ТЕХНОЛОГІЇ ХІМІЧНОЇ, ХАРЧОВОЇ ТА ЛЕГКОЇ ПРОМИСЛОВОСТІ

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OPTIMIZATION OF THE DECORTICATION STEMS OF RETTED STRAW OF BAST CROPS DEPENDING ON THEIR MOISTURE

The paper contains the results of theoretical and experimental studies aimed at determining the effect of moisture content of retted straw stems on the quality of their mechanical processing in the process of decortication and subsequent scutching for clearing a fibrous part of the stems from wood – shives. To achieve the main goal, mathematical planning of the experiment on identifying the optimal values of moisture content of the stems of bast crops for their mechanical processing has been conducted, which resulted in a high degree of fiber clearing from shives ranging between 1.83 to 4.53 % with full strength retention of the fiber.
Keywords: moisture content, bast crops, stems, oil flax, technical hemp, raw fiber, decortication, scutching, strength.

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ОПТИМІЗАЦІЯ ПРОЦЕСУ ДЕКОРТИКАЦІЇ СТЕБЕЛ ТРЕСТИ ЛУБ'ЯНИХ КУЛЬТУР ЗАЛЕЖНО ВІД ЇХ ВОЛОГОСТІ

Представлена робота містить результати теоретичних та експериментальних досліджень спрямованих на оптимізацію механічних процесів переробки луб'яних культур в залежності від вологості стебел, які подаються на декортикацію і подальше тіпання для очищення волокнистої частини стебел від деревини – костриці. Вказується на те, що модернізація лляного виробництва повинна проходити через застосування сучасних технологічних розробок і обладнання обробки лляної сировини. Для досягнення основної мети роботи проведено математичне планування експерименту з виявлення оптимальних значень вологості стебел луб'яних культур для їх механічного оброблення, за яких одержується висока ступінь очищення волокна від костри від 1,83-4,53 % при повному збереженні міцності волокна.

Вологість стебел луб'яних культур є найважливішою технологічною характеристикою, оскільки від вмісту вологи у стеблах залежить їх зберігання, біологічний процес розстилання на полі під час перетворення стебел соломи в тресту й механічний процес виділення волокна від деревної частини стебел. Так, основні характеристики якості луб'яних волокон після механічного оброблення стебел – вміст костри у волокні і міцність його напряму залежить від первинної вологості стебел, які подаються на переробку. Тому в даній роботі поставлено завдання визначити оптимальні значення вологості трести луб'яних культур для одержання високої якості оброблення стебел на декортикаторах в процесі м'яття і тіпання на тіпальних машинах для різних типів та сортів луб'яних культур і льону-довгунця сортів «Гладіатор», «Есмань», льону олійного сортів «Південна ніч», «Дебют» та технічних конопель сорту «ЮСО-31».

У результаті аналізу впливу вологості трести луб'яних культур льону олійного, технічних конопель на якість одержаного волокна встановлена чітка залежність фізико-механічних характеристик волокна: відсоткового виходу волокна сирцю, розривного навантаження волокна та вмісту костри від вологості стебел, які подаються на механічну обробку. Чим менша вологість стебел перед механічною обробкою, тим вища якість одержуваного волокна і ступінь його очищення від костри.
Ключові слова: вміст вологи, луб'яні культури, стебла, льон олійний, технічні коноплі, сирець, декортикація, тіпання, міцність.

Introduction

The moisture content of the bast crop stems is the most important technological characteristic, as their storage, a biological process of laying out in the field during the transformation of straw stems into the retted straw and the mechanical process of fiber separation from the woody part of the stems depend on moisture content in the stems. Thus, the main characteristics of the quality of bast fibers after mechanical processing of the stems such as, the content of shives in the fiber and its strength directly depend on the primary moisture content of the stems that are sent to be processed. Therefore, it is important to establish the optimal moisture values of the bast crop stems for obtaining high-quality fiber with the lowest content of shives and high strength after mechanical processing of the stems in decorticators during breaking and scutching on scutching machines.

