Furthermore, a colleague conducting the steam explosion has died unexpectedly at the time of this research.

The results from the vibroscope measuring were the most important outcome of this research. Although the regression analyse has showed that more data would be needed for more accurate results, as well as more samples, it gave us some perception on the quality of winter retted hemp fibre. An ideal strength for the spinning of flax on cotton system is no less than 28 g/tex, converted to units used in this research 28,28 cN/tex (Harwood et al. 2008). This could also be set as a desired quality for hemp strength, as these two fibres have similar properties and most spinning mills today are constructed for cotton spinning. When compared to the results of flax strength in a study conducted by Harwood et al. (2008), hemp from our study had higher strength than all the researched flax varieties. Although the methodology differed, this comparison can indicate that the winter retted hemp fibre has the desired strength for the textile purposes. According to Das (2013), this fibre would be evaluated as very strong. Elongation has also been met as a minimal value is 1–2 %.

The desired fineness was stated at less than 7 Micronaire, converted to 2.75 dtex. Based on the vibroscope method, our sample has not met the fineness requirements for spinning. However, the Micronaire method and the cross-section method for measuring the fineness have both measured 1,3 dtex, which would be a sufficient fineness quality. The difference can be explained by the average number of elementary fibres in a tested bundle in the vibroscope method. It is probable, that this number was more than one elementary fibre; thus, these values are not representative of one elementary fibre. However, the properties of one fibre would be probably found somewhere on the regression line. Based on the Micronaire and cross section methods, it could be estimated that the fineness of one fibre would be lower than the measured values, but the strength would decrease too. If, hypothetically, one elementary fibre would meet the fineness requirements of 2.75 dtex, the estimated absolute strength would be around 35 cN, based on the regression line equation. This would meet both the strength and fineness requirements. The comparison between winter retted fibre and fibre used in textile industry under the microscope and the Micronaire and cross section method all suggest that this is the case, but more research would be needed for more reliable results.

Due to the complexity of this study, only one sample has been picked from the whole field, from the three varieties and from three harvest dates for further processing and evaluation. Although it was picked by relevant factors, maybe other samples would give us interesting outcomes as well. Furthermore, the best way to assess the fibre would be actual spinning into yarn and making the fabric and a piece of clothes. However, at the end, the hemp fibre is usually blended with cotton, so the requirements for its quality can be lowered.

Besides conducting the practical experiment focused on the fibre quality as a most important part of the profitability of hemp winter retting, it has been highlighted by scanning the literature that the textile industry is amongst the most promising industries for successful hemp application. The existing literature has proved that the hemp winter retting would also be profitable due to lower agronomy costs and it would be suitable for organic farming systems.

There are many possible uses of hemp as a sustainable alternative material, but most of them still have their limitations. There is a big potential in hemp fibre insulation in housing industry, but the quality requirements for this purpose are minimal and they can be met by using less sophisticated methods outside of the EU, where a lower price for the end product could be reached. Other uses of hemp such as CBD production or the hemp seed oil are still unsure. Replacing cotton or plastic fibres is a good chance for hemp to regain its hectares on farms.

Meanwhile, this method makes it easy for farmers to incorporate hemp into their crop rotations. The initial investments are often holding farmers back, but growing hemp and harvesting it with the machines they already have makes it less difficult. Even more interesting would be the option of sowing hemp during the summer after harvesting previous crops, but this variant needs to be researched. Dry summer could prevent the seeds from rising, while short growing season might not be enough for a sufficient yield or fibre quality.

Overall, hemp is an ideal crop for organic farming as its cultivation can be done without the use of agrochemicals. This again lowers the costs of production and benefits the environment and the soil. It is an ideal crop to diversify the crop rotations and prevent the soil degradation. However, this study was conducted on the conventionally farmed soil, so the obtained data only back up these claims hypothetically. More studies would be needed to prove in depth all the benefits stated in the literature overview. Some nutrient disbalances may be possible.

The given hypothesis has been partially proved. There is more research needed to be done, but it can be stated, that the hemp winter retted fibre can be blended with cotton and used to make textiles, which would be one of the most profitable applications for this material. This would motivate the farmers to include this method in their crop rotations, while most advantages of this crop would be rewarded in the organic farming. Besides that, most of the scanned literature agrees that hemp is an ideal crop for organic farming and should be included in crop rotations.

