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ABSTRACT

Of the dissertation for the degree of doctor of sciences

THEORETICAL AND PRACTICAL STUDY OF STORAGE AND PROCESSING OF RAW COTTON UNDER VARIOUS CLIMATE CONDITIONS

Specialty:	3313.02- Machines, equipment and processes
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The dissertation was reviewed by the Dissertation Council ED 2.02 operating under the "Azerbaijan State Oil and Industry University" under the Supreme Attestation Commission under the President of the Republic of Azerbaijan.

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GENERAL CHARACTERISTICS OF THE WORK

Relevance of the topic and completion degree. Important issues such as improving the quality of processed raw cotton, increasing the production capacity of processing enterprises should be solved through the application of modern technology, machinery, and mechanisms, along with mechanization and automation of existing equipment.

The practice of processing raw cotton shows that the storage of cotton following the requirements of existing regulations does not prevent the decline in the quality of its components. Besides, the technology used does not have a modern, effective method that can be used to prepare raw cotton for storage.

Shortcomings in the study of the storage process of cotton, the lack of basic methods and techniques for pre-storage preparations, accurate technological regulations depending on the maturity, moisture, trash, harvesting period of raw cotton, lead to a decrease in the quality of raw cotton during storage. Therefore, the development of new technologies and technical means to ensure the quality storage and processing of raw cotton, based on theoretical and experimental research, is the most urgent issue. Solving this problem will lead to maintaining the quality of raw cotton, increasing the yield of lint, the germination rate of seed material, reducing energy consumption in cotton processing plants, the cost of production, and, consequently, increasing the competitiveness of the product on the world market.

In this regard, this topic dealing with the development of new technologies to ensure the quality storage and processing of raw cotton and the improvement and systematic analysis of existing ones is relevant.

Object and goal of the research. The object of the study is the processing industry and the goal is to develop new technology ensuring the storage of cotton in the cotton ginning plants without losing its quality and ensuring the production of finished products whose quality indicators meet the requirements of regulatory documents.

The purpose and tasks of the research. The purpose of the dissertation was the development of effective methods, techniques, new technologies, and technical means ensuring the storage and processing of raw cotton, improving the storage regime of raw cotton, selection of an appropriate drying agent, taking into account the specific characteristics of raw cotton.

To achieve these purposes, the following issues have been solved in the dissertation.

- The classification of the existing methods and technological regulations for the storage of raw cotton was studied and systematically analyzed.
- Air permeability was studied depending on the type and quality indices of raw cotton.
- Variation of density depending on the height of the cotton layer baled for storage and air permeability of the layer depending on the density were studied.
- Increasing bulk mass depending on density, increasing of the adhesion force between fiber and small trash due to emerging pressure, and its effect on the cleaning efficiency of the ginning machine were studied.
- Constructive changes were made in the feeding mechanism of cotton processing machines, which resulted in the enhancement of cleaning efficiency of the machines and increased productivity of the technological line.
- A mathematical model of the dependence between the process of self-heating of raw cotton in the bale and the moisture content was built, the nature of the heating process, the mechanism of heat dissipation, the coordinates of the heat source, the area of heat dissipation, the rate of dissipation were studied.
- Depending on the type, quality indices, and density of raw cotton, the thermal conductivity of the cotton mass was studied.
- The percentage of seed material yield and growth energy were studied experimentally depending on the storage period and

conditions.

- As a result of theoretical research, the regularity of the dependence of the drying speed on the kinetics of the process during the drying of raw cotton was revealed.
- A universal equation was proposed to determine the kinetics of drying of raw cotton.
- A mechanism was proposed to form the upper part of the raw cotton bale.
- A drying agent was identified by experiments that did not adversely affect the quality of raw cotton.
- The results of theoretical research were confirmed by experiments.

Research methods.

Theoretical and experimental methods were used in the dissertation. Theoretical methods are based on information technology, technical means of vision, textile materials science, theoretical mechanics, drying theory, heat transfer theory, moisture transfer theory, and the application of heat and moisture transfer patterns of materials with capillary cavities.

Experimental methods are based on the mathematical planning of experiments. The analysis of the results was carried out using mathematical-statistical methods and computer technology.

Main points presented to the defense of the dissertation.

- Classification of raw cotton depending on its moisture content, methods of studying the mechanism of the effect of moisture retention, and technology of preparation of raw cotton before storage.
- The method of predicting the process of self-heating in raw cotton, the conditions of heat dissipation, limits, the method of determining the rate of dissipation.
- Methodology of growing seeds in large masses of raw cotton by creating special conditions.
- New technological regulations, which ensure the quality storage of raw cotton, taking into account the specific characteristics of raw cotton at the stage of supply and baling.

