THE EFFECT OF ELECTRIC PULSE TREATMENT ON THE PROPERTIES OF HEMP FIBRE

Rastorhuieva, Mariia[1]; Yevtushenko, Valentyna[1]; Shvets, Galina[2]; Andronov, Vladimir[3]; Danchenko, Yuliya[3] and Olijnyk, Halina[2*]

[1] Kherson National Technical University, Instytutska str.11, Khmelnytskyi, 29016, Ukraine
[2] Khmelnytskyi National University, Instytutska str.11, Khmelnytskyi, 29016, Ukraine
[3] National Academy of the National Guard of Ukraine, 3 Zakhysnykiv Ukrainy sq., Kharkiv, 61001, Ukraine

ABSTRACT

The production of competitive textile products can be ensured by using natural, environmentally friendly fibres, which include hemp fibre, as raw materials. To expand the possibility of its use, an essential operation is the pre-treatment of the fibre. The use of electric pulse processing of hemp fibre will provide the ability to control the depth of cottonization, select optimal parameters that collectively evaluate the spinning ability of the fibre and correspond to the permissible similar indicators of cotton fibre. The purpose of the work done is to study the mechanism of electric pulse processing of hemp fibre by identifying its structural characteristics under various processing modes for further use. The work carried out studies of the process of cottonization of hemp fibre by a physical-mechanical method using an electric pulse discharge from 500 to 2500 cycles. An effective mode of electric pulse processing of fibres has been established, amounting to 2500 pulses of electric discharges, which makes it possible to obtain cottonized hemp fibre with the required spinning ability. The parameters of cottonized hemp fibre have been determined, allowing the use of hemp cottonin to produce mixed yarn using a card spinning system on cotton spinning equipment.

KEYWORDS

Electric pulse treatment; Hemp fibre; Microscopic sections; Cottonization; Morphological structure; Yarn.

INTRODUCTION

The production of competitive textile products can be achieved by using various threads and yarn made from natural, environmentally friendly fibres as raw materials for input.

Today, textile materials are subject to requirements for the efficient and rational use of the potential resource of their fibrous base, ensuring the necessary durability of finished products, their level of environmental safety, and, in general, their level of competitiveness in the market [1, 2].

An alternative to cotton can be bast fibres (flax and hemp). Textiles from bast fibres have higher medical, biological and protective properties than cotton. The environmental properties of hemp fibre and their positive impact on human health in terms of everyday clothing use and ecological impact, consistent with the European Green Deal Strategy, are presented in [3]. The authors of [4] provide recommendations for the use of hemp fibre for the production of environmentally friendly building materials, cosmetics and medicines, as this is supported by environmental legislation, due to which there is a growth in the market for biodegradable and recyclable materials. Thanks to such a unique set of properties of bast fibres, such as hygiene, high strength, low electrical resistance, comfort, and natural bactericidal properties, the demand for textile products made from bast fibres, not only for technical but also for household purposes, is growing all over the world.

Thanks to natural antiseptic properties, items made from hemp fibre are hypoallergenic. In addition, hemp fibres have high hygroscopic and thermophysical characteristics. These materials are a priority for clothing manufacturers since modern consumers prefer high-quality and comfortable products. Apparel and textile research focuses on intelligent production. Modern, environmentally friendly textile materials can enhance selected design solutions that meet high aesthetic properties and requirements. Therefore, when creating clothing, it is necessary to use new scientific achievements when choosing methods for processing raw textile materials [5-10], methods for the calculation of different garment types patterns [11, 12], using digital tools for calculating indicators of

* **Corresponding author:** Olijnyk H., e-mail: *galina_olijnyk@ukr.net*

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material properties [13], and the sewing techniques of garment manufacturing [14].

The problems of processing industrial hemp into spinning fibre have been raised by researchers who have used mechanical cottonization methods and ultrasonic cavitation to increase the degree of decomposition of complex hemp fibres. The hydroacoustic effect was used, but it was limited due to the complexity of the technological process [5]. The method of mechanical cottonization, which consists of processing the core (stem) material of bast fibre by using structural developments of node connections of devices for processing bast fibre raw materials, has been considered by scientists [6].

Research of the method of mechanical cottonization of bast fibres, namely the process of stomping best raw materials, along with which the separation of woody parts, removal of scales, and separation of fibres from the woody part and non-fibrous impurities takes place; proposed new methods of stem destruction, promoting stem disintegration and increasing fibre separation, were considered by scientists in the article [7]. Researchers [8] considered the use of ultrasonic cavitation and chemical-mechanical cottonization to improve the water absorption (moisture properties) and mechanical (tensile and elongation strength, increased linen, colour fastness) properties of hemp fibres that were pre-treated with the enzyme laccase.

