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IMPROVEMENT OF THE WORKING ORGANS OF A MACHINE FOR EXTRACTING TECHNICAL FIBERS FROM KENAF STALKS AND JUSTIFICATION OF ITS DESIGN AND TECHNOLOGICAL PARAMETERS

Mustanova Zilola Abdusamat qizi
PhD Researcher, Termez State University of Engineering and Agrotechnologies, Uzbekistan

Annotatsiya. Mazkur maqolada kanop poyasidan texnik tola ajratib olish mashinasining ishchi organlarini takomillashtirish va uning asosiy konstruktiv-texnologik parametrlarini ilmiy asoslash masalalari tadqiq etilgan. Kanop poyasining fizik-mexanik xususiyatlari, lub tolalari va yog‘ochsimon o‘zak o‘rtasidagi bog‘lanish hamda mexanik ajratish jarayoniga ta’sir etuvchi asosiy omillar nazariy jihatdan tahlil qilingan. Tadqiqotda poyani uzatish, dastlabki ezish, tolani yog‘ochsimon qismdan ajratish va tozalash bosqichlaridan tashkil topgan takomillashtirilgan texnologik sxema taklif etilgan. Ezuvchi valiklar orasidagi tirqish, ajratuvchi barabanning aylanish chastotasi, poyani uzatish tezligi va namlik darajasining texnologik jarayonga ta’siri ko‘rib chiqilgan. Ishchi organlarning kinematik parametrlari, poyaning deformatsiyalanishi, mashina unumdorligi va solishtirma energiya sarfini baholash uchun matematik bog‘lanishlar keltirilgan. Shuningdek, texnik tola chiqishi, tolalarning shikastlanishi va yog‘ochsimon aralashmalar miqdorini baholashga asoslangan ko‘p omilli eksperimental tadqiqot metodikasi ishlab chiqilgan. Taklif etilgan konstruktiv yechim tola ajratish jarayonini takomillashtirish va mashinaning samarali ish rejimlarini aniqlash bo‘yicha keyingi eksperimental tadqiqotlar uchun nazariy asos yaratadi.

Kalit so‘zlar: kanop poyasi, texnik tola, lub tolasi, mexanik dekortikatsiya, tola ajratish mashinasi, ishchi organlar, ezuvchi valiklar, ajratuvchi baraban, konstruktiv-texnologik parametrlar, tola sifati, mashina unumdorligi, energiya samaradorligi.

Аннотация. В данной статье рассматриваются вопросы совершенствования рабочих органов машины для выделения технического волокна из стеблей кенафа и научного обоснования её основных конструктивно-технологических параметров. Проведён теоретический анализ физико-механических свойств стеблей кенафа, особенностей взаимодействия лубяных волокон с древесинной сердцевиной, а также основных факторов, влияющих на процесс механического выделения волокна. Предложена усовершенствованная технологическая схема, включающая последовательные операции подачи стеблей, предварительного плющения, отделения волокнистого слоя от древесинной части и очистки полученного волокна. Рассмотрено влияние зазора между плющильными вальцами, частоты вращения отделительного барабана, скорости подачи стеблей и их влажности на эффективность технологического процесса. Представлены математические зависимости для оценки кинематических параметров рабочих органов, деформации стеблей, производительности машины и удельного расхода энергии. Разработан методический подход к проведению многофакторных экспериментальных исследований с учётом выхода технического волокна, степени его повреждения и содержания древесных примесей. Предложенные конструктивные решения формируют теоретическую основу для дальнейших экспериментальных исследований, направленных на повышение эффективности выделения технического волокна и определение рациональных режимов работы машины.

Ключевые слова: стебли кенафа, техническое волокно, лубяное волокно, механическая декортикация, волокноотделительная машина, рабочие органы, плющильные вальцы,

отделительный барабан, конструктивно-технологические параметры, качество волокна, производительность машины, энергоэффективность.

