INNOVATIVE TECHNOLOGIES OF OILSEED FLAX STRAW MECHANICAL PROCESSING AND QUALITY OF OBTAINED FIBERS
/
ІННОВАЦІЙНІ ТЕХНОЛОГІЇ МЕХАНІЧНОЇ ПЕРЕРОБКИ СТЕБЕЛ ЛЬОНУ ОЛІЙНОГО ТА ЯКІСТЬ ОДЕРЖАНИХ ВОЛОКОН

Prof. Ph.D. Eng. Chursina L. [1)], Prof. Ph.D. Eng. Tikhosova H.[1)], Ph.D. Assoc. prof. Holovenko T. [2)], PhD. Assoc. prof. Shovkomud O. [2)], PhD. deputy director Kniaziev O. [3)], Ph.D., Assoc. prof Yanyuk T.[4)]
[1)] Kherson National Technical University, Faculty of Integrated Technologies, Kherson / Ukraine;
[2)]Lutsk National Technical University, Faculty of Biotechnical Systems Engineering, Lutsk / Ukraine;
[3)] State enterprise «Research farm «Askaniisky» Askaniyskaya state agricultural research station of the Institute of Irrigated Agriculture of the National Academy of Agrarian Sciences of Ukraine / Kherson region, Kakhovsky district, village Tavrichanka, Ukraine;
[4)] National University of Food Technologies, Educational and Scientific Institute of Food Technologies, Kiev / Ukraine
Tel: +38 (050) 85-534-80; E-mail: tanyushkagolovenko@ukr.net

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ABSTRACT

The article presents scientific and practical achievements in creating innovative mechanical technologies for oilseed flax straw processing. As a result of systematic research by scientists of Kherson National Technical University, the technology and equipment for mechanical processing of oilseed flax retted straw based on modernization of existing equipment is proposed. As a result, at certain stages of mechanical processing of the retted straw, oil flax fiber with different physical and mechanical characteristics was obtained, which is suitable for use in various industries.

Due to the absence of standards for products of oilseed flax straw in Ukraine and in the world, the technical specifications TU U 01.1-2303511525 - 001:2016 "Oilseed flax straw. Specifications" and TU U 01.1-05480298 - 001:2017 "Oilseed flax retted straw. Specifications" were developed and registered in the State enterprise "Kherson standard metrology". This will allow analyzing this industrial raw material, determining the feasibility of mechanical processing and the quality level of fiber as finished product.

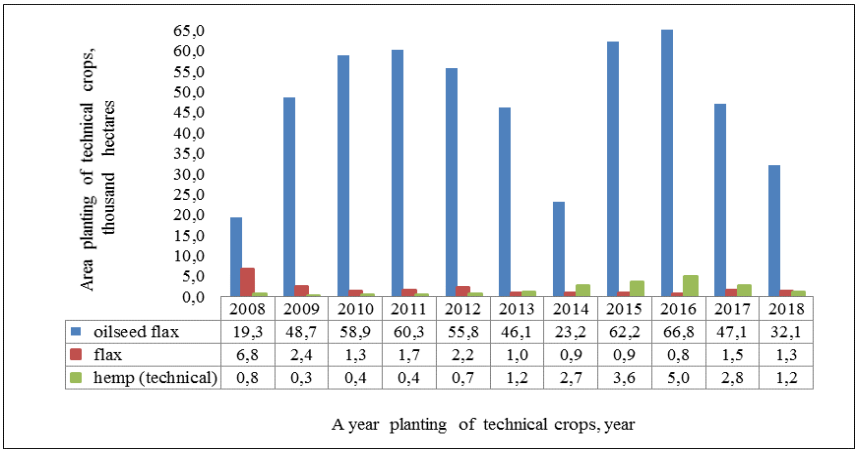
РЕЗЮМЕ

У статті представлені наукові та практичні досягнення в створенні інноваційної технології механічної переробки стебел льону олійного. В результаті систематичних досліджень вченими Херсонського національного технічного університету було запропоновано технології і устаткування для поглибленої механічної обробки трести льону олійного на основі модернізації існуючого обладнання. В результаті чого, на певних стадіях механічної обробки трести, одержується волокно льону олійного з різними фізико-механічними характеристиками, яке придатне для використання в різних галузях промисловості.