In previous scientific papers (Tikhosov A.S., et. al 2019) standardized moisture parameters by which the stems of bast crops of flax, oil flax, technical hemp should be processed using the technologies of storage, a biological process of obtaining retted straw, and mechanical processing of the stems for obtaining the fiber have been identified. But the normalized values of moisture content of straw, retted straw, and bast crops fiber, which are given in the relevant standards DSTU 4149: 2003, DSTU 8422: 2015, and TUU 01.1-05480298-002.2018 do not correspond to the optimal values of a moisture content depending on the type and variety of bast crops and require systematic control of moisture content at each stage of technological processes of bast stems processing. At present, modern moisture and temperature sensors (Arduino-ua.com) which can be successfully used in automated control of moisture content of bast-fiber stems based on the RaspberryPl B + microcomputer have been developed (Petin V.A, 2015). The application of the moisture control system based on the RaspberryPl B + microcomputer in the technological process of obtaining retted straw by laying out fiber flax stems in the field is shown in the work of A.S. Tikhosov. (Tikhosov A.S., et. al. 2017). But the influence of moisture content on the quality of mechanical processing of bast crop stems from the process of decortication and scutching is not revealed in this paper.

Therefore, the task of this paper is to establish the effect of moisture content of bast-fiber stems on the quality of processing the stems in decorticators in the process of breaking and scutching on scutching machines for different types and varieties of bast crops such as fiber flax "Gladiator" and "Esman", oil flax "Pivdennanich", "Debut" and technical hemp "YUSO-31" intending to determine the optimal values of moisture content for obtaining a high quality of mechanical processing of the stems.

Materials and methods

For conducting systematic experimental studies, the retted straw biologically obtained in the field in the process of laying out the straw stems of different varieties of oil flax "Pivdennanich", "Debut", fiber flax "Gladiator" and "Esman", and technical hemp "YUSO-31" was used. The maturation process of the retted straw was monitored using the installed sensors SU-21NTI21 in the field, moisture content and temperature were fed to the server of the microcomputer RASPBERRY Pl B + (Tikhosov A.S. et.al., 2017). As a result of automated control of the biological process, the retted straw with standardized indices of separation of 3.6–4.0 units was obtained. Hereinafter, the retted straw stems were decorted in the breaking machine. The initial moisture content of the retted straw, which was processed in the breaking machine, was 8%. Then, after artificial moistening, the moisture content of the stems varied from 8.0 to 22%. After decortication of the retted straw stems the fiber - raw fiber was obtained. The quality of the fiber was evaluated by physical and mechanical parameters of the raw fiber, such as fiber yield, breaking load (strength), and the content of shives, by DSTU 5015: 2008 "Flax fiber, short". Technical conditions, GOST 9993-2014 "Hemp short". Specifications U 01.1-05480298-002: 2018 "Oil flax fiber", GOST 23087-78 "Short hemp for export". Technical conditions, DSTU 8422: 2015 "Hemp retted straw". Technical conditions according to standard methods.

The fiber yield was determined by weighing the retted straw stems (Cт) before mechanical processing in the decorticator or scutching machines, and the fiber (Cв) obtained after mechanical processing:

$$B = \frac{C_в}{C_т} 100\% \tag{1}$$

Breaking load (strength) of raw fiber after decortication and fiber after complete clearing in the process of scutching was determined by breaking the fiber samples on the tensile-testing machine ДКВ-60.

The content of shives was determined by weighing the shive (Cк), which was isolated from the fiber and the resulting amount of shives was attributed to the primary weight of the raw fiber (Cв) after decortication or fiber weight (Cв) after additional cleaning on scutching machines:

$$К = \frac{C_к}{C_т} 100\% \tag{2}$$

The results of the effect of moisture of the bast crop stems on the quality of retted straw processing after decortication are shown in table 1. (Beresovsky Yu.V., et.al., 2016)

Table 1

The effect of moisture content of the retted straw on the quality of obtained raw fiber after decortication of stems on a breaking machine

Types of bast-fiber retted straw	Moisture content of retted straw, %	Yield of raw fiber after decortication, %	Breaking load, daN	Content of shives, %
Oil flax "Pivdennanich"	8,0	26,15	17,87	36,90
	15,0	21,34	16,53	39,26
	22,0	17,69	13,93	41,04
Oil flax "Debut"	8,0	26,21	18,46	36,87
	15,0	21,42	17,39	39,25
	22,0	17,74	14,31	41,01
Fiber flax "Gladiator"	8,0	27,87	23,28	36,03
	15,0	23,85	22,54	38,02
	22,0	19,63	19,72	40,04
Fiber flax "Esman"	8,0	27,96	24,35	35,96
	15,0	23,91	23,61	37,94
	22,0	19,78	19,97	39,98
Industrial hemp "YUSO-31"	8,0	26,92	27,31	36,50
	15,0	22,47	26,79	38,73
	22,0	18,59	23,84	40,62

After breaking the retted straw stems of the studied varieties of bast crops listed in table 1, and their decortication, raw fiber, and shives were obtained. Subsequently, raw fiber was processed on a scutching machine of the SMT machine for additional cleaning of it from shives. The results of the influence of moisture content on the yield of fiber and shives after the process of scutching are shown in table 2.