- Criteria justifying the application of the proposed technological regulations.
- Construction of bale yards, which provide initial heating of raw cotton and then cooling to ambient temperature.

Scientific novelty of the research. The development of technology, which ensures the storage and processing of raw cotton without losing its quality, taking into account the climatic conditions of the Republic of Azerbaijan.

As a result of the research, for the first time:

- The reasons for the decline in the quality of raw cotton during its storage based on existing regulatory technology in the cotton processing industry were studied.

- A methodology for classifying raw cotton depending on its moisture content was developed, and using this method, the effect of moisture on storage and the technology of pre-storage preparation of raw cotton were studied.

- An increase in the adhesion force between fibers and small trash depending on the period of storage in the stack due to the bulk mass pressure was studied.

- Constructive changes were made in the feeding mechanism of processing machines, an increase in cleaning efficiency and productivity was achieved.

- The possibility of theoretically predicting the process of self-heating in raw cotton was substantiated, heat dissipation conditions, limits, and rates were determined. The predicted parameters were confirmed by the results of the experiments.

- A methodology for modeling the storage process of raw cotton and analysis of the self-heating process was developed.

- Theoretical methodology of growing seeds in a large volume of raw cotton was developed by creating special conditions, and these theoretical results were confirmed by experiments.

- The air permeability of the raw cotton mass and the conditions for the free passage of air between the individual layers were studied theoretically. The results of theoretical research were confirmed experimentally.

- Taking into account the specific characteristics of raw cotton, a new technological operation was developed at the stage of preparation and baling.

- Before storage, depending on the quality indices of raw cotton, criteria were developed to justify the application of various technological processes intended for use.
- New methods were applied to improve the quality of seeds, increase the breaking load of the fiber, and reduce the preventive measures taken during storage. The moisture content of raw cotton was taken into account during the application of these methods.
- To ensure the heating of raw cotton with hot air at low temperatures, the construction of bale areas equipped with a special complex mechanism was developed.
- The effect of heat agents from various sources on the germination and growth energy of seed material during the drying of raw cotton was studied experimentally. Recommendations based on the results of the experiments were given to cotton farms.

Theoretical and practical significance of the research.

- As a result of theoretical and experimental research, technological regulations were developed to ensure the quality of raw cotton.
- A mathematical model of the process of self-heating of raw cotton depending on the moisture content was made, a methodology was developed to determine the coordinates and dimensions of the heating source.
- Constructive changes in the feeding mechanism of processing machines were made, the cleaning efficiency and productivity of ginning machines increased.
- Depending on the storage period, a method was proposed that ensured an increase in the percentage of seed yield and growth energy.
- The method and technique of supplying the bale with hot water ensuring the initial drying of raw cotton before storage was proposed.
- Technical documents of bale areas with special channels were prepared and submitted to cotton processing enterprises.

Approbation and application of the dissertation work. The main provisions of the dissertation were discussed and approved at the following international and local scientific and technical conferences:

- “Development of the national economy and increasing its efficiency”, International scientific-practical conference, 2012. Baku, p.

- “Prospects for the development of Azerbaijan” scientific-practical conference, Baku, 2013

- “Sustainable development and technological innovations”, International scientific-practical conference, 2014, Ganja, p.

- International scientific-technical conference dedicated to the 50th anniversary of Azerbaijan Cooperation University, 2014, Baku, p.

- “European conference on Innovations in Technical and Natural Sciences” Austria, Vienna, 2015.

- International Scientific and Technical Conference “Intellectual Technologies in Mechanical Engineering” Baku, AzTU, September 28-30, 2016.

- The 2nd International Scientific and Technical Conference “Problems of Metallurgy and Materials Science”. 28-30 November 2017. AzTU, Baku, Azerbaijan.

- Azerbaijan State Economic University. Prospects for the production and processing of raw cotton in Azerbaijan. International scientific-practical conference. Baku, 25-26 April 2018.

Proceedines of XII international scientific and practical konferense February 5-7, Kiev 2024

- Proceedines of XII international scientific and practical konferense February 5-7, Kiev 2024

- For being an active participant in VI International Scientific Practical Conferense, 12-14 Februaru, Berlin 2024

Name of the institution where the dissertation was carried out: Azerbaijan State University of Economics (UNEC).

Structure and volume of the dissertation: The dissertation consists of 6 chapters, conclusions and recommendations, a list of references, and an appendix. The introduction contains 13,710 characters, Chapter I – 37,570 characters, Chapter II – 54,318 characters, Chapter III – 97000 characters, Chapter IV – 30,741 characters, Chapter V – 44,261 characters, and Chapter VI – 33,296 characters. In total, the dissertation comprises 313734 characters.

Name of the organization where the dissertation work was

performed. The dissertation work was performed at the Azerbaijan State University of Economics, Salyan, Shirvan, and Sarijalar cotton ginnery plants.