The study was carried out on the diameter of the stem of industrial hemp, on which the yield of bast depends, and the results of mathematical planning of the experiment were proposed, which made it possible to obtain optimal regimes for processing the stems with 5-6% cleaning of the bast from the fire [9]. The method of biochemical cottonization, which consists of the pre-treatment of hemp seeds with a biological method to retain moisture and chemical processes to increase resistance to diseases, is dedicated to the work of researchers [10]. These seed treatments have improved the survival rate of hemp seeds in terms of disease incidence.

Research [15] reviews the structure and properties of hemp and possible directions for further technological development. Particularly noteworthy is the use of hemp components in industrial products. Attention is drawn to potential areas of research on the use of cannabis in the medical industry. The study [16] proposed using hemp fibres modified with graphite oxide as an environmentally friendly and effective solution for water purification.

The aim of the [17] was to discuss the issues of processing industrial hemp into goods for various functional purposes. The presented research is relevant for creating its raw material base for pulp and paper enterprises and light industry enterprises. The goal [18] is to produce cottonized hemp fibres with improved thermal stability. It was first found that the fine hemp fibres produced from technical non-retted hemp fibres by steam explosion exhibited enhanced thermal stability. Tests of yarn obtained by mixing cotton with 50% hemp fibre content were carried out [19]. Hemp fibres are also suitable for vortex spinning, and Air vortex yarn, made from a blend of hemp and Tencel fibres, has less hairiness and roughness than ring-spun and dry-spun yarns. Fabric from this type of blended yarn significantly improves elasticity and shape development [20]. Hemp bast fibres were degummed using combined microwave energy (MWE) and deep eutectic solvent (DES) to generate pure hemp cellulose fibres for potential textile applications. The treated fibres had much enhanced thermal stability due to removing the gummy materials [21].

Of interest are studies related to the use of electric pulse processing. Researchers [22] proposed processing seed pulp to increase the efficiency of obtaining cottonseed oil from industrial hemp seeds using an electric pulse processing method. Thanks to electric pulse processing, it is possible to increase the amount of oil extracted from seeds and reduce the cost of electricity, which is successfully sold in the food industry.

Investigation [23] presents studies on using electric pulse processing in metallurgy for plastic moulding of metals; attention is paid to forming blanks for stainless steel packages.

However, there is currently a lack of research on electrical pulsing in the textile field, specifically pulsing hemp fibre to improve its spinnability.

The research aim is to study the mechanism of electric pulse processing of hemp fibre by identifying its structural characteristics under various processing modes for further use.

Today, issues related to the production of mixed yarn are of great importance in the textile industry. This is explained by the fact that mixtures of fibres, different in properties, design and structure, make it possible to satisfy the conflicting market requirements for textile products. However, the technological process for obtaining yarn, the quality and the cost of the products largely depend on the composition of the selected mixture. Therefore, the choice of the technological chain and optimization of the parameters of the yarn production process parameters must be carried out in each case for each type.

The fact that the specific weight of the cost of raw materials in the cost price of the finished yarn is 70–80% further emphasises the need to optimise the technology of fibre mixing processes to include in the composition of the mixture relatively cheap fibres of domestic origin - flax and hemp. One way to increase hemp's spinning ability is the technological process of cottonization of hemp fibres, which is an integral part of preparing hemp fibres for spinning. Cottonization is used to intensify the process of fibre separation and shortening and remove contaminants. Thanks to this, hemp fibres become suitable for mixtures with other fibres in cotton spinning equipment. However, pre-processing is necessary to obtain hemp fibre suitable for use in finished products in a mix with other fibres. One of the methods of such processing may be the physical and mechanical cottonization of hemp fibres using an electric pulse method, after which the fibre becomes suitable for spinning; the process of grinding and shortening the fibres and removing debris is intensified. This process makes hemp fibre ideal for use in multi-component mixtures.

The current method of electric pulse processing of hemp fibre is that the electrical discharge in water, which causes energy conversion, leads to destruction processes and the destruction of the physical and mechanical forces of the fibrous materials. The result will be an increase in product duration and supply. Under the influence of underwater electrical discharges, chemical-mechanical processes lead to chemical reactions to remove lignin and pectin and mechanical damage to the fibre surface, that is, the splitting of bundles into individual elementary fibres. An important task is to select the conditions for grinding hemp fibre and the optimal mode for obtaining high-quality cottonized hemp fibre that can be used in spinning.