Table 2

The effect of moisture content of decorticated raw material on the efficiency of mechanical processing of fiber in the process of scutching

Types of bast fibre raw material	Moisture content of retted straw, %	Fibre yield, %	Content of shives, %
Oil Flax “Pivdennanich”	8,0	16,45	2,19
	14,0	16,57	2,27
	18,0	16,74	3,03
	21,0	16,86	3,73
Oil Flax “Debut”	8,0	20,01	2,16
	14,1	20,14	2,24
	18,0	20,23	3,01
	21,0	20,34	3,69
Fiber Flax “Gladiator”	8,0	28,18	1,83
	14,0	28,30	1,96
	18,0	28,41	3,48
	21,0	28,52	3,85
Fiber Flax “Esman”	8,0	29,21	1,86
	14,1	29,33	1,99
	18,0	29,45	3,53
	21,0	29,57	3,91
Industrial Hemp “YUSO-31”	8,0	27,98	2,05
	14,0	28,11	2,24
	18,0	28,35	3,75
	21,0	28,48	4,28

Analysis and generalization of results

According to Table 1, diagrams of the dependence of the yield of raw fiber (Fig. 1), breaking load (Fig. 2), and the content of shives (Fig. 3) on a moisture content of the stems of retted straw after decortication have been constructed.

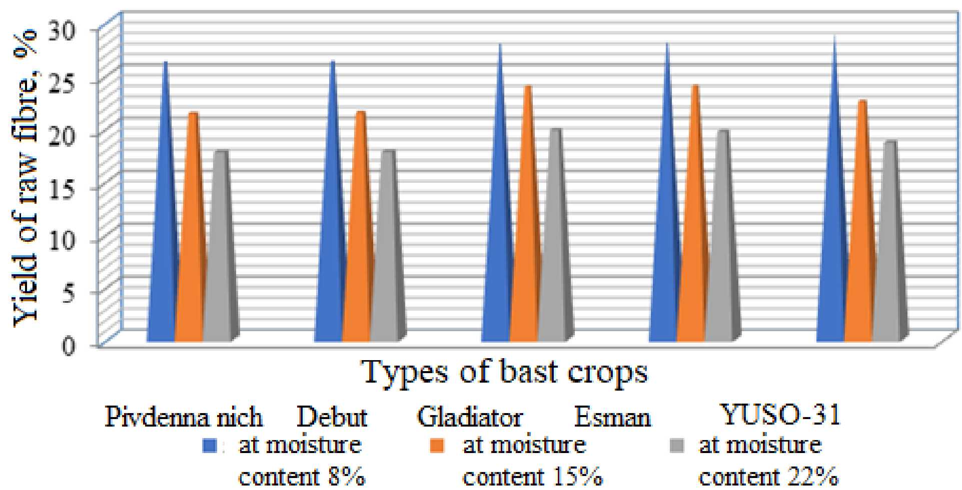

Fig. 1. Dependence of the yield of raw fiber on moisture content of the retted straw stems after decortication

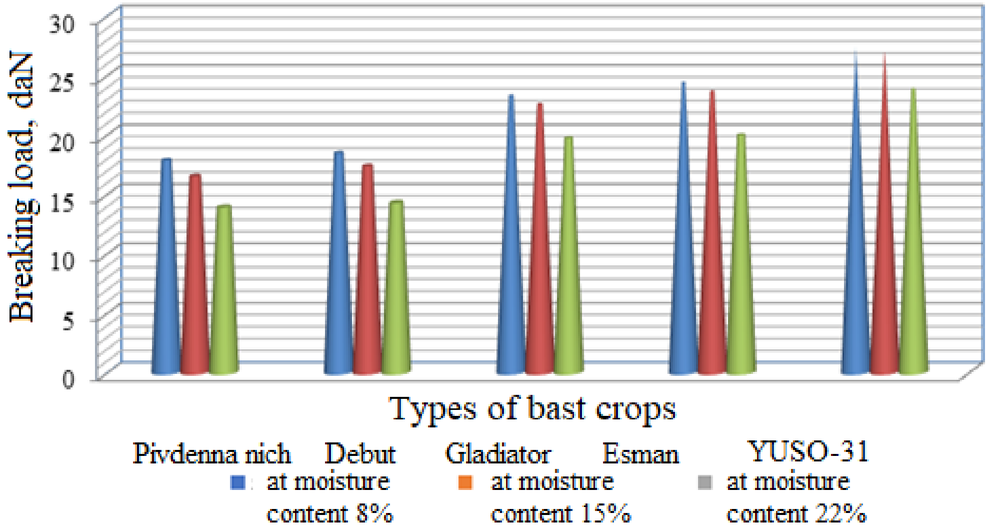

Fig. 2. Dependence of the breaking load of raw fiber on moisture conten to the retted straw stems after decortications