THE MAİN CONTENT OF THE WORK

The introduction substantiates the relevance of the topic. The purpose of the research and the issues that need to be solved, the practical significance, and the scientific novelty of the dissertation have been described. It was noted that the technological regulations, methods, techniques, and technical means that serve to ensure the preservation of raw cotton without losing its quality do not fully solve the issues.

The first chapter provides a comprehensive analysis of the current state of supply, assembly, and storage of raw cotton, the requirements, and recommendations of state standards and technological regulations in this area, the current state of the research object.

In the first chapter of the dissertation, foreign experience in the field of storage of raw cotton is widely studied. As a result of the research, it can be concluded that the technology of storage of raw cotton does not correspond to the "Khajki" system, which is the most widespread abroad. Thus, the analysis of the existing methods and technological regimes related to the supply and storage of raw cotton shows that the preventive measures taken for the storage of wet and contaminated cotton do not fully solve the problems faced.

Raw cotton drying is mainly due to the drying of the fiber and the seed husk. The seed, which is the main source of moisture, does not dry out completely and its vital activity continues. Thus, the seed breathes, and during this process, moisture and heat are released. Therefore, it is necessary to take preventive measures to reduce the moisture content and heat in the bale. [73][1]

Analysis of existing state standards, technological regulations shows that the duration of mechanical harvesting and flow technology

[1] Instructions for the Harvesting and Preparation of Raw Cotton. No. 9-9-82 M. Approved by Order No. 225/175 of the Ministry of Agriculture of the USSR dated 09.07.83. – Moscow: 1982, – 82 pages.

"field-bunker- transportation -supply point" creates conditions for the diversity in the maturity degree of harvested raw cotton and high moisture content.

Due to the high speed of harvesting, lack of special areas for drying raw cotton in cotton farms, lack of natural drying facilities in the field conditions, contaminated and wet raw cotton is delivered to supply points and accepted with a reduced weight according to the norms taking into account the percentage of the trash and moisture. The current technological regulations do not stipulate that raw cotton with a moisture content of up to 20% should be subjected to any preventive measures before storage. Such technology does not exist.

The development of new technology is relevant and of great practical importance for the elimination of the existing inconsistencies and shortcomings in the storage technology of raw cotton, to ensure the quality storage and processing of the product. Such a technological regime should be between the process of determining the quality of the product and the processes of baling and storing.

The second chapter is about the examination of the quality of raw cotton supplied, the dependence of biological inequality on the time and method of harvesting, the technical, physical, and chemical properties of freshly harvested raw cotton and its components, and the effects of storage conditions and duration on raw cotton quality.

The quality of raw cotton depends primarily on the development nature of the cotton shrub and its product (cotton bolls). Bolls grow on the cotton shrub at different times. The different stages of development of the cotton shrub occur sequentially with a certain regularity. Development occurs in two directions: the development of the branches themselves from the lower branches to the next ones, which bring the product from the bottom to the top of the shrub, and in a horizontal direction. [171][2]

The flowering and ripening of individual bolls occur three times faster in the cotton shrub from bottom to top than from the center to the side direction (Figure 1).

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[2] Sailov R.A., Veliev F.A. The Influence of Harvesting Time on the Quantity and Quality of Raw Cotton under the Conditions of Azerbaijan // International Scientific-Practical Conference, – Vienna: – 2015. – 4 pages.

First of all, bolls inside the cotton shrub grow. This part includes the bolls located in the first, second, and third steps from the bottom up.