7 Conclusions

- A major drawback to hemp cultivation are the outdated retting technologies; thus, more research needs to be done in this field. The winter retting represents an alternative method with considerable benefits such as lower costs or environmental friendliness.

- *Cannabis sativa* is an ideal crop for crop rotations, especially in organic farming, where it utilizes its ecological benefits. The hemp materials need to find practical applications in order to spread its beneficial cultivation.

- In practice, the inclusion of hemp winter retting in crop rotations will largely depend whether the fibre can reach the textile quality.

- The hypothesis that the winter retted hemp fibre can reach the textile quality has only been proved partially. From the vibroscope test, the properties of one single fibre were not clear. However, the results suggested that if the desired fineness was reached, the hemp fibre would still have the optimal strength. In order to be sure, it was suggested to try actual spinning of yarn and making a piece of clothes. If successful, such study would prove the stated hypothesis with high certainty.

- The hemp retted over winter would only cover the soil up until around January because longer retting may lead to over-retting. However, it would be interesting to research the possibility to sow the hemp field for fibre production after harvesting the main crop in summer.

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9 Enclosers

Figure 1

Agrochemical soil analyse conducted in spring 2021 measuring content of nutrients in the soil where the hemp field for this experiment was cultivated near to Chraštice, Czech Republic.

Sample identificator	P mg/kg	N-Kjeldahl %	Mg mg/kg	Ca mg/kg	pH	K mg/kg	Ratio K:Mg
Hemp - Chraštice Spring	17	0,19	275,6	2554,3	5,7	64,7	0,2

Figure 2

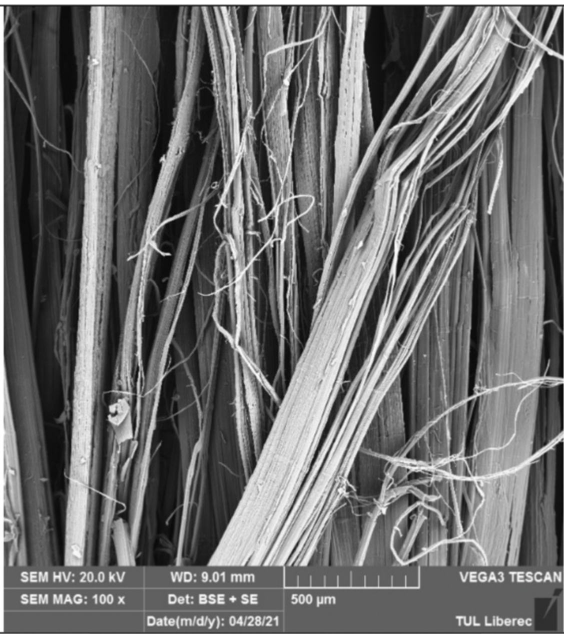
Decortication yields of each variety harvested in December, January and February.

Sample	Weight before decortication (g)	Long fibre weight	Tow	Hurd	Long fibre yield (%)	Long fibre + Estimated 40% short fibre from tow	Total fibre yield (%)
Sylvana December	1300	220	520	560	16,92	428	32,92
Santhica December	1320	180	330	810	13,64	312	23,64
Finola December	1010	120	210	680	11,88	204	20,20
Sylvana January	1800	290	910	600	16,11	654	36,33
Santhica January	1170	120	700	350	10,26	400	34,19
Finola January	1470	240	320	910	16,33	368	25,03
Sylvana February	1350	200	710	440	14,81	484	35,85
Santhica February	1420	190	190	1040	13,38	266	18,73
Finola February	1130	130	270	730	11,50	238	21,06
						total	27,55
Average total fibre yields (%)	December	25,59	Sylvana	35,04			
	January	31,85	Santhyca	25,52			
	February	25,22	Finola	22,10			