MATERIALS AND METHODS

Microscopic and instrumental methods were used to study the structure of hemp fibre after electric pulse treatment.

The essence of the microscopic examination method was to determine the percentage of groups of fibres containing different numbers of cottonized fibres (from 1 to 9) and varying depending on the mode of electric pulse treatment from 500 to 2500 cycles.

An orthoscopic eyepiece was used to determine the number of elementary fibres in groups, and a photographic glass was used to project an image of a cross-section of fibres onto photographic film. The studies were carried out using a biological microscope MBR-1, designed for studying transparent objects in penetrating light. Microscopic studies of cross sections of hemp fibres were conducted at a general microscope magnification of U_0=160 and a microscope field of view diameter of D_0=1mm.

The preparation of cross-sections of fibres was placed on the microscope stage and moved to find the necessary area for the examined object. Under a microscope, the number of elementary fibres in bundles of about 100 square meters was visually inspected. Ten microscopic sections of fibres were monitored and separated under different electric pulse processing modes, ensuring 95% reliability of the traceability used in the textile industry.

Light microscopy of fibre cross-sections was used to assess the effectiveness of the hemp fibre cottonization process. In this method, a thin bundle of test fibres, lightly twisted by hand, is pulled in a loop through a small circular hole in a thin metal plate. As a result, the fibre bundle is clamped in a perpendicular hole in the plate. The ends of the protruding bundle of fibres are cut off with a razor on both sides at the level of the plate. The plate is placed under a microscope to view the cross-section in reflected light.

Instrumental studies were carried out on an experimental installation for electric pulse processing, the central part of which is a discharge chamber with an electronic system in which a powerful discharge and the destruction and removal of encrusting substances from the fibre are carried out [24].

Non-flowing process water without heating and chemicals was used as a working medium during the experiment. The processing of hemp fibre was based on the principle of a powerful electrical discharge in the liquid into which the hemp fibre being processed was immersed.

The discharge technological unit, containing working electrode systems, is designed to convert electrical energy into other types of energy and transfer it to the processing object. The pulse current generator (power source) converts electrical energy to form a powerful discharge of the liquid in which the fibre is immersed. In this case, the discharge circuit connects the technological unit with the power source. The block of primary devices moves the organs performing processing and the working environment, and the block of auxiliary devices loads and unloads hemp fibres and removes processing waste.

The integrated control unit coordinates the operation of the pulse current generator and the technological process of cottonization in a given sequence. The auxiliary systems block is designed to transport and regenerate the working fluid and perform control functions.

The main technological unit that forms the basis of the equipment for electric pulse processing of hemp fibre is a discharge chamber with an electrode system - a metal cube measuring 350x350x350 mm^3 with an observation window. The chamber volume is 42.875 l. Following the requirements of resource-saving technology, tap water with a resistivity of 8-10 Ohm·m, surface tension - 72.75 erg/cm^2 (at 20°C) is used as the working medium – 30 l of water was used for the study.

Hemp fibre processing was based on the principle of a powerful electrical discharge in water. As a result of this treatment, complex fibres are split into elementary ones while maintaining the integrity of the cellulose component of the fibres. A high-voltage electric discharge in water is accompanied by some physicochemical phenomena, one of which is electric discharge cavitation. Water is simultaneously a medium for generating and reproducing electrical discharges, transporting the energy of electrical discharges to the processing object, and placing various processing objects in it. At the same time, it not only surrounds the processing object - the fibre but also penetrates inside, ensuring movement inside the fibre. This flow brings new germs of cavitation (cavitation inside the fibres that does the work of splitting the fibre, destroying lignin, pectins and other non-cellulosic substances).

The electric pulse installation [24] operates as follows. The processed batch of fibre weighing 5 kg is loaded into the technological discharge unit and placed in the observation area through the viewing window. Electric discharges from the control panel unit launch a pulse current generator for fibre processing.

During the experiments, the electrical parameters of the discharge circuit of the installation can vary in the range: voltage U_0 of charging the capacitor bank from 14 to 50 kV; capacitance from 0.5 to 3 µF; pulse frequency v from 0.5 to 5 Hz; The radius of curvature of the tip of the positive electrode is from 5 to 6 mm. The inductance of the discharge circuit L is 3.4 µH. The reserve energy of the discharge circuit W_0 varies from 100 to 2000 J. The length of the interelectrode gap is 10 to 35 mm (considering the specific resistance of the working medium – 8...15 W·m, necessary for processing hemp fibre).