У зв'язку з відсутністю як в Україні, так і в світі в цілому стандартів на продукцію зі стебел льону олійного були розроблені і зареєстровані в державному підприємстві "Херсонстандартметрологія" технічні умови ТУ У 01.1- 2303511525 – 001:2016 «Солома льону олійного. Технічні умови» та ТУ У 01.1-05480298-001: 2017 «Треста льону олійного. Технічні умови». Це дозволити оцінювати дану промислову сировину, визначати доцільність її механічної переробки та рівень якості готової продукції - волокон.

INTRODUCTION

According to the analysts of Oil World, the largest cropped areas of oilseed flax are concentrated in Canada (about 2 million hectares), Argentina (101 thousand hectares), China (570 thousand hectares), India (930 thousand hectares), Great Britain (101 thousand hectares), the USA (135,17 thousand hectares), Germany (110,048 thousand hectares). Such countries as Finland, Poland, France, Belgium and Belarus (2.5 thousand hectares) have begun to cultivate this crop recently (Saskatchewan Flax Development Commission, 2015). Ukraine is not an exception. If in 2008 the crop sown area in Ukraine amounted to 19.3 thousand hectares (State Statistics Service of Ukraine, 2016), to 66.8 hectares in 2016 and to 32.1 hectares in 2018 (fig.1).



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
oilseed flax	19,3	48,7	58,9	60,3	55,8	46,1	23,2	62,2	66,8	47,1	32,1
flax	6,8	2,4	1,3	1,7	2,2	1,0	0,9	0,9	0,8	1,5	1,3
hemp (technical)	0,8	0,3	0,4	0,4	0,7	1,2	2,7	3,6	5,0	2,8	1,2

Fig. 1 - Dynamics of cropped areas of technical crops grown on the territory of Ukraine from 2008 to 2018 (State Statistics Service of Ukraine, 2016)

The rapid increase in this crop acreage is explained by the fact that flax seeds, which contain 48% of oil, is of great demand in the world nowadays. It is widely used in food, pharmaceutical and paint industries. The cost of flax seeds for super elite is $4 000-3 500 per ton and that of commodity seeds is $800-500 per ton.

World experience in using oilseed flax straw shows that it has a wide range of applications. It is due to the fact that oilseed flax stems, as well as the common flax stems, contain cellulose fibers in bast part *(Zhyvetyn V.V. et al., 2000)*. However, oilseed flax straw is not used in Ukraine. Every year a large amount oilseed flax straw, namely about 64 000 tons is burned after harvesting flax seeds causing great harm to the environment and being accompanied by large penalties for farms that grow oilseed flax. However almost 25 600 tons of fiber and 19 200 tons of cellulose for textile, pulp and paper production in Ukraine are wasted. With this amount of straw 38 400 tons of shives for producing biofuel, fireplace wood and building materials can be obtained *(Tihosova A.A. et al., 2010)*.

In the world practice, flax straw burning becomes history, and oilseed flax is regarded not only as a seed production crop, but also as a cost-effective supplementary textile raw material. In Ukraine, oilseed flax is the only domestic raw material, which can be an alternative to imported cotton and flax fiber for use in the textile, pulp and paper industries and the production of reinforced composite materials. Not rational use of oilseed flax stems in Ukraine is primarily connected with the lack of technological process of deep mechanical processing of oilseed flax retted straw.

Oilseed flax retted straw as opposed to linen retted straw suitable for obtaining long fiber, is a matted and differently directed mass of fibers with shives, among which there are a lot of whole stems no longer than 40 cm. Combination of short stems and fibers of different length in the oilseed flax retted straw defines a similar processing of it with unconditioned low-grade retted straw of common flax for using traditional technology for processing on tow-preparation aggregates of known brands: TPAL (Tow-Preparation Aggregates of Linen fiber), ASLF-1 (Aggregate of Short Linen Fiber), ASLF-1-01 (Aggregate of Short Linen Fiber) and their foreign counterpart firms "Charle", "Laroche", "Temafa", etc.

On the basis of the study of physical and mechanical properties of oilseed flax straw stems and their change after combine harvesting we can conclude that mechanical technology of processing oilseed flax retted straw should be similar to the technology of getting the single type linen fiber and unconditioned low-grade retted straw of common flax, taking into account morphological features and anatomical structure of oilseed flax stems.