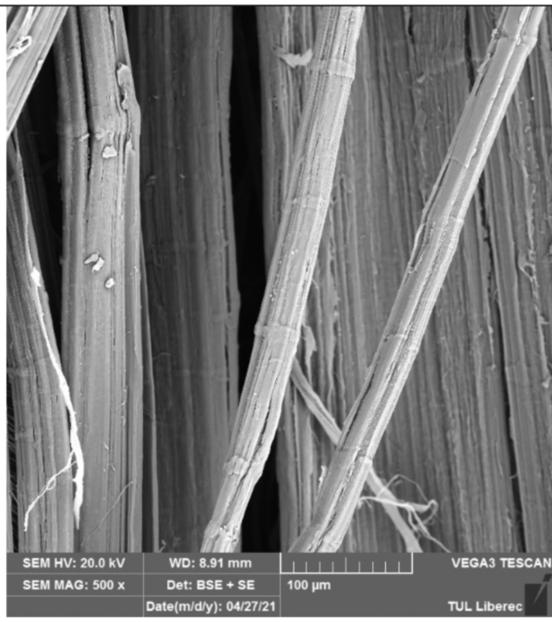
Figure 3

A demonstration photo of some of the varieties after the decortication. Sylvana harvested in January (top), Sylvana harvested in December (middle) and Santhica harvested in December (bottom), which was chosen for further assessments.

Figure 4



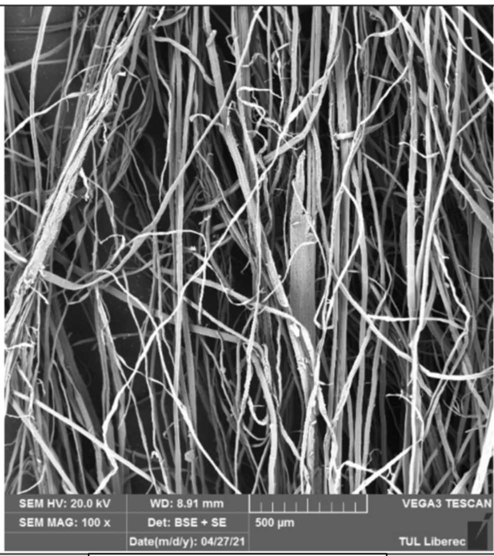
Picture 4a Sample 1



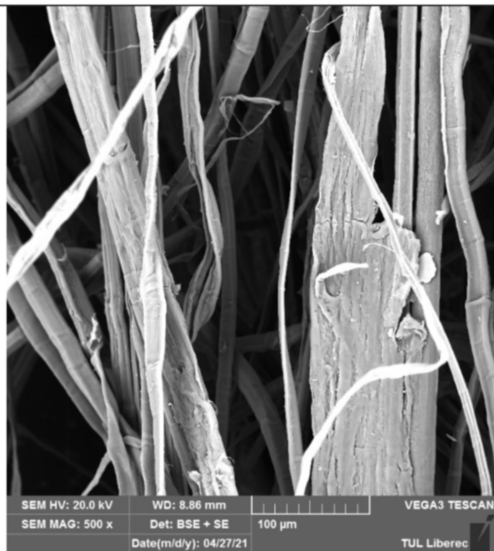
Picture 4b Sample 1 detail

Cotttonised hemp fibre under microscope. It comes from a fibre that is being used for actual hemp T-shirt production, observed for a comparison with the winter retted fibre.

Figure 5



Picture 5a Sample 2



Picture 5b Sample 2 detail

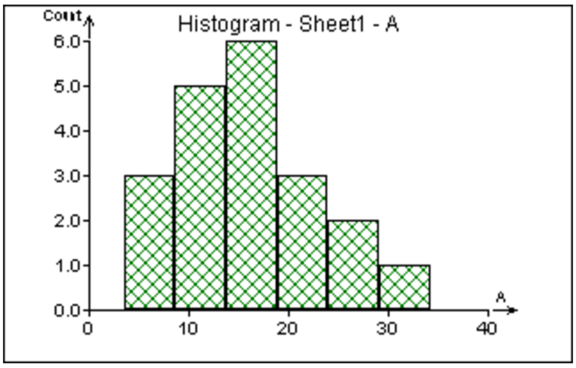
Winter retted hemp fibre under microscope – Santhica harvested in December.

Figure 6

Table of vibroscope measurements of fibres pulled out of the sample of winter retted hemp fibre of Santhica harvested in December – 20 replicates.