The pulse voltage is changed within a given range using a block of auxiliary devices. Removing encrusting substances from hemp fibre is controlled through a viewing window using a translucent lamp. After eliminating encrusting substances is completed, the auxiliary systems unit replaces the working fluid to remove processed waste from the fibre's surface.

After the electric pulse processing of hemp fibres is completed, the primary device unit unloads the discharge technological unit, from which the processed batch of fibre is extracted.

As a result of this treatment, complex fibres are split into elementary ones while maintaining the integrity of the cellulose component of the fibres. For cottonization, a batch of hemp fibre was used after primary processing in the conditions of the scientific and experimental laboratory of the Department of Commodity Research, Standardization and Certification of the Kherson National Technical University. The amount of fibre to be processed was 50 kg.

To destroy and remove encrusting substances and subsequent separation of technical fibres into elementary ones, the original fibres were subjected to electric pulse processing in an aqueous environment with 500, 1000, 1500, 2000, and 2500 electric discharge pulses.

$$t = \frac{n}{60\,f} \qquad (1)$$

where: *t* – action time, min.; *n* – number of pulses;

f – pulse frequency [Hz].

Therefore, the fibre processing times in the chamber were 5, 8, 11, 13, and 16 min.

The technological mode of electric pulse processing of hemp fibre, selected following the theoretical and experimental studies of the electric pulse influence on fibrous structures, is presented in Table 1.

During the electric pulse processing of hemp fibre, the capacitor's capacitance, the pulses' frequency, and the length between the electrode (discharge) gaps remained unchanged.

Fibre length was determined by measuring the straightened length of individual fibres according to the standard [25] using the measuring scale on the test board. The fibre was extended to full extension without stretching the fibre along the measuring scale. The fibre length was red to the nearest 1.0 mm (0.02 in.)

The load [cN] of cottonin was determined using the method for cotton fibre, that is, the breaking of fibre bundles on tensile testing machine DSH-3M according to the standard [26].

RESULTS AND DISCUSSION

As a result of research, we found that electric pulse treatment is an effective and environmentally friendly method of cotonization. Indeed, when using this method of processing industrial hemp, the process of obtaining hemp cottonin is accompanied by 7-8 kilowatt-hours of electricity per 1 kg of fibres. This increased energy allows us to bring this method to an energy-saving.

Electropulse processing of hemp fibre occurs due to a pulsed electrical discharge in a liquid, a process with a high concentration of energy. The most commonly used operating voltage range is from 10 kV to 70 kV.

Variating the physical parameters of the colonization process, modes, and type of emitters can achieve complete or partial removal of encrusting substances. However, to prevent cellulose destruction, it is necessary to additionally control the duration and intensity of exposure to physical processes on the fibre.

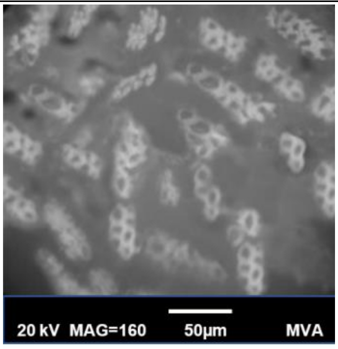
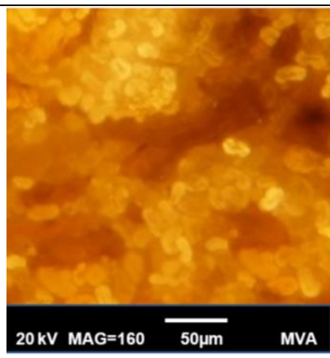
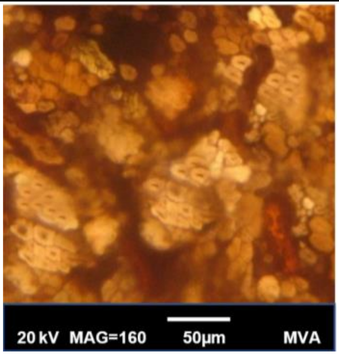
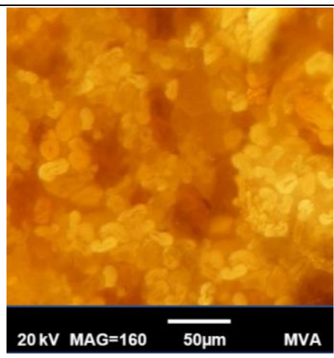
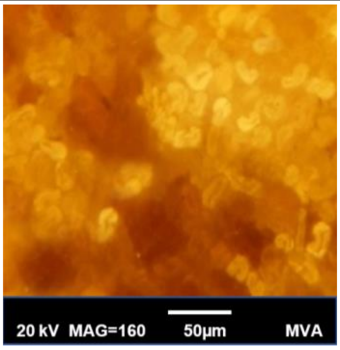
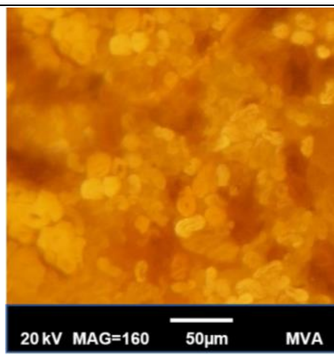
The physical model of an electrical discharge in a liquid and the mechanism of destruction of lignified plant cell walls is as follows. A voltage exceeding the breakdown voltage of this medium and applied to pairs of electrodes immersed in a weak electrolyte causes a powerful electrical discharge. The resulting energy heats the liquid substance to a temperature of 103 K, and the pressure rises to 102 mPa. That is, high plasma pressure is transferred to the water-fibre medium, under the influence of which it is compressed.