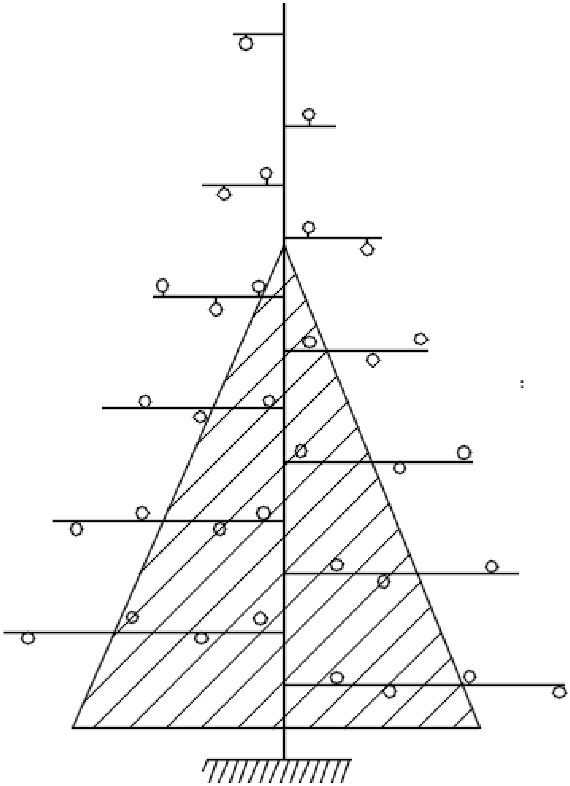
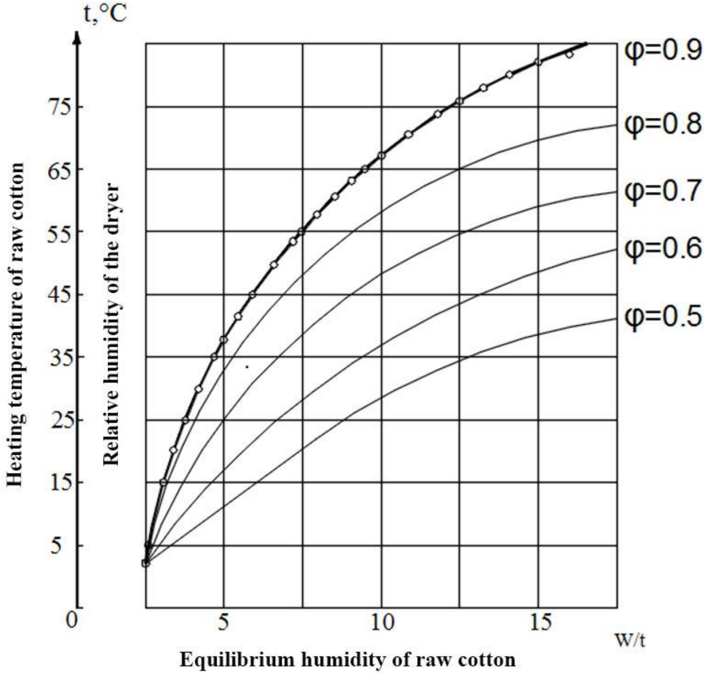


Figure 1. Conditional partitioning scheme of raw cotton based on the ripeness degree.

The formation of bolls in the inner zone occurs at a more favorable time than in the outer zone. First, the ripening of bolls in this zone occurs during the biologically strong time of the cotton shrub. On the other hand, the development period of bolls in the inner zone falls in July and August, the best times of natural conditions for growth. The ripening of the bolls in the outer zone occurs under unfavorable environmental conditions and during the poor vital activity of the cotton shrub. The quality of each type of raw cotton is different.

The variety of raw cotton mass affects all its quality indicators, including its hygroscopicity (Figure 2).



Graph 1. Dependence of equilibrium humidity of raw cotton on the relative humidity of the dryer and heating temperature of the material

The lower the ripeness level of raw cotton, the higher the equilibrium moisture content. The reason for the increase in the equilibrium moisture content is the presence of prematurely broken, immature raw cotton in the accepted raw cotton mass. To study the effect of harvesting time on the quality of raw cotton supplied is of practical importance.

The research was conducted in cotton farms of the Salyan region. Raw cotton of C-4727 and C-3038 breeding species was used for the test. Preparation of the planting area, planting of seeds, maintenance of cotton shrubs were carried out in accordance with agro-technical norms.

The studies showed that the bolls in the lower branches and closer to the stem are more mature. When 50-60%, 70%, and 80% of the bolls are opened in the cotton shrub, respectively, 60% (firmness 4.5 g/strength), 45-50%, and 30-40% of raw cotton harvested meet the requirements of quality indicators of the first grade. When harvesting is delayed, the quantity of raw cotton increases but the quality decreases. According to the research plan, the cotton after each harvesting was assembled separately, and quantitative and qualitative indicators were determined.

In mechanical harvesting, productivity increases as the number of open bolls increases. This situation is more pronounced during the first harvesting. When 50-60% of the bolls are opened, the productivity of the cotton-picking machine is 21-22 cwt per hectare, when 70% of the bolls are opened, it is 27.5%, and when 80% of the bolls are opened, it is 29-30%. Thus, when 50–60% of the bolls are opened, the total productivity is 35–36 cwt per hectare and when 80% of the bolls are opened, it is 39-40 cwt per hectare.

This difference is explained by the fact that the first harvest is performed when 50-60% of the bolls are opened. Meanwhile, the remaining half-opened bolls are damaged. When the number of opened bolls is 70-80%, there is less damage during harvesting.

It should be noted that there is a difference of 10-15 days between 50% opening and 80% opening of the bolls in the shrub. During this time, biological changes occur in the structure of the fiber and the husk. Fibers and seeds grow and their mass increases leading to an increase in the total productivity.