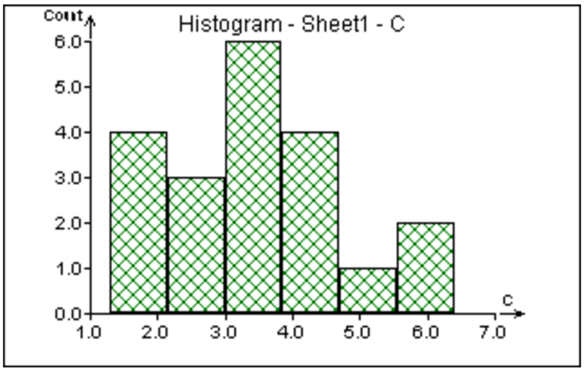
Replicate #	Fineness [dtex]	Absolute strength [cN]	Elongation at break [%]	Relative strength [cN/tex]	Modulus [cN/tex]
1	19,12	88,57	4,3	46,32	1003,35
2	26,19	213,2	6,4	81,41	845,69
3	17,85	73,54	3,1	41,2	1144,68
4	13,65	79	3,6	57,88	1843,59
5	21,06	87,84	3,3	41,71	1101,38
6	8,46	13,23	1,9	15,64	971,12
7	10,29	25,92	1,3	25,19	1910,04
8	7,91	38,51	2,4	48,69	2213,34
9	8,66	41,02	2,1	47,37	3092,96
10	3,51	23,55	3,1	67,09	2404,56
11	15,98	52,13	2,9	32,62	1138,45
12	10,54	62,39	3,6	59,19	1726,28
13	14,95	80,3	5,9	53,71	689,8
14	24,42	157,2	4,1	64,37	1590,17
15	34,24	24,13	1,4	7,05	509,35
16	18,37	169,1	4,4	92,05	1696,52
17	19,43	47,99	2,4	24,7	1095,47
18	13,5	107,3	4,3	79,48	1853,15
19	16,18	71,46	3,1	44,17	1461,43
20	15,37	131,9	4,9	85,82	1813,01
Mean	14,86	72,91	3,35	49,86	1428,25
Median	15,68	72,50	3,20	48,03	1525,8

Figure 7



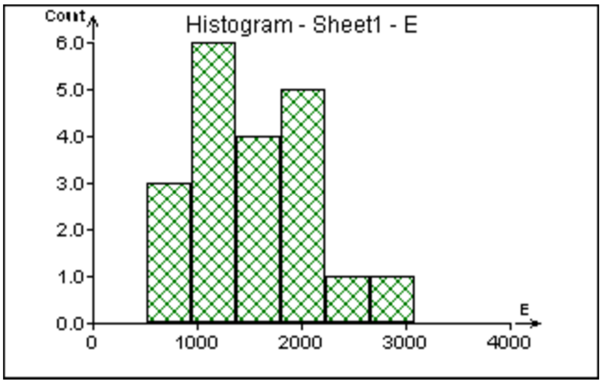
Histogram of the fineness of winter retted hemp fibre of Santhica harvested in December – 20 replicates, obtained by the vibroscope method.