From the above diagrams it is clear that the increased yield of raw fiber is obtained at low moisture of retted straw stems for all types of bast crops of oil flax, fiber flax and technical hemp and the studied varieties – Pivdennanich, Debut, Gladiator, Esman, YUSO-31. The analysis of Fig.1 makes it possible to conclude that reducing the moisture content of the retted straw stems from 22 % to 8 % can increase the yield of the raw fiber from 17.69 to 27.87 % after decortication, while the content of shive in the fiber reduces from 41.04 to 35,96 % (Fig. 3), and the breaking load of the fiber in processing stems with low moisture content of 8 % has increased indices (Fig. 2).

After processing of the raw fiber on a scutching machine, the content of retted straw in the fiber (Table 1) is significantly reduced from 4.28 % to 1.83 %. The lowest values of the retted straw are contained in the fiber obtained from the raw fiber with the lowest values of moisture content (Table 2).

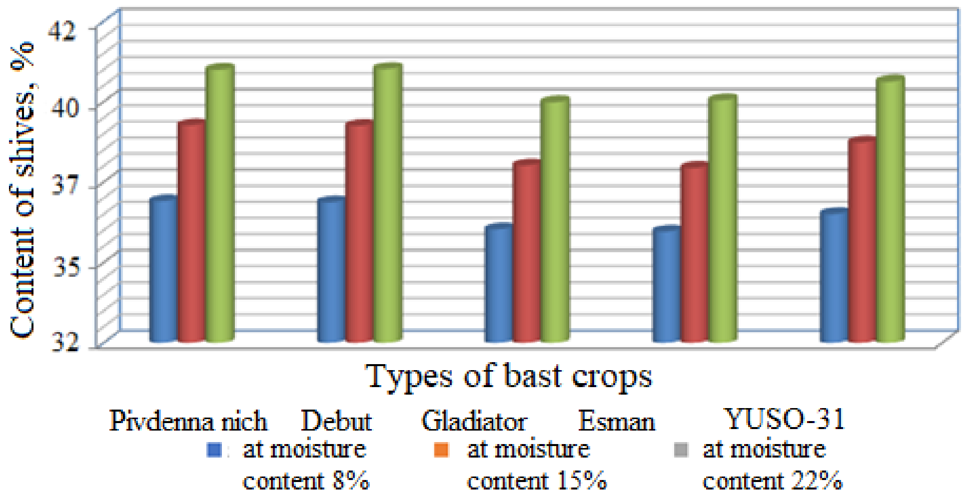

Fig. 3. Dependence of the content of shives in fiber on moisture content of the retted straw stems after decortications

The fiber yield after additional cleaning on the scutching machines doesn't depend on the moisture of the raw fiber (Table 2), and the content of shives in the acceptable fiber with reduced moisture content in the raw fiber is significantly reduced (Table 2). So, for a type of flax oil "Pivdennanich" at the decrease in the moisture content of the raw fiber from 21-8 %, the content of shives decreases from 3,73 to 2,19 %, and for the fiber of technical hemp at the same decrease of moisture content of the raw fiber, the content of shives decreases from 4.28 to 2.05 %, i.e. almost twice, and the fiber yield remains at the same level of 27.98 - 28.48 %.

Resultsand discussion

To determine the optimal values of moisture content of bast crop retted straw, which must be used for high-quality mechanical processing of the stems, a complete factorial experiment on determining the mathematical dependence of raw fiber yield, breaking load, and the shive content in the fiber after decortication using the innovative technologies on the moisture content of the bast crop stems, which are fed to mechanical processing using the innovative technologies has been conducted in this paper. (Beresovsky Yu.V., et.al., 2020). The stems of technical hemp of YUSO-31 type were taken as an example for a complete factorial experiment. Levels and intervals of the variation of factors of mechanical processing of technical hemp stem in the process of decortication are given in table 3. (Putintseva S.V., et.al., 2017)