Studies show that during the cotton harvest, the average maturity percentage decreases when the bolls are opened too much. During the first harvest, the maturity factor decreases by 0.1–0.2 breaking strength, and by 0.1–0.4 breaking strength in the second harvest. Moisture and trash in the harvested cotton are reduced when the bolls are opened too much. Thus, when 50–60% of the bolls are opened, the humidity is 11.5–12.5%, and when 80% is opened, the humidity is 10.5%. This is explained by the fact that the number of bolls opened during late harvesting increases relative to the total number. The leaves dry up and fall. Studies show that the harvesting time does not affect the quality of the raw material.

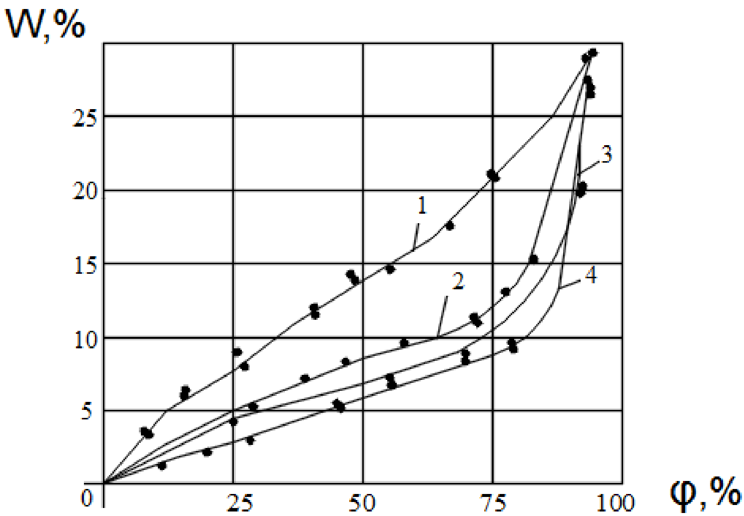
The quality of raw cotton depends on the quality indices of its individual components. Therefore, it is of practical importance to study how the moisture content of raw cotton produced in Azerbaijan, which causes self-heating during storage, is distributed among the individual components and the sorption properties of these components.

The studies showed that the moisture content of the seed husk exceeds the moisture content of the kernel, regardless of ambient temperature and relative humidity. The low moisture content of the kernel is explained by the fact that it contains oil.

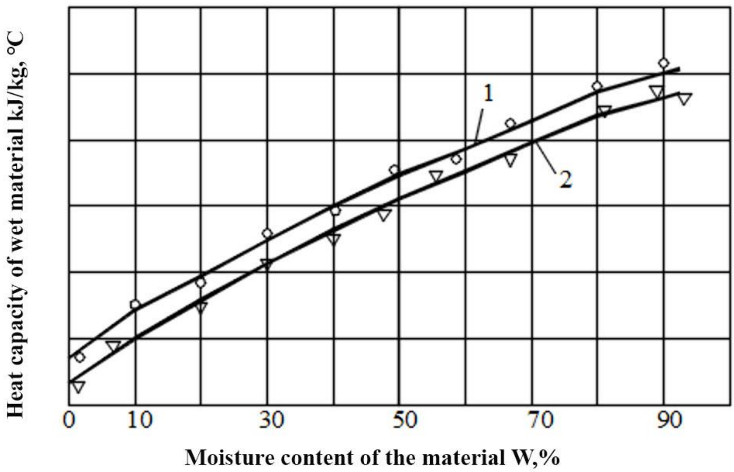
It is especially important to determine the thermal conductivity and temperature transfer coefficients of the material during the development of the initial drying process of raw cotton before storage. The results of our research using purified and unpurified seeds with different moisture content as the object of research allow us to find the coefficient of thermal conductivity of the seeds for engineering calculations using the following empirical formula.

$$\alpha=(4.1+0.28\omega) \cdot 10^{-3}\ m^2/h \qquad (1)$$

The research was conducted in the laboratory to study the physical and thermal characteristics of the components of raw cotton. As a result of the research, the physical and thermal characteristics of the components of raw cotton C-3038 belonging to the first-grade breeding species with a moisture content of 9% were determined. The results of the research are given in Figures 3, 4, and 5.

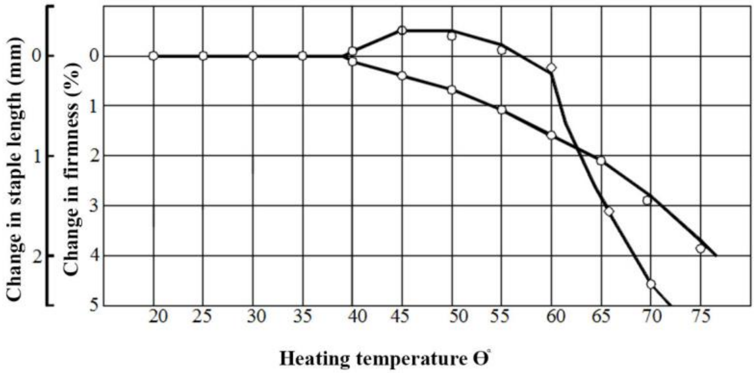


Graph 2. Dependence of raw cotton components on the environment. 1-fiber, 2-seed husk, 3-kernel, 4-lint



Graph 3. Dependence between heat capacity and the moisture content of the raw material.