Figure 8



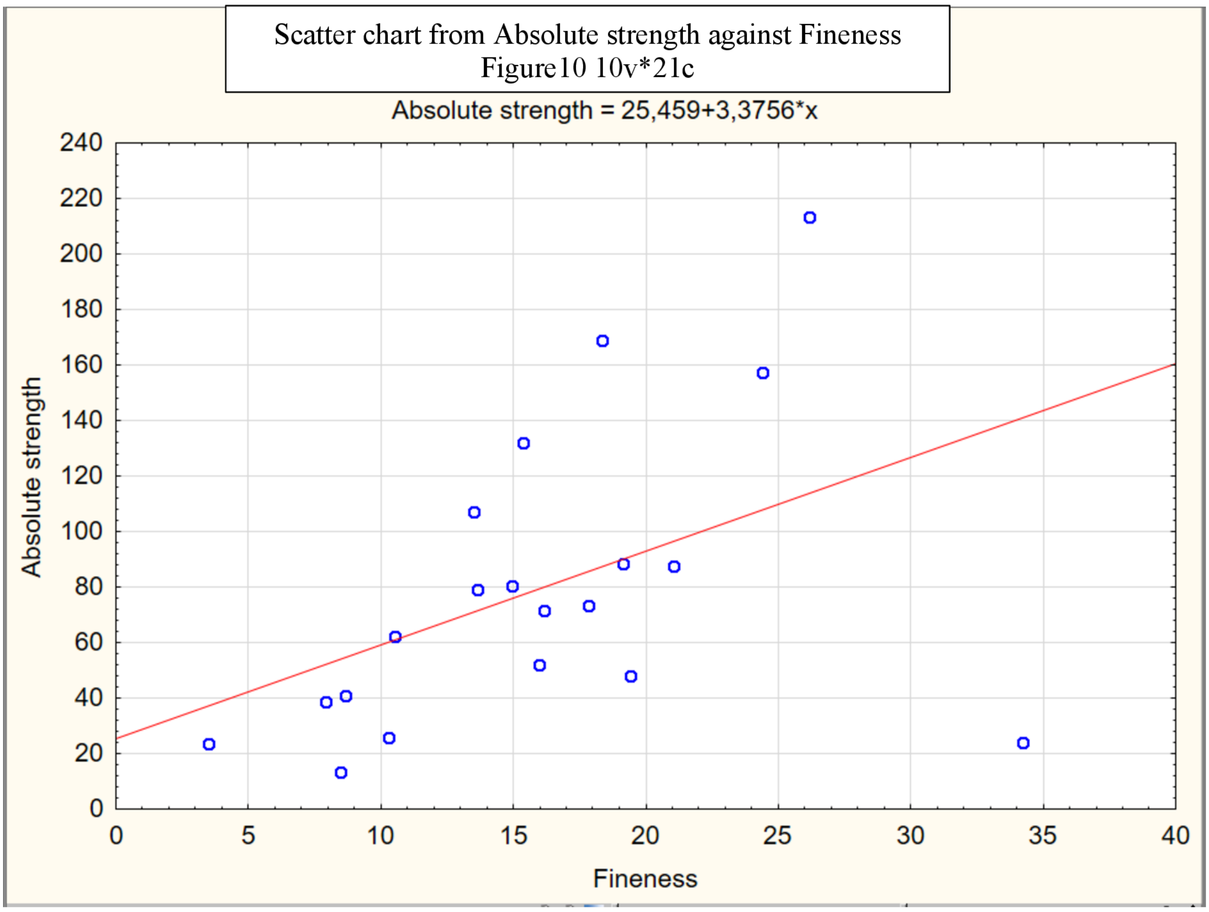
Histogram of the elongation at break of winter retted hemp fibre of Santhica harvested in December – 20 replicates, obtained by the vibroscope method.

Figure 9



Histogram of modulus of winter retted hemp fibre of Santhica harvested in December – 20 replicates, obtained by the vibroscope method.

Figure 10



Regression line scatter chart measuring correlation between fineness (independent value) and absolute strength (dependent value) of winter retted hemp fibre of Santhica harvested in December – 20 replicates, obtained by the vibroscope method.

Figure 11

Table containing results from the regression analyses measuring correlation between fineness and absolute strength of winter retted hemp fibre of Santhica harvested in December – 20 replicates, obtained by the vibroscope method.

	Results from Regression with the dependent variable : Absolute strength (Figure 10) R= ,45122407 R2= ,20360316 Denoted R2= ,15935889 F(1,18)=4,6018 p<,04583 Standard error : 49,045					
N=20	b*	Standard error from b*	b	Standard error from b	t(18)	p-value
Abs.člen			25,45899	27,43868	0,927851	0,365761
Fineness	0,451224	0,210343	3,37556	1,57356	2,145180	0,045831