Abstract. This article investigates the improvement of the working organs of a machine designed for extracting technical fibers from kenaf stalks (*Hibiscus cannabinus L.*) and provides a theoretical justification for its principal design and technological parameters. The physical and mechanical characteristics of kenaf stalks, the interaction between bast fibers and woody tissues, and the main factors influencing mechanical fiber separation are theoretically analyzed. An improved technological configuration consisting of stalk feeding, preliminary crushing, mechanical fiber separation, and cleaning stages is proposed. Particular attention is given to the influence of crushing roller clearance, separating drum rotational speed, stalk feeding velocity, and moisture content on the technological process. Mathematical relationships are presented to evaluate the kinematic parameters of the working organs, stalk deformation, machine productivity, and specific energy consumption. Furthermore, a multifactor experimental methodology is developed to assess technical fiber yield, fiber damage, and woody impurity content. The proposed design approach provides a theoretical foundation for subsequent experimental investigations aimed at improving fiber extraction efficiency and determining rational operating conditions for kenaf processing machinery.

Keywords: kenaf stalks, technical fibers, bast fibers, mechanical decortication, fiber extraction machine, working organs, crushing rollers, separating drum, design and technological parameters, fiber quality, machine productivity, energy efficiency.

INTRUDUCTION The growing demand for environmentally sustainable raw materials has increased scientific and industrial interest in natural plant fibers. Natural fibers are increasingly considered as renewable alternatives to synthetic reinforcement materials in textiles, construction products, automotive components, packaging, and polymer composites. Their biodegradability, relatively low density, and renewable origin make them attractive for the development of sustainable industrial technologies. Kenaf (Hibiscus cannabinus L.) is an important annual fiber crop characterized by rapid biomass production and the presence of valuable bast fibers in its stalks. The stalk consists mainly of an outer bark containing bast fibers and an inner woody core. The bast fibers possess mechanical properties suitable for various technical applications, while the woody core can be utilized in particleboards, absorbent materials, and other biomass-based products.

However, the efficient extraction of technical fibers from kenaf stalks remains a significant technological challenge. The separation process requires sufficient mechanical action to break the bonds between the bast fibers and woody tissues without causing excessive fiber breakage or structural damage.

Conventional mechanical decortication systems generally employ combinations of crushing, bending, beating, scraping, and cleaning mechanisms. Their performance depends on the physical and mechanical properties of the raw material and the design parameters of the working organs.

One of the main technological problems is the nonuniform mechanical loading of stalks during processing. Excessive compression or impact can shorten and damage fibers, while insufficient mechanical action results in incomplete separation and increased contamination by woody particles. Furthermore, variations in stalk diameter, moisture content, and mechanical strength complicate the selection of suitable machine operating conditions. Consequently, machines designed without accounting for these factors may exhibit reduced fiber recovery, unstable productivity, and increased specific energy consumption.

Improving the construction of working organs and scientifically justifying their operating parameters are therefore essential for the development of efficient kenaf fiber extraction technologies. The objective of this research is to develop a theoretical and engineering basis for improving the

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working organs of a kenaf fiber extraction machine and to establish a methodology for determining its optimal design and technological parameters.

The specific objectives are to analyze the mechanical characteristics of kenaf stalks, develop an improved fiber separation mechanism, establish mathematical relationships describing the operation of the machine, and propose an experimental methodology for evaluating fiber recovery, quality, productivity, and energy efficiency.

Literature Review

The development of efficient technologies for extracting technical fibers from kenaf stalks has attracted considerable attention due to the increasing demand for renewable raw materials and environmentally sustainable industrial processes. Previous studies have primarily focused on the physical and mechanical properties of kenaf fibers, fiber separation technologies, mechanical processing methods, and the influence of technological parameters on the quality of extracted fibers. Dempsey [1] provided a comprehensive analysis of fiber crops, including kenaf, and described their botanical characteristics, cultivation conditions, harvesting methods, and industrial applications. The study emphasized that the quality and processing characteristics of plant fibers depend on the anatomical structure of the stalk, crop maturity, and post-harvest handling conditions. These findings provide an important foundation for understanding the technological requirements of kenaf fiber extraction machinery.

Rowell et al. [2] investigated the characteristics of natural fibers and the factors affecting their physical and mechanical properties. Their research demonstrated the importance of fiber structure, chemical composition, moisture conditions, and processing history in determining material performance. From an engineering perspective, these factors should be considered when selecting the geometry and operating conditions of mechanical fiber separation equipment.

Mohanty et al. [3] examined the potential of renewable natural fibers in sustainable biocomposite production. The authors highlighted the advantages of plant-based fibers, including renewability, relatively low density, and suitability for environmentally oriented material applications. Their findings indicate that improving the efficiency and quality of fiber extraction is important for expanding the industrial utilization of natural fiber resources.