1. Third-grade raw cotton
2. First-grade raw cotton



Graph 4. Dependence of fiber firmness and the length of a staple on the heating temperature of raw cotton.

During the research, a model was developed to study the characteristics of raw cotton depending on the ripening period. This allows us to determine the optimal harvesting period of raw cotton. Besides, the application of the model justifies the preventive measures carried out before the storage of cotton and storage technology. The results of the impact of the shelf life and storage conditions of raw cotton on the quality of its components are also described in the second chapter.

One of the main factors affecting the initial processing of raw cotton is storage condition. The correct storage technology is known to facilitate the improvement of the quality of raw cotton components. Therefore, in order to study many issues in this direction, it is necessary to create a “model” of the bale by imitating the processes that take place during the storage of raw cotton. This will allow studying the factors that affect the quality of cotton during storage.

The maturity of raw cotton primarily depends on the characteristics of the cotton plant and its product—bolls. Maturity does not occur simultaneously. First, the bolls located on the branches close to the stem of the cotton plant mature. This zone (A) includes branches located in the first, second, and to some extent, third levels from bottom to top. Bolls located in the inner part of the plant are considered part of zone (B). The remaining bolls are those situated on the outer branches of the plant (zone C) (see figure 2). The maturation of bolls in the inner part of the plant coincides with a period when the environment is most favorable and the plant is biologically robust. The bolls in zones A and B mature in July and August, which are considered the most favorable months for the development of the cotton plant.

The maturation of bolls in zone C, however, occurs during a time when the plant is somewhat weaker and the environmental conditions are less favorable. During this period, the cotton plant's growth and photosynthesis capabilities decrease, resulting in a weaker absorption of nutrients from the soil.

Based on the above observations, the study of the maturation process of raw cotton after harvesting was conducted in two directions:

1. Raw cotton was manually harvested separately from the inner and outer parts of the plant under ideal conditions for research purposes.
2. Raw cotton was harvested by machine at the beginning, middle, and end of the harvesting period, reflecting real-world conditions. The raw cotton mass contained varying degrees of maturity.

The experiments for the first method were conducted in the cotton farms of the Salyan district. During the study, the following agrotechnical measures were recorded:

- Vegetation period, including the number of rainy, cloudy, and sunny days during the vegetation cycle.
- Frequency and duration of irrigation, the quantity and timing of mineral fertilizers applied to the soil, and defoliation of the cotton plant.

For the bolls in the inner zone (zone A), the harvesting period began 70 days after the cotton plant blossomed. The cotton in the inner zone was manually harvested after 8–10 bolls opened. During this period, the bolls in zone A were better matured compared to those in zones B and C. Ten days after the first harvest, cotton was collected from zone

B, and another ten days later, from zone C. Both mature and immature cotton were found in the harvested mass

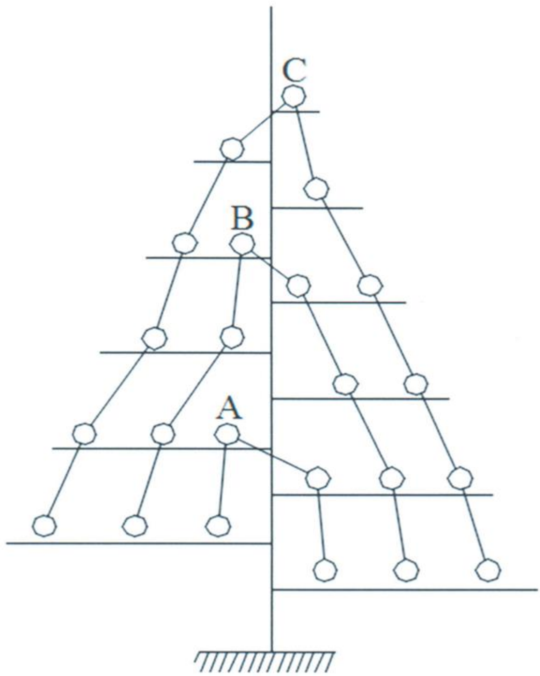
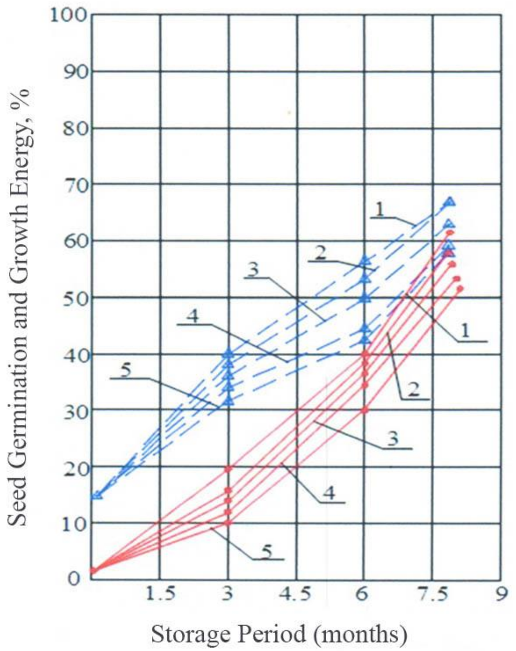