Figure 12

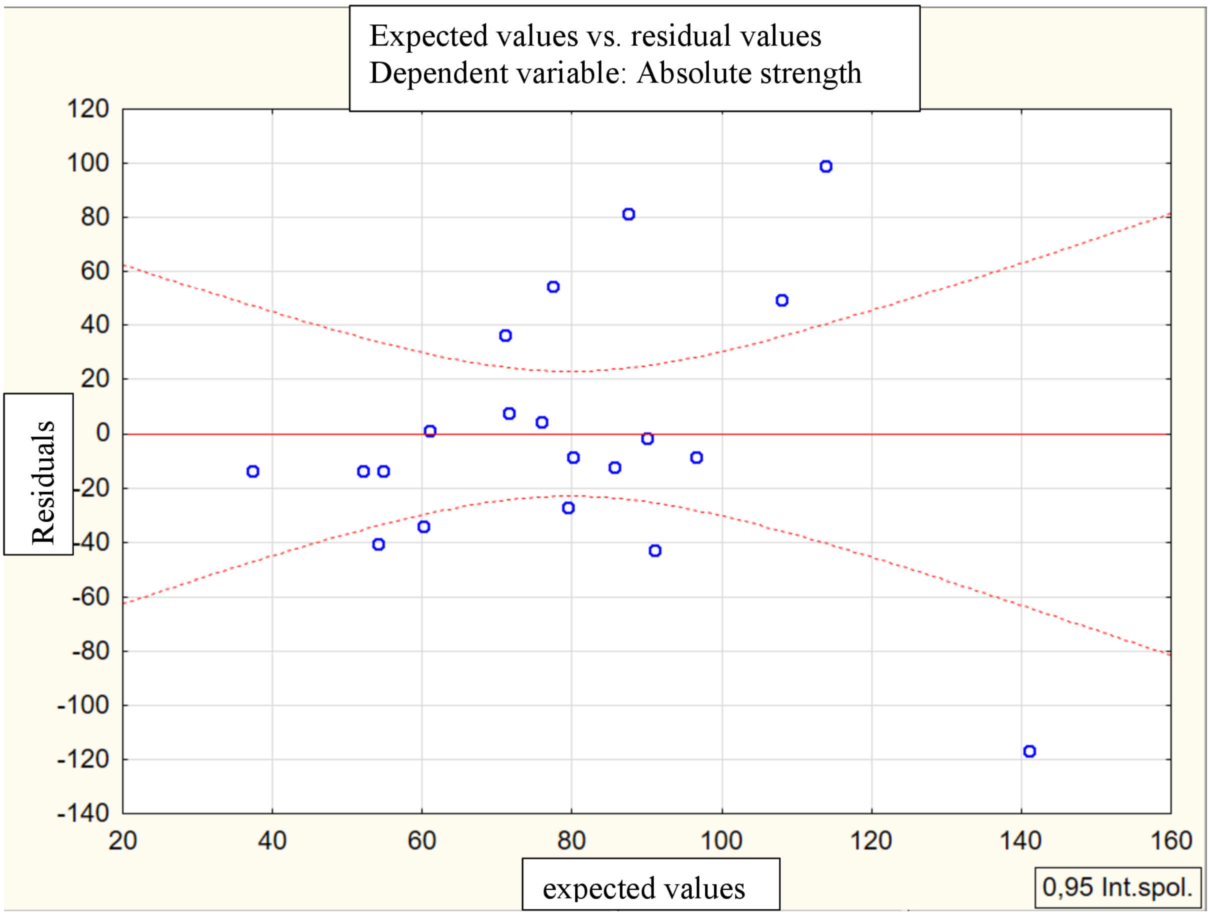
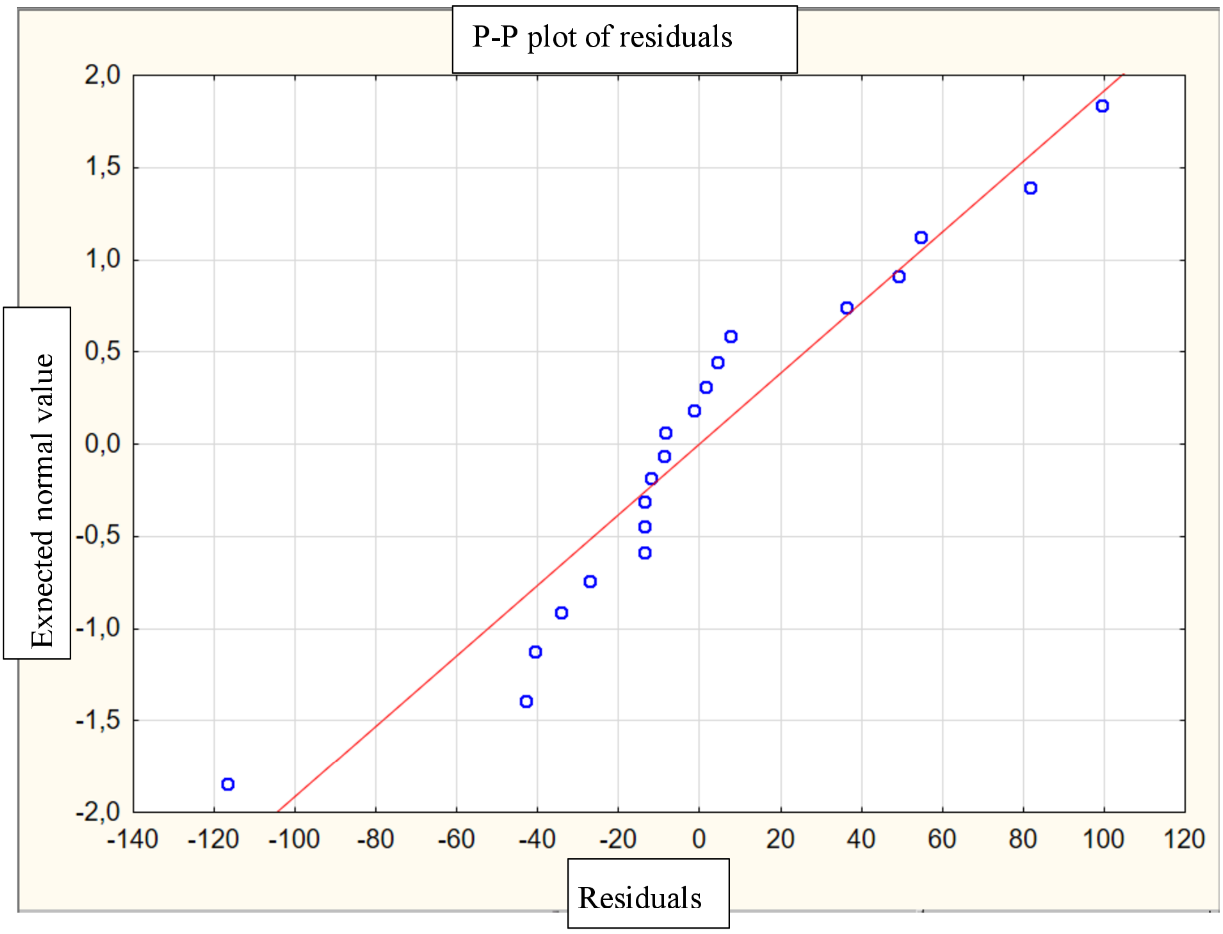