MATERIALS AND METHODS

At present, the theoretical foundations of mechanical processing of unconditioned low-grade retted straw of common flax are developed by Ipatov A. *(Ipatov A., 1989)*. The technology of getting single type linen fibers was introduced by the Central Research Institute of bast fibers by Derbenev A. *(Derbenev A., 1983)* and the Institute of bast crops of the National Academy of Agrarian Sciences of Ukraine by Hilyazetdinov R. *(Helyazetdinov R., 2009)*.

According to the technology of the Institute of bast crops of NAAS of Ukraine, unlike existing tow-preparation aggregates a new construction of the breaker rollers stripping type is proposed and instead of the stripping part the construction of the stripping-combing aggregate is developed. Under the new technological scheme the pre-production model of the aggregate for getting the single type fiber of common flax is manufactured (figure 2).

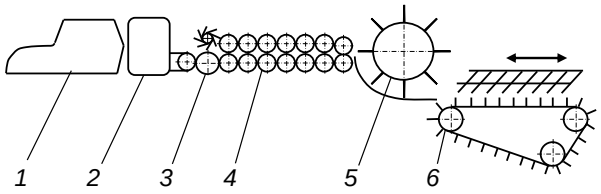


Fig. 2 - The basic technological scheme of the aggregate for selecting the single type flax fibers

1 - machine for unwinding rolls, 2 - drying machine, 3 – layer-forming machine, 4 – breaking part, 5 - stripping part, 6 – tow-shaking part (Helyazetdinov R., 2009)

Despite the fact that these developments would be important to determine the technologies and equipment for processing the oilseed flax stems, now there is no serial production of such equipment. Furthermore, the fibre obtained by this technology is chaffy (contains 37-40% unseparated and bulk wood) that limits the scope of its use.

Well known works on purification and separation of oilseed flax fiber is performed by Rome Research Center (Istituto Poligrafico e Zecca dello Stato) in Italy *(Assirelli A. et al., 1997)*. Figure 3 shows the scheme of processing of oilseed flax stems according to the technology developed by IPZS.

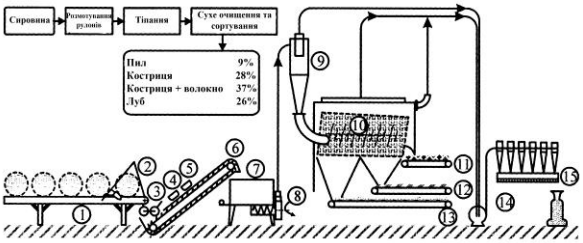


Fig. 3 - Scheme of oilseed flax stems processing to obtain a cellulose

1 – round bales conveyor, 2 – "Gemelli" blades, 3 – cylinder press, 4 - metal detector, 5-metal extractor, 6-transporter, 7 - vertical stripping machine, 8 - fan with dryer, 9-cyclone, 10-cylinder separator, 11 - conveyor for bast fiber, 12 - conveyor for shives and bast, 13 - conveyor for shives, 14 - a fan with heating, 15 - transport of dust (Assirelli A. et al., 1997)

Under this scheme, stems are processed on a vertical stripping machine (7) and purified in the cylinder separators (10). Yet, buying this line in Italy would cause large additional foreign exchange costs.

In the works of scientists of Kostroma State Technological University (Russia), *Pashin E*. and *Fedosova N*., there are only schemes of processing of oilseed flax straw stems, but the mechanism of separating shives is not developed, which is a major technological operation of mechanical processing *(Pashin E. et al., 2003)*. Thus, open remains the question, what equipment can be used for mechanical processing of oilseed flax retted straw, its parameters and operation modes. Therefore, in this paper, the technology of processing unconditioned low-grade retted straw of common flax, which may be analogous to the new technology for the processing of oilseed flax was analyzed.

Usually, unconditioned low-grade retted straw of common flax, which is similar to the oilseed flax stem is processed at the typical tow-preparation aggregate TPAL (*Ipatov A., 1989*). The technological scheme is shown in figure 4.