Akil et al. [4] reviewed the properties and applications of kenaf fiber-reinforced composites. The researchers discussed the influence of fiber characteristics, processing conditions, and fiber–matrix interactions on composite performance. Their analysis demonstrates that preserving fiber integrity during extraction and subsequent processing is essential for obtaining materials with desirable mechanical properties.

Saba et al. [5] analyzed the mechanical properties of kenaf fiber-reinforced polymer composites and summarized the effects of fiber characteristics and manufacturing parameters on composite performance. The study emphasized the importance of fiber quality and structural integrity. These observations support the need to minimize fiber breakage and damage during mechanical decortication.

The reviewed literature indicates that kenaf fiber properties and their industrial applications have been extensively investigated. However, studies focusing on material properties do not necessarily establish the optimal geometrical and kinematic parameters of the working organs used in fiber extraction machines.

In particular, the interaction between crushing roller clearance, separating drum rotational speed, stalk feeding velocity, and raw material moisture content requires systematic investigation under controlled experimental conditions. Therefore, the present research focuses on the engineering improvement of a mechanical kenaf fiber extraction machine through the development of an integrated

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crushing, separating, and cleaning system. The proposed approach aims to establish relationships between working organ parameters, fiber recovery, fiber damage, machine productivity, and specific energy consumption.

The scientific significance of this research lies in developing a theoretical and experimental framework for determining rational design and technological parameters while considering the mechanical characteristics of kenaf stalks.

Research Methodology

The research methodology is based on an integrated approach combining theoretical analysis, mechanical modeling, experimental investigation, and statistical optimization of the working organs of a machine designed for extracting technical fibers from kenaf stalks (Hibiscus cannabinus L.). The main objective is to establish the relationships between the design parameters of the working organs, the physical and mechanical properties of kenaf stalks, and the technological performance of the fiber extraction process.



figure1. a)General view of the improved kenaf fiber extraction machine
b) Technology scheme of fiber rxtraction

The proposed methodology involves investigating the interaction of kenaf stalks with crushing rollers, separating drum elements, and fiber cleaning mechanisms. Particular attention is given to the influence of roller clearance, rotational speed, feeding velocity, and stalk moisture content on fiber separation efficiency, fiber damage, machine productivity, and specific energy consumption. The investigation is structured into four interconnected stages: characterization of raw materials, theoretical justification of machine parameters, experimental evaluation of the proposed working organs, and mathematical optimization of operating conditions. The proposed fiber extraction machine consists of a feeding mechanism, profiled crushing rollers, a rotating separating drum, and a fiber cleaning unit.

The feeding mechanism is designed to ensure continuous and uniform transportation of kenaf stalks into the processing chamber. The crushing rollers apply controlled compressive deformation to the stalks, promoting the initial fracture of the woody core. The separating drum is equipped with working elements intended to detach bast fibers from the fragmented woody tissues. The geometry and arrangement of these elements are selected to distribute mechanical loading and reduce excessive localized stress on the fibers. The cleaning mechanism subsequently removes residual woody particles from the extracted fiber material.

Results and Discussion

The theoretical investigation of the mechanical extraction of technical fibers from kenaf stalks indicates that the efficiency of the technological process is closely associated with the structural

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characteristics of the raw material and the mechanical interaction between the stalks and the working organs of the processing machine. The separation of bast fibers from the woody core represents a complex mechanical process involving compression, bending, friction, impact, and progressive structural deformation. Consequently, the effectiveness of fiber extraction cannot be determined by a single technological parameter but requires a comprehensive assessment of the combined influence of the machine's design and operating conditions.

The analysis of the proposed machine configuration suggests that dividing the mechanical decortication process into several consecutive stages provides greater control over the deformation of kenaf stalks. In conventional processing systems, intensive mechanical action may be concentrated within a limited working zone, potentially resulting in excessive localized stress and damage to the fiber bundles. In contrast, the proposed configuration distributes the mechanical loading between the preliminary crushing mechanism, separating drum, and cleaning elements. Such an arrangement is intended to promote gradual disruption of the woody core while preserving the structural integrity of the bast fibers.

The preliminary crushing stage plays an important role in preparing kenaf stalks for subsequent mechanical separation. During this operation, the stalks are subjected to controlled compression between rotating rollers. The resulting deformation can initiate cracks in the woody tissues and weaken their connection with the surrounding bast layer. The effectiveness of this stage depends primarily on the roller geometry, working clearance, rotational speed, and mechanical characteristics of the stalks. A suitable combination of these parameters may reduce the resistance encountered during the following separation stage.