In this case, a complex stress state arises in the fibrous material, which can cause various types of destruction, crushing, etc. As a result, the fibre is freed from accompanying substances.

Table 1. The technological regime of electric pulse processing of hemp fibre.

Voltage, *U* [kV]	**The capacitance of capacitor, *C* [μF]**	**Pulse frequency, *f* [Hz]**	**Number of pulses, *n***	**Discharge gap length, *l* [mm]**	**Working environment temperature, *t* [°C]**
34 – 38	0.5	3	500 – 2500	20	30 – 40

Table 2. General view of microscopic sections of hemp fibre depending on the number of electrical discharge pulses.

Fibre sample	**Number of electrical discharge pulses**	**Photographs of microscopic sections**	**Fibre sample**	**Number of electrical discharge pulses**	**Photographs of microscopic sections**
Reference sample	0		Sample 3	1500	
Sample 1	500		Sample 4	2000	
Sample 2	1000		Sample 5	2500	

For the study, several fibres were taken from 30 locations to form 6 groups of helm fibres (6 samples).

Six samples of hemp fibre were studied for the structure of hemp cotton, which were exposed to different numbers of electric discharge pulses. Microscopic sections of hemp fibre were assessed before and after treatment with electric pulse discharge, and changes in its morphological structure were recorded using a microscope. Photographs of microscopic sections are presented in Table 2.

Photos of microscopic sections of hemp fibre are presented in Table 2, which testify to changes in the structure of fibres, which led to the splitting of complex fibres into elementary ones and the formation of complexes from them due to electropulse treatment. After processing, elementary fibres were combined into complexes with different numbers of elementary fibres in them. The number of elementary fibres in the complexes was counted under a microscope. The complexes identified in the studied samples consisted of 1 elementary fiber or contained 2, 3, 4, 5, 6, 7, 8, or 9 elementary fibers. It should be noted that the number of complexes with a certain number of fibres (for example, 9 elementary fibres in a complex) varied depending on the number of processing pulses of samples.

It should be noted that even when industrial hemp fibre is treated in an aqueous medium with 500 pulses of electric discharge (sample 1), a change in the fibre structure and formation of complexes of elementary fibre is observed. Thus, in sample 1: complexes containing 1 elementary fibre make up 15% of the total number of complexes identified in this sample; complexes containing 2 elementary fibres - 18%; complexes with 3 elementary fibres - 20%, etc.

Images of a section of technical hemp fibre to be processed in an aqueous environment with 1000 pulses of electric discharge (sample 2) show significant changes in the fibre structure and a decrease in the number of complexes with the number of elementary fibres of 7, 8, and 9 fibres. At the same time, a more significant number of complexes with a small number of elementary fibres (1, 2, 3 or 4 fibres in each complex) is observed.

Photos of sections of industrial hemp fibres treated in an aqueous environment with electric discharge pulses of 1500, 2000 and 2500 (samples No. 3-5) show an increase in the number of small complexes, including 1-4 elementary fibres.

A visual examination of microscopic sections of hemp fibres obtained after electric pulse treatment at varying degrees of intensity confirmed the hypothesis that such treatment changed the structure of the fibres and increased the number of elementary fibres.