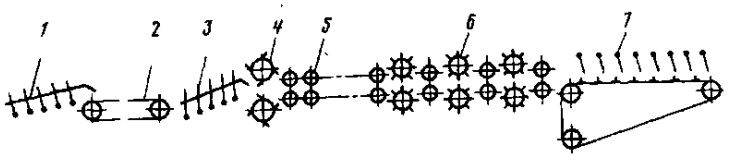


Fig. 4 - Technological scheme of processing unconditioned low-grade retted straw of common flax

1,3,7 – tow-shaking machines, 2 - drying machine, 4 - layer-forming machine, 5 - breaking machine, 6 - stripping machine (*Ipatov A., 1989*)

According to scheme 3, the technology of getting linen fiber consists of primary enrichment of tows on the first tow-shaking machine *1*, drying in a drying machine *2*, shaking on the second tow-shaking machine *3*, forming a layer in layer-forming mechanism *4*, breaking in a breaking machine *5*, stripping in a stripping machine *6*, and final cleaning on the third tow-shaking machine *7*.

Systematic research of Kherson National Technical University revealed significant differences of physical and mechanical properties of oilseed flax stems *(Tikhosova H. et al., 2010)*. As a result, it outlined significant heterogeneity of stems:

- in thickness: the ratio of diameters of basal and vertex parts of stems varies between 1.3-4.1 mm;
- content and hardness of wood: basal and middle parts have a strong connection between the shives and fiber, and the vertex of the stalk, which has a small diameter of a thinner and flexible wood.

Such heterogeneity of stems connected with difficulties in separation of shives from fibers and causes a significant impact on the results of processing of the stems, particularly the degree of purity of the obtained fiber product.

Harvesting of oilseed flax is known to be carried out by combine harvester. By this technology stems of the flax group are mowed at a height of 5 cm over the ground, as a result of which, as mentioned before, they have an average length of stems of not more than 40 cm. In addition, approximately 30% of this length is an inflorescence with large amount of thin branches. Therefore, to the processing middle and vertex parts of the stems are entered. These stems are not able to get in the clamp conveyors of stripping machines in the first and second sections of breaking-stripping aggregates BSA. Therefore, the relevant task today is to create a new technological line for processing oilseed flax stems.

Experimental part

Scientists of Kherson National Technical University proposed technology and equipment for mechanical processing of oilseed flax retted straw on the basis of modernization of existing equipment. For this purpose, on the experimental technological line of TPAL, the stripping part was replaced by two sections of stripping machines "Charle". This was done considering the peculiarities of technological properties of oilseed flax stems to prevent the formation of fibers winds on stripping drums, fiber breakage, which will increase the intensity of fiber cleaning from shives. General view of the modernized tow-preparation aggregate is shown in figure 5.

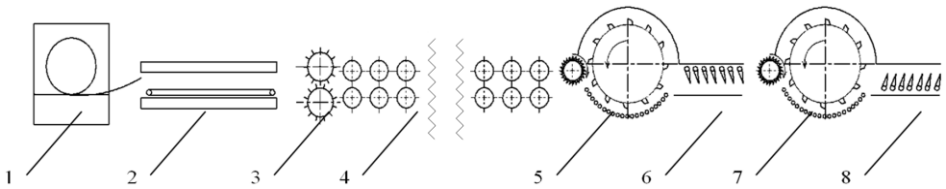


Fig. 5 - Technological scheme of modernized tow-preparation aggregate

1 - machine for unwinding rolls, 2 - drying machine, 3 - nourishing rollers, 4 - breaking machine; 5 - stripping sections of machine «Charle»; 6 – tow-shaking machine with upper ridge field, 7 - stripping sections of machine «Charle»; 8 - tow-shaking machine with the lower ridge field (the author's development)

By the proposed technology of the technological process in comparison with traditional technology (figure 3) tow-shaking machine *1* is excluded. Oilseed flax retted straw after unwinding rolls on the machine for unwinding rolls *1* is sent to a drying machine *2,* DCS-10TU1 (Drying Conveyer Steam - 10 Tow Unified). This operation is necessary to increase the distinction of rigidity between fiber and wood, which is achieved by previous drying of oilseed flax retted straw from the moisture of 12-13% to technological moisture of 6-8%. Thus, by changing the moisture in this range the flexibility and strength of the fiber are slightly decreased and stiffness of shives dramatically increases, which rises the effectiveness of impact of breaking and stripping.