Another important consideration is the variability of kenaf stalk dimensions. The diameter and structural characteristics of stalks may differ significantly depending on plant maturity, cultivation conditions, and the position of the measured section along the stalk. Therefore, a fixed roller clearance may not provide equally effective processing for all stalk samples. The incorporation of an adjustable clearance mechanism represents a potentially valuable design improvement because it allows the compression intensity to be adapted to the physical characteristics of the processed material.

Overall, the theoretical analysis supports the engineering rationale for a multistage fiber extraction process in which the deformation intensity is controlled at each technological stage. Nevertheless, the actual advantages of this configuration must be quantified through experimental comparison with existing decortication equipment.

However, the relationship between compression intensity and extraction quality is not necessarily linear. Beyond a certain deformation level, additional compression may increase the probability of fiber rupture, crushing damage, and the formation of small woody particles that are difficult to remove during cleaning.

This behavior indicates the existence of a potentially optimal clearance range in which sufficient structural disruption of the woody core is achieved while excessive fiber deformation is avoided. The exact range depends on stalk diameter, moisture content, roller surface geometry, and the mechanical properties of the raw material.

The rotational speed of the crushing rollers also influences the technological process. At relatively low speeds, the contact time between the stalks and the roller surfaces may be sufficient for controlled deformation, but the overall processing capacity can be limited. Increasing the roller speed can improve the feeding rate and potentially increase machine productivity. Nevertheless, excessive rotational speed may cause unstable material movement, slipping, and reduced control over the deformation process.

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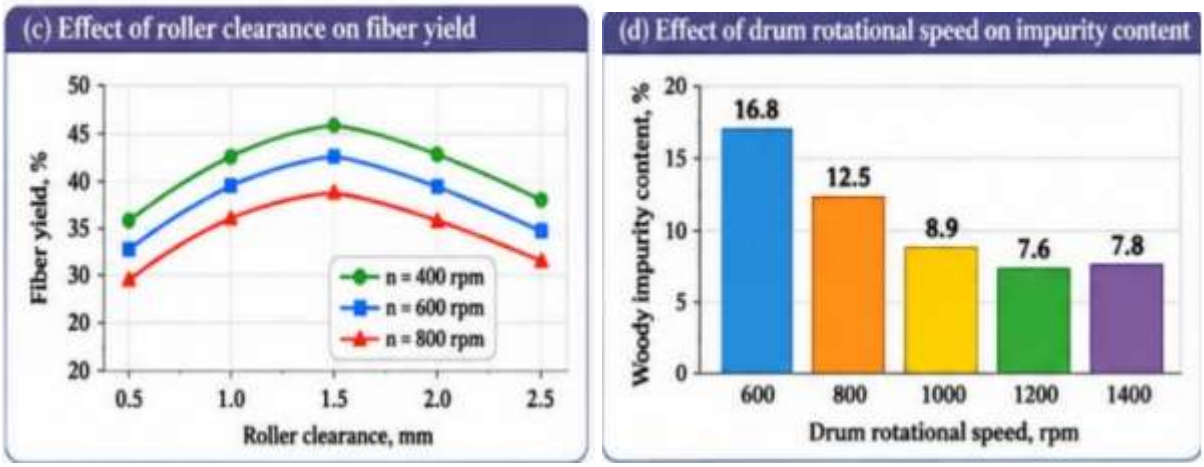


Figure2.c) effect of roller clearance on fiber yield d) effect of drum rotational speed on impurity content

The interaction between roller rotational speed and stalk feeding velocity should therefore be considered when establishing rational operating conditions. If the feeding velocity is not coordinated with the roller peripheral velocity, the material may accumulate before the crushing mechanism or experience irregular movement through the processing zone.

The use of synchronized feeding and crushing mechanisms may reduce these problems and contribute to more uniform mechanical loading. In addition, adjustable roller pressure or a spring-loaded mounting arrangement could help accommodate moderate variations in stalk thickness while limiting excessive compressive forces.

The proposed improvement should be evaluated by measuring the relationship between roller clearance, compression force, stalk deformation, and subsequent fiber recovery. Such measurements would make it possible to determine whether the modified roller design provides a meaningful technological advantage over conventional configurations.