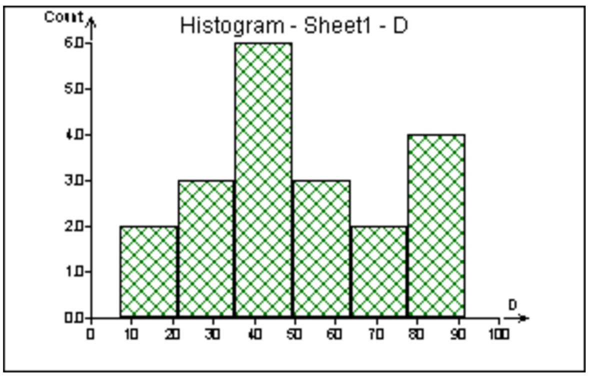
Chart of residuals of the regression analyses measuring correlation between fineness and absolute strength of winter retted hemp fibre of Santhica harvested in December – 20 replicates, obtained by the vibroscope method.

Figure 13



P-P plot of residuals of the regression analyses measuring correlation between fineness and absolute strength of winter retted hemp fibre of Santhica harvested in December – 20 replicates, obtained by the vibroscope method.

Figure 14



Histogram of the relative strength of winter retted fibre of Santhica harvested in December – 20 replicates, obtained by the vibroscope method.