Further, to destroy the connection between fiber and wood in those stems in which it was not broken during laying by nourishing rollers *3*, retted straw will be supplied to the breaking machine of tow-preparation aggregate *4*, with 19 pairs of breaking rollers that provide a deep breaking of the oilseed flax stems.

Broken flax is fed with the help of feed rollers to stripping sections of machine "Charle" *5*, then after the first stripping, fiber is supplied to tow-shaking machine of tow-preparation aggregate with upper ridge field *6* and then to the second stripping sections of machine "Charle" *7*.

The process of stripping of this raw material as an unconditioned low-grade retted straw of common flax, is designed for intensive separating of shives. The most intensive process of stripping the oilseed flax fiber after breaking is made by using stripping sections of the machine "Charle", in which stripping drum has a diameter of 120 cm, with 12 beating planks. Depending on the fibers quality with the help of leverage the gaps between the knives and beating planks of stripping drum are controlled.

Final operation on the modernized tow-preparation aggregate is tow-shaking machine with the lower ridge field (8), which is used for final cleaning of fiber from shives.

Despite the possibility of regulating the process of tow-preparation, obtained by this technology, fiber contains a large amount of shives, over 28-31%, so this fiber is not suitable for using in textile, pharmaceutical, paper industries and for production of composite materials. After all, for the use in the paper industry, it is required that the fiber has chaffiness of 0.2%, in textile industry the chaffiness should not exceed 1.5%, in the pharmaceutical industry - 0.5%, and for the production of composite materials it must be 0%. At the same time, previous studies show that oilseed flax fiber contains 70% of cellulose by fiber length and the form of elementary fibers on the microscopic sections, it is close to cotton. Thus, in case of proper processing it is possible to use it instead of cotton fibers, in its blends and to obtain cellulose *(Tihosova A.A. et al., 2010).*

Therefore, to expand the scope of applications of the oilseed flax fiber it is proposed to use the following technological line and equipment for deep mechanical processing of the oilseed flax retted straw (figure 6).

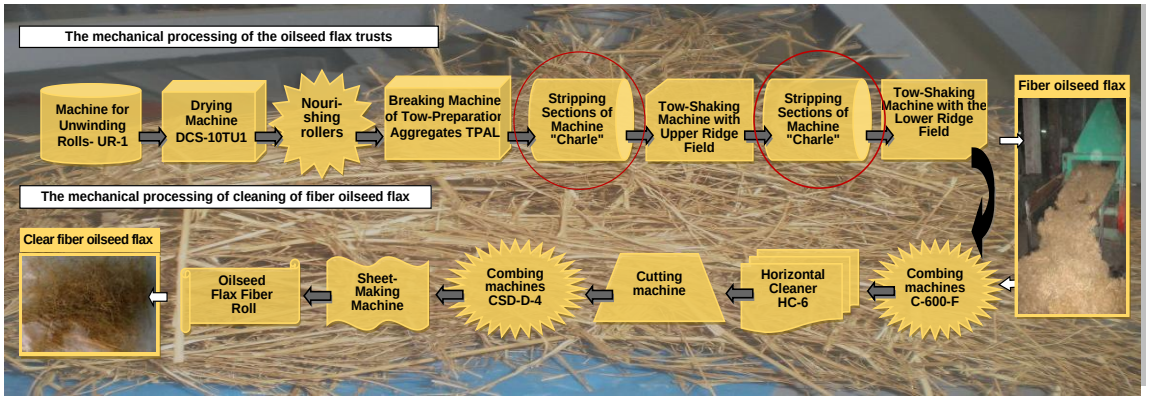


Fig. 6 - Technological line for obtaining the cleaned fiber from the oilseed flax retted straw (the author's development)

For a complete cleaning of oilseed flax fiber the major technological operation is the process of carding on combers of hard and fine carding such as brand C-600-F (Comberss-600-Flax) and CSD-D-4 (Comberss Smallest Double-Drum-4). Optimal operation modes of individual components of this aggregate were identified in the works by Lytvyn Z., Valko N., Kobyakov S. and Meshkov Yu. *(Lytvyn Z., 2000; Valko N. 2002; Kobyakov S., 1993; Mieshkov Yu., 2007)*. Therefore, optimization of technological operation modes of modernized tow-preparation aggregate was not performed.