Figure 2. Diagram of boll maturation in the cotton plant

A total of 1500 kg of raw cotton was harvested. Before storing the raw cotton in stacks (bunts), samples were taken from manually harvested cotton and from machine-harvested cotton during the beginning, middle, and end of the harvesting period. The raw cotton designated for storage was packed into containers and “models” according to a known methodology. Consequently, an experimental stack model was created to reflect real conditions. Changes in temperature and humidity in the container and the environment were recorded simultaneously.

Three and six months after the experiments began, the tops of the stacks were opened, and samples were taken for analysis. The experiments were repeated nine times, and average values were obtained. Research results indicate that the moisture content of raw cotton changes depending on the storage duration, maturity, density, and storage conditions. Based on experimental results, dependency graphs (Graphs 5, 6, 7) were constructed to show the relationship between the germination percentage of seeds and the maturity, density, and storage conditions of raw cotton. In all cases, as the maturity of raw cotton increased, the germination percentage of seeds also increased.



Raw cotton stored at room temperature for 50 days.

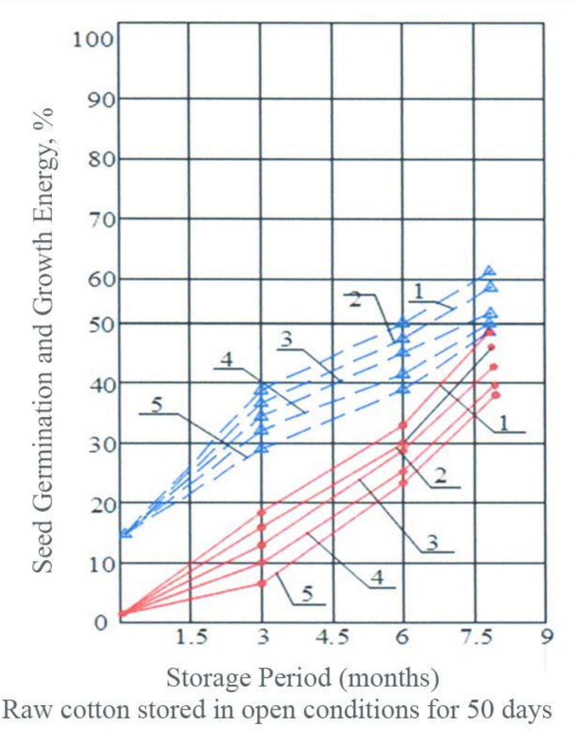
Graph 5: Dependency of seed germination percentage and growth energy on the maturity, density, and storage conditions of raw cotton.

Density of raw cotton: 1 - 700 N/m³ 2 - 1500 N/m³ 3 - 2000 N/m³ 4 - 2500 N/m³ 5 - 3000 N/m³

--Δ-- Seed germination percentage

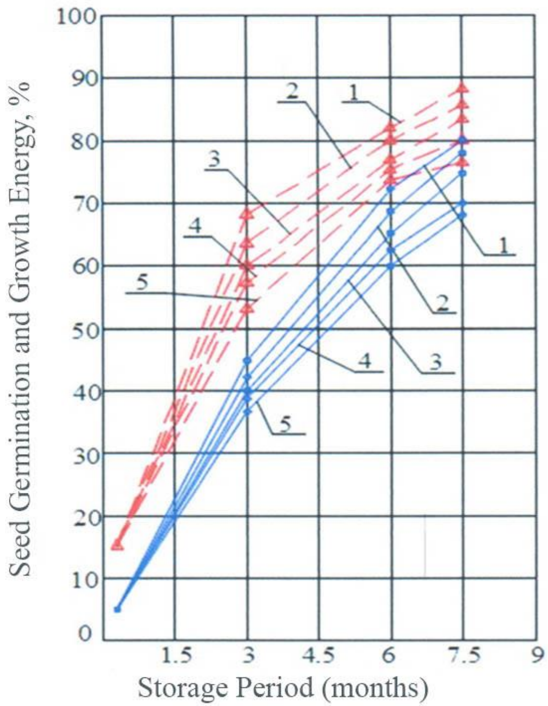
-- • -- Seed growth energy

It appears the graph illustrates the relationship between raw cotton density and its effect on seed germination and growth energy under various conditions. The trend likely highlights how changes in density influence these factors.