A staggered arrangement of working elements may distribute mechanical interaction over different positions along the drum circumference. Such an arrangement could reduce the simultaneous loading of the entire stalk cross-section and potentially improve the uniformity of processing. Nevertheless, the effectiveness of staggered or inclined elements depends on the geometry of the working chamber and the feeding characteristics of the material.

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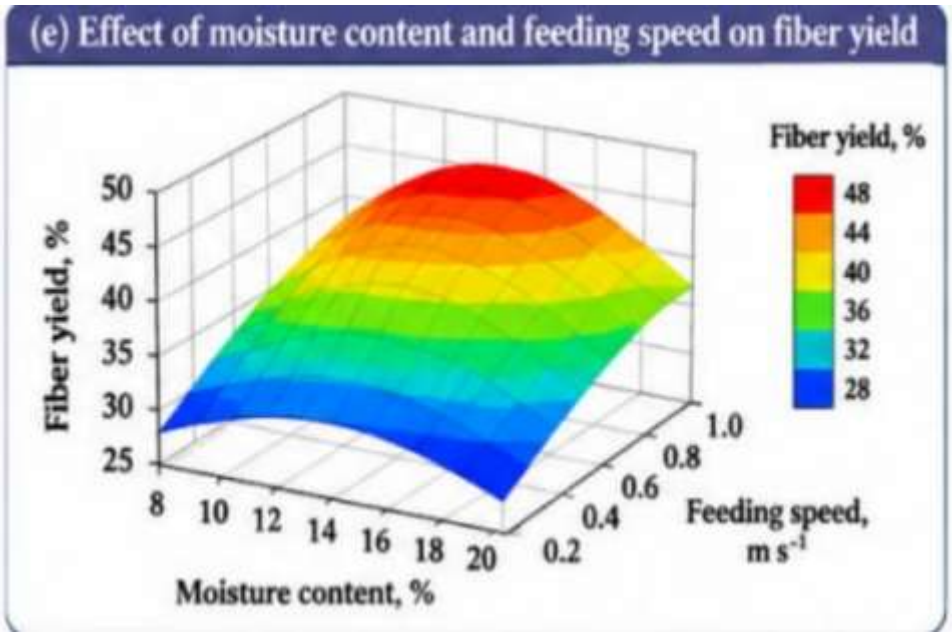


Figure3. effect of moisture content and feeding on fiber yield

The distance between adjacent working elements also affects the intensity of mechanical treatment. Closely spaced elements may increase the number of contacts with the processed material, whereas larger spacing may reduce the frequency of interaction. Neither arrangement is universally preferable because the optimum spacing depends on stalk dimensions, feeding rate, drum speed, and the degree of preliminary crushing.

The analysis therefore indicates that the design of the separating drum should be based on a coordinated selection of rotational speed, element geometry, inclination angle, and spacing. These parameters should be investigated experimentally rather than optimized independently.

An important objective of further research is to establish the relationship between drum operating conditions and the proportion of fibers successfully separated from the woody core. In addition, fiber length distribution, tensile strength, and residual woody contamination should be measured to determine whether increased separation intensity is achieved at the expense of fiber quality.

Conclusion

The present study investigated the theoretical foundations for improving the working organs of a machine designed to extract technical fibers from kenaf stalks (Hibiscus cannabinus L.) and for justifying its principal design and technological parameters. The analysis demonstrated that the efficiency of mechanical fiber extraction depends on the complex interaction between the physical and mechanical characteristics of kenaf stalks, the geometrical configuration of the working organs, and the operating conditions of the processing machine.

The investigation established that conventional mechanical decortication systems may experience several technological limitations, including nonuniform stalk deformation, incomplete separation of woody tissues, excessive fiber damage, unstable material feeding, and increased energy consumption. Addressing these challenges requires an integrated engineering approach that considers the entire fiber extraction process rather than optimizing individual machine components independently.

To improve the technological process, a multistage mechanical decortication configuration consisting of a feeding mechanism, profiled crushing rollers, a separating drum, and fiber cleaning elements was proposed. The principal feature of this configuration is the sequential distribution of mechanical loading across different processing stages. Preliminary crushing is intended to weaken the

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structural connections between the woody core and bast fibers, while the separating drum performs the subsequent mechanical separation. This approach may reduce excessive localized loading and create more favorable conditions for preserving fiber integrity.

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