RESULTS

As a result of processing the oilseed flax retted straw by all technological transitions, according to the technology, presented in figure 5, after a double combing, the fiber was obtained. Fiber distribution according to length is shown in figure 7 and in the form of diagram (figure 8).

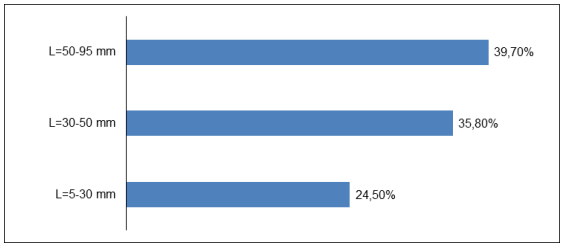


Fig. 7 - Percentage of distribution of oilseed flax fibers by length after processing within all technological cycles

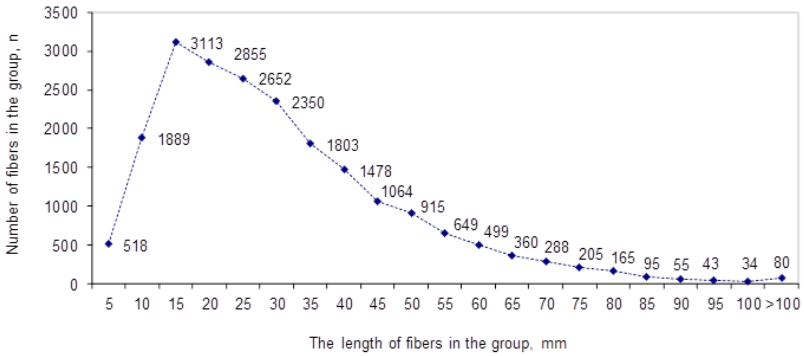


Fig. 8 - Distribution of oilseed flax fiber by length in each group

The results show that the fiber content suitable for processing in conditions of cotton textile production is 35.80 %, in which the length of fibers is from 30 to 50 mm, and the number of fibers suitable for processing in cellulose production, where fiber length is in from 5 to 30 mm, is 24,49 %. The share of fibers, suitable for wool processing, is 39.71 %, with the length of fibers ranging from 50 to 80 mm. The result of production tests of the shives content in fiber, obtained after each cycle of treatment, was analyzed. The shives content after processing on tow-preparation aggregate equals to 23.0 – 25.5%. The shives content after processing on combers C-600-F equals to 7.5 – 8.6% and after processing on the machines of fine carding CSD-D-4 after the double combing, the shives content was 0.05-1.0%.

As a result of analysis of the fiber quality it was found that processing of oilseed flax retted straw by the developed technological process of the mechanical processing, according to figure 5, allows obtaining fibers with high technological characteristics that can be recommended to be used in various fields of industrial production. In manufacturing and laboratory conditions, the samples of innovative products from oilseed flax have been obtained.

Namely, it is the mixed yarn: oilseed flax-cotton, oilseed flax- polyethyleneterephthalate (lavsan), oilseed flax-wool, oilseed flax-capron (LLC "Boguslaw Textile", Kiev region) *(Boiko G., 2014)*, composites (SE "Plastmass" LLC "TD Plastmass-Priluki", Chernihiv region.) semi-finished cellulose materials, non-woven fabrics (JSC "Flax processing mill Starosamborskyi», Lviv region.) *(Holovenko T., 2014)* and filter paper (LLP "Tsyurupinsk pulp and paper mill", Kherson region.) *(Putintseva S., 2015)*. Schematic representation of laboratory samples of innovative products is given in figure 9.