Based on the experimental data obtained, graphs of the distribution of fibres in complexes were constructed after treating hemp fibres with an electric pulse discharge. The graph (Fig. 1) shows the share (%) of complexes with a certain number of elementary fibres in the total number of isolated fibre complexes in a particular sample after processing. The reference sample was not processed.

When processing fibres with an intensity of 500 pulses of electric discharge, sample 1 contains the entire range of fibre complexes. In this case, the share of fibre complexes containing 4 elementary fibres is the most significant (22%).

The next mode of processing hemp on an electric pulse installation was 1000 pulses of electric discharge - sample 2. Based on the diagram analysis (Fig. 1), it was found that with a processing intensity of 1000 cycles, the number of complexes, which contain from 4 to 7 elementary fibres noticeably decreases. At the same time, complexes containing 8 and 9 fibres disappeared because they were split into smaller ones. As a result of processing, the most significant number of complexes includes 2 and 3 elementary fibres, which is 26%.

At a processing intensity of 1500 cycles of electrical discharges (sample 3), the number of groups containing 2 fibres increased to 40%.

In a processing mode with an intensity of 2000 pulses of electric discharge (sample 4), complexes, which contain 1 to 5 elementary fibres, are observed in microscopic sections. The most significant share comprises complexes containing 2 elementary fibres (42%).

It has been established that the most effective mode of electrical pulse processing of fibre is 2500 pulses of electric discharge, which allows one to obtain cottonized hemp fibre with the most significant change in structure. This change is caused by splitting complex technical fibres into elementary fibres. In these samples, 32% are complexes containing 1, 2 and 3 elementary fibres, which creates the prerequisites for obtaining a thin and uniform yarn structure.

However, based only on microscopic sections about the change in the fibre structure caused by splitting complex fibres into elementary ones, one cannot judge the possibility of using them in mixtures with other fibres for further processing into yarn. The criterion for the suitability of fibres for further technological processing on spinning equipment is the study of the physical and mechanical parameters of hemp cottonin obtained at 2500 pulses of electric discharge, which allows one to evaluate the spinning ability of the fibre.

The length of cottonin fibres (short and long) was assessed by measuring single fibres according to the method [25], after which the share of fibres of a certain length in the total number of fibres in the experimental group was determined. Using the same method, the length of cotton fibre was determined, a group of which was also subjected to electric pulse treatment of 2500 pulses of electric discharge. A comparison of the properties of cottonin and cotton was carried out to confirm the possibility of using cottonin fibres in spinning production instead of cotton.

According to the study results, hemp cottonin obtained with 2500 processing cycles (Fig. 2) has a staple length of 37.9 mm, corresponding to the cotton fibre length. At the same time, the percentage of short fibres and fluff is 17.2%, staple fibres are 75.8%, and a length of more than 45 mm is about 7% (Fig. 3), corresponding to the standardised indicators.

Analysis of the hemp fibre diameter distribution diagram showed that the largest number of fibres (Fig. 4) have diameters from 10 to 27 μm. In this case, the average diameter is 15.46 μm, corresponding to the thickness of medium-fibre cotton used in the carded spinning system, equal to 0.28 tex.

The diagram of the distribution of fibres by strength (Fig. 5) shows that the maximum strength of cottonin (30.8 cN/tex) is 4.4 cN/tex higher than the maximum value of cotton fibres (26.4 cN/tex).

The diagram of the strength distribution of hemp cottonin (Fig. 5) shows that the average strength of