Table 3

Levels and intervals of the variation of the factors of mechanical processing of the retted straw stems of technical hemp of YUSO-31 type in the decorticator

Factors	Variation Levels					Interval of variation
	-1,68	-1	0	+1	+1,68	
Unit pressure on 1 linear cm of the stem layer in a pair of breaker rollers, (x_1)	8,12	8,8	9,8	10,8	11,48	1,0
Moisture content of raw materials, (x_2)	7,96	10	13	16	18,04	3,0
Separability of retted straw stems, (x_3)	2,64	4,0	6,0	8,0	9,36	2,0

The initial parameters of this experiment corresponded to the physical and mechanical characteristics of the obtained fiber after mechanical processing: fiber yield (y_1), breaking load (y_2), and the content of shives(y_3). The independent input parameters such as the unit pressure in a pair of breaker rollers of the decorticator (x_1), moisture content of the stems (x_2) and separability (x_3) are shown in Table 3.

The results of a complete factorial experiment are shown on the graph of the dependence of the fiber yield $y_1$on the unit pressure of the rollers in the decorticator (x_1), moisture content of the retted straw stems(x_2) and the degree of retted straw aging (x_3), and described by mathematical dependence:

$$y_1 = 22.76 + 2.37x_1 + 0.72x_3 - 1.02x_1^2 - 0.79x_2^2 - 0.57x_3^2 \quad (3)$$

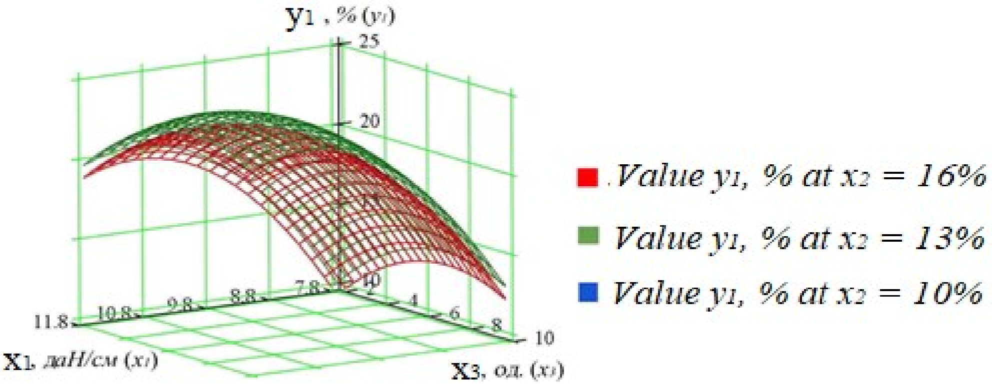

Fig. 4. Dependence of the yield of raw fiber y_1 on the unit pressure of the rollers in the decorticator (x_1), moisture content of the raw material (x_2) and the degree of retted straw aging (x_3)

The obtained mathematical dependence confirms the hypothesis that reducing the moisture content of retted straw stems improves the quality of mechanical processing and increases the fiber yield. The optimal value of moisture content is the values that are in the range of 8-11 %. The mathematical dependence of the breaking load (y_2) on the unit pressure of the rollers in the decorticator (x_1), a moisture content of retted straw stems (x_2),and the degree of retted straw aging (x_3) have also been obtained:

$$y_2 = 18,02 - 0,60x_1 - 0,27x_2 - 0,23x_3 - 0,62x_1^2 - 0,34x_2^2 - 0,18x_3^2 \quad (4)$$

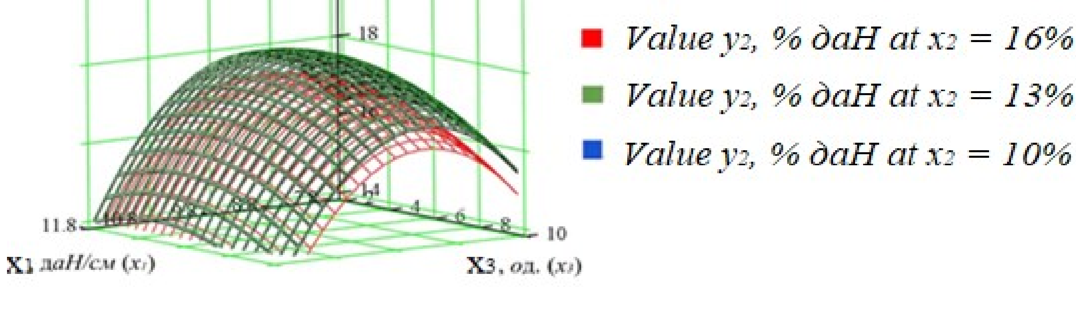

Fig. 5. Dependence of the breaking load (y_2) on the unit pressure of the rollers in the decorticator (x_1), moisture content of the raw material (x_2) and the degree of retted straw aging (x_3)

From the obtained dependence (4) and the graph (Fig. 5), it is clear that the breaking load of the fiber in the process of decortication remains unchanged as moisture content is reduced, which makes it possible to confirm that the fiber strength is preserved with increasing the fiber yield and reducing the moisture content of the stems fed to mechanical processing.