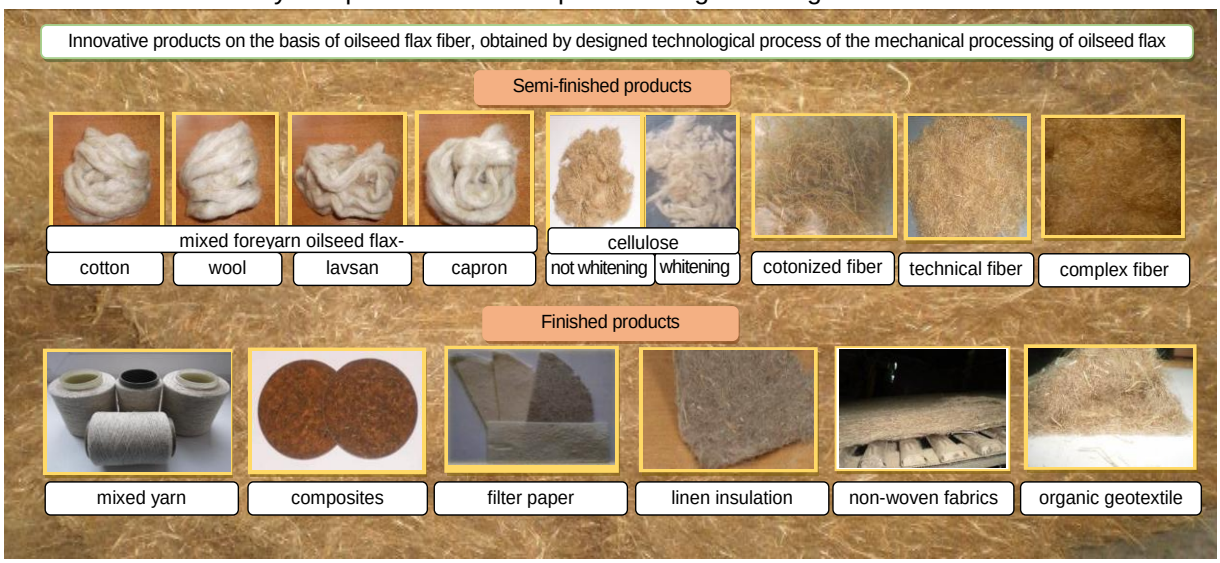


Fig. 9 - Innovative products on the basis of oilseed flax fiber

This product is of great economic importance, environmentally friendly, meets modern consumer needs, can compete with imported products, but above all, there are domestic raw materials for its production. Organization of the industrial complex for processing oilseed flax straw in Ukraine, will provide domestic textile enterprises with cellulose-containing raw material, which is of strategic importance in conditions of complete import dependence of our country.

However, large-scale manufacturing of innovative products for the purpose of domestic and international marketing opportunities is only possible upon condition of their standardization. In developing regulations for assessing quality of oilseed flax straw stems and fibers obtained in order to determine the scope of industrial application, it is necessary to take into account their specific anatomical, physical and mechanical properties.

The analysis of standardization of straw and oilseed flax products indicates the absence of regulations determining their quality, the development of such regulations is a crucial issue. At present, there is no clear classification of fibers and physical and mechanical properties that would characterize the scope of their industrial application. Thus, scientists have developed and registered in the state enterprise "Khersonstandardmetrology" the technical specifications TU U 01.1-2303511525 - 001: 2016 "Oilseed flax straw. Specifications" and TU U 01.1-05480298 - 001: 2017 "Oilseed flax retted straw. Specifications". This will allow analyzing this industrial raw material, determining the feasibility of mechanical processing and the quality level of fiber as finished product.

CONCLUSIONS

World practice shows that oilseed flax is annually renewable “biological raw material” of new generation. In Ukraine, oilseed flax is the only domestic raw material, which can be an alternative to imported cotton and fibre flax for using in the textile, pulp and paper industries and the production of reinforced composite materials.

For complex processing of oilseed flax straw stems in Kherson National Technical University systematic research is carried out. As a result, it was found that their physical and mechanical properties, morphological, anatomical structure and distribution of fibers length of oilseed flax straw stems are significantly different in all technological parameters from common flax. Therefore, it is not appropriate to carry out mechanical processing of oilseed flax stems according to the schemes used for common flax processing.

Thus, to use oilseed flax fibres in various fields of industries on the basis of the results obtained, the technology and equipment for mechanical processing of oilseed flax retted straw based on modernization of existing equipment is proposed.

So far, in Ukraine and in the world there are no normative documents for standardization of oilseed flax straw and retted straw. Thus, scientists have developed and registered in the state enterprise "Khersonstandardmetrology" the technical specifications TU U 01.1-2303511525 - 001: 2016 "Oilseed flax straw. Specifications" and TU U 01.1-05480298 - 001: 2017 "Oilseed flax retted straw. Specifications". This will allow analyzing this industrial raw material, determining the feasibility of mechanical processing and the quality level of fiber as finished product.

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