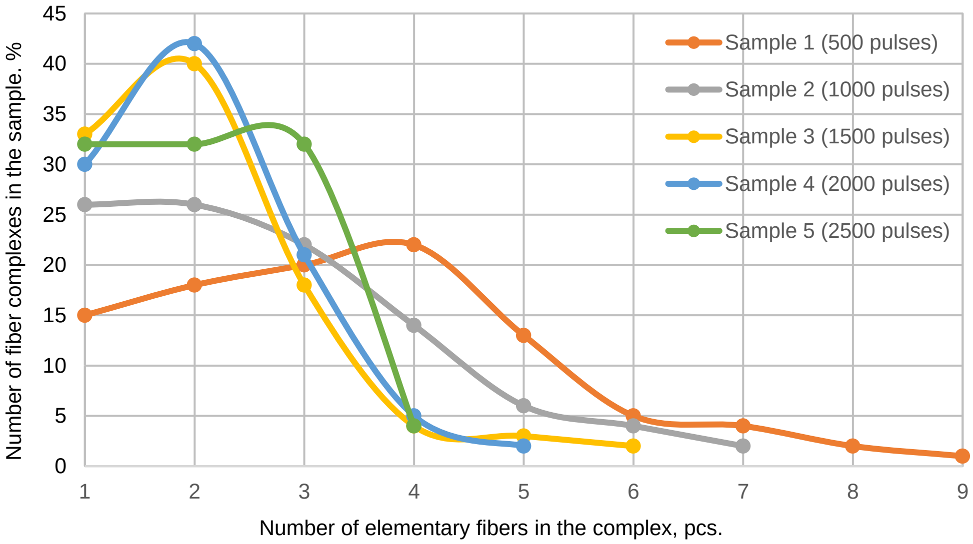


Figure 1. The influence of the number of cycles of electric pulse processing on the change in fibre structure.

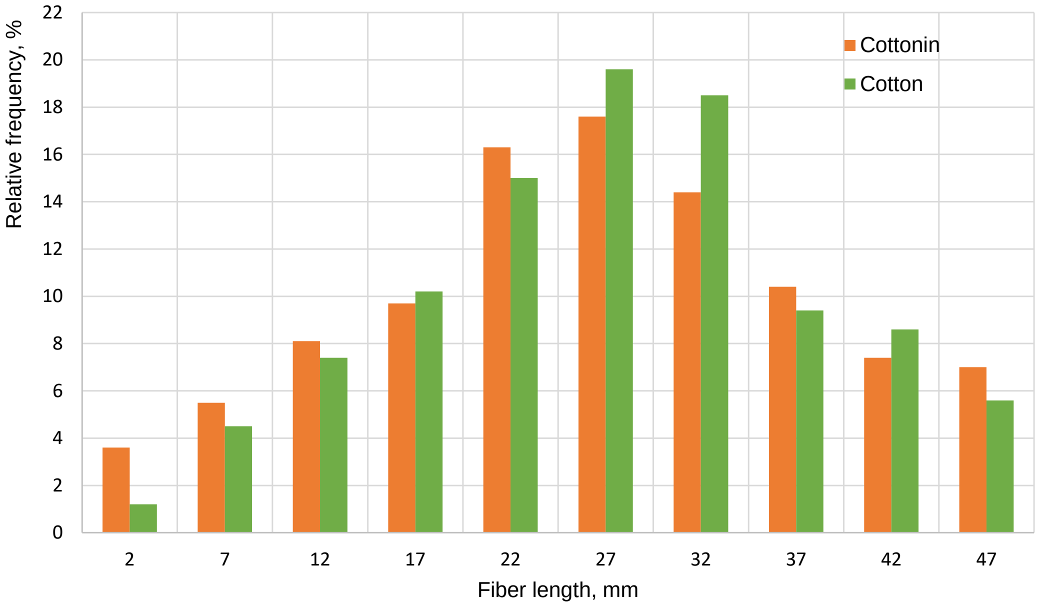


Figure 2. Diagram of the length distribution of hemp cottonin.

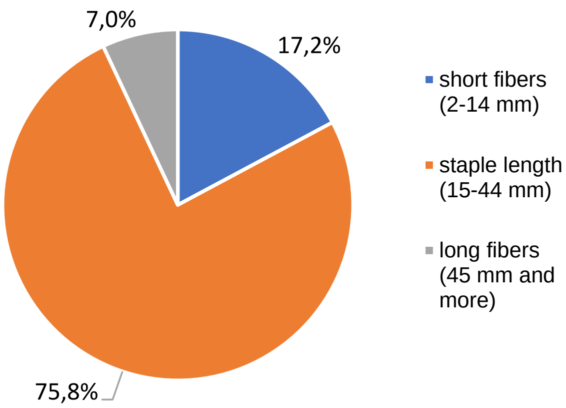


Figure 3. Distribution percentages of staple length in the sample with 2500 processing cycles.

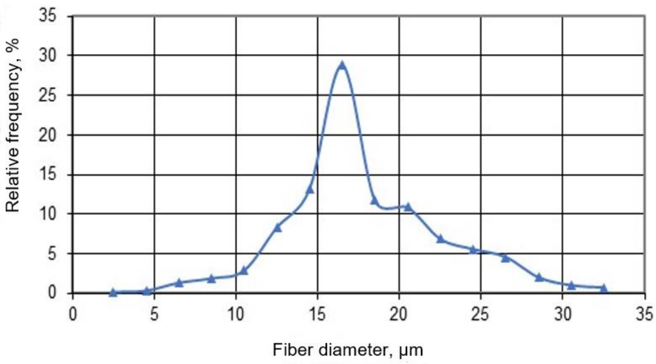


Figure 4. Diagram of distribution of hemp cottonin by diameter.