The third mathematical dependence of the content of shives in the fiber after mechanical processing of the retted straw stems (y_2) on the unit pressure of the rollers in the decorticator (x_1), moisture content of the retted straw stems (x_1), and the degree of retted straw aging (x_1), is described by equation (5):

$$y_3 = 71,77 - 0,81x_1 - 0,25x_3 + 0,33x_1^2 + 0,28x_2^2 + 0,20x_3^2 \quad (5)$$

and is presented on the graph (Fig. 6).

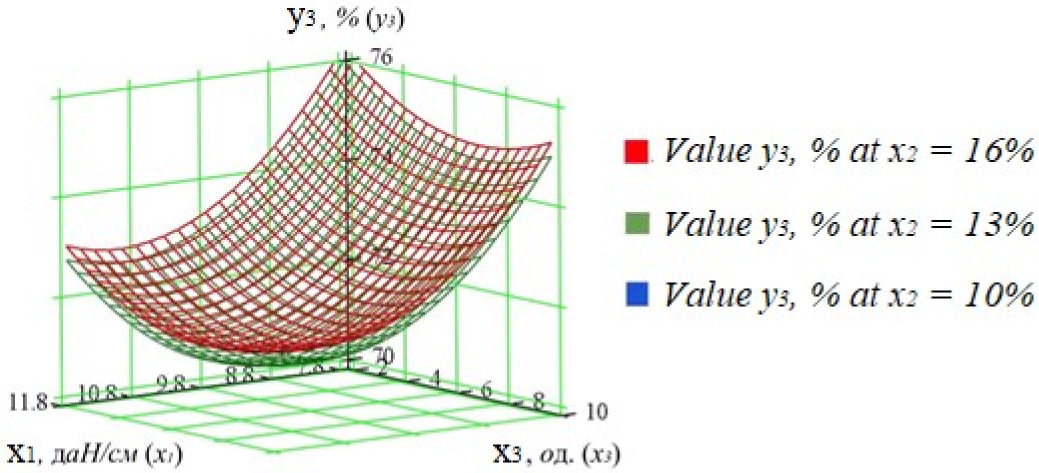

Fig. 6. Dependence of the shive content, K,% (y_3) on the unit pressure of the rollers in the decorticator (x_1), moisture content of the raw material (x_2) and the degree of retted straw aging (x_3)

From the obtained data of equation (5) and graphical dependence (Fig. 6), it is clear that the increased moisture content of stems of hemp retted straws for their mechanical processing has a negative effect on the process of shive extraction from the fiber. With an increased moisture content of the stems the content of shives in the fiber increases, so to clean the fiber from shives it is necessary to maintain the lowest values of moisture of the retted straw stems, which is subject to mechanical processing at 8-10%. (Kuzmina T.O., et.al., 2020).

On the basis of the obtained regression dependences, 3-5 on the example of retted straw stems of technical hemp of YUSO-31 type a control program for the mechanical processing of retted straw stems of bast crops with constant control of moisture content of stems will be developed in the future, which will be fed to decortication at certain values of the unit pressure of a stem layer in a pair of breaker rollers and separability of retted straw.

Summary

As a result of the analysis of the influence of moisture content of bast crops retted straws of oil flax "Pivdennanich" and "Debut", fiber flax “Gladiator” and “Esman”, technical hemp “YUSO-31” on the quality of the obtained fiber, a clear dependence of physical and mechanical characteristics of the fiber such as, percentage of the yield of raw fiber, breaking load of the fiber and the content of shives on the moisture content of the stems that are fed to mechanical processing: the lower the moisture content of the stems before mechanical processing, the higher the quality of the fiber and the degree of its cleaning from shives. It is established that the increase in moisture content in the stems of bast crops straw above 10% leads to a loss of quality of the obtained fiber by 11% and its consumer value. (Tikhosov A.S., et.al., 2020).

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