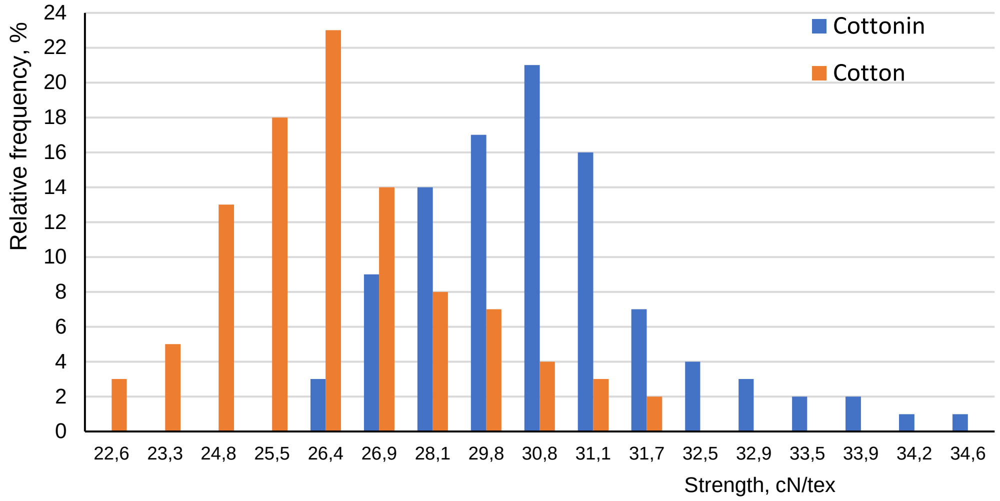


Figure 5. Diagram of distribution of hemp cottonin by strength.

Table 3. Calculation results of fiber properties after 2500 processing cycles.

Fiber properties	**Mean ±SD**		**95 % CI**		**CV [%]**	
	cottonin	**cotton**	**cottonin**	**cotton**	**cottonin**	**cotton**
Upper half mean length, UHML [mm]	26.8 ± 6.89	28.39 ± 8.09	(22.53 ; 31.07)	(23.38 ; 33.4)	25.7	28.5
Fiber diameter, *D* [μm]	15.5 ± 4.07	13.4 ± 3.27	(12.94 ; 17.98)	(11.37 ; 15.43)	26.3	24.4
Strength, *F* [cN/tex]	31.1 ± 3.36	26,9 ± 3.2	(22.26 ; 31.54)	(25.01; 28.79)	10.8	11.9

cottonin is 30.8 cN/tex, and the coefficient of variation is 10.8%, less than medium-fibre cotton.

The strength of medium-fibre cotton ranges from 24 to 27 cN/tex, indicating its spinning ability. The experimental strength values are within the required limits.

The sample size, providing a 95% confidence level, was 1300 fibers, used to determine fiber length, diameter, and strength. The research results are presented in Table 3.

Thus, hemp cottonin, obtained through 2500 cycles of processing using the electric pulse method, corresponds to medium-fibre cotton in its main physical and mechanical parameters and can, therefore, be used to form yarn using a carded spinning system at cotton factories.

The results of experimental studies of the physical and mechanical parameters of hemp cottonin after the process of electric pulse processing of hemp suggest that processing hemp fibre in a mode corresponding to 2500 pulses gives a good result, and the resulting fibre can be used in the preparation of multicomponent mixtures with other natural and chemical fibres.

CONCLUSIONS

The process of colonization of hemp fibre was studied using physical and mechanical methods, including electric pulse discharge.

An effective mode of electric pulse processing of fibres has been established, amounting to 2500 pulses of electric discharges, which makes it possible to obtain cottonized hemp fibre with the necessary spinning ability.

The parameters of customized hemp fibre were determined, which together evaluate its spinning ability: average fibre length 26.8 mm, fibre diameter 15.5 µm, and average strength 30.8 cN/tex.

The spinning ability of cottonized hemp fibre corresponds to the permissible similar indicators of cotton fibre, which allows hemp cottonin to produce blended yarn using a carded cotton spinning system.

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