Graph 6: Dependency of seed germination percentage and growth energy on the maturity, density, and storage conditions of raw cotton.

Raw cotton density: 1 - 700 N/m³ 2 - 1500 N/m³ 3 - 2000 N/m³
4 - 2500 N/m³ 5 - 3000 N/m³
-- Δ -- Seed germination percentage
-- • -- Seed growth energy



Graph 7: Seed germination percentage and growth energy based on the density and storage conditions of cotton.

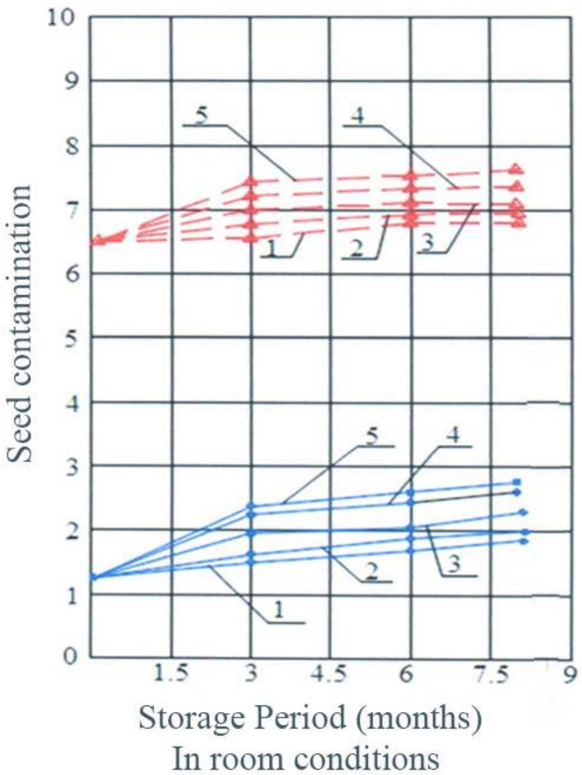
70-day-old raw cotton stored in open conditions. Raw cotton density: 1 - 700 N/m³ 2 - 1500 N/m³ 3 - 2000 N/m³ 4 - 2500 N/m³ 5 - 3000 N/m³

- Δ -- Seed germination percentage

-- • -- Seed growth energy

As observed from the graph, as the density of raw cotton in the stack increases, the seed germination percentage and growth energy decrease by approximately 8–10%. The raw cotton harvested from zone A, 70 days after the cotton plant bloomed, matures faster during storage compared to cotton harvested from zone C. Furthermore, the seed germination percentage is 20–30% higher in cotton harvested from zone A.

Graphs 8 and 9 provide visual representations of how seed quality indicators vary with the maturity, density, and storage conditions of raw cotton.

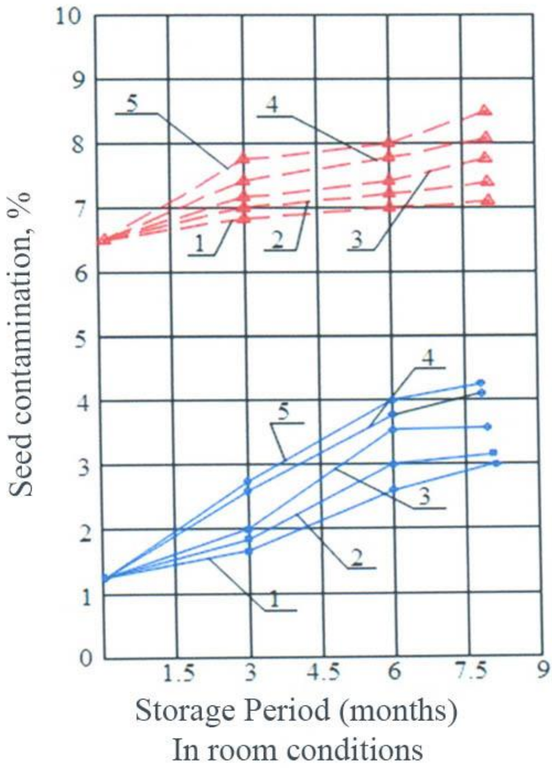


Graph 8: Dependency of the impurity percentage of seeds on the density and storage conditions of raw cotton.

Raw cotton density: 1 - 700 N/m³, 2 - 1500 N/m³, 3 - 2000 N/m³, 4 - 2500 N/m³, 5 - 3000 N/m³

-- Δ -- 50-day-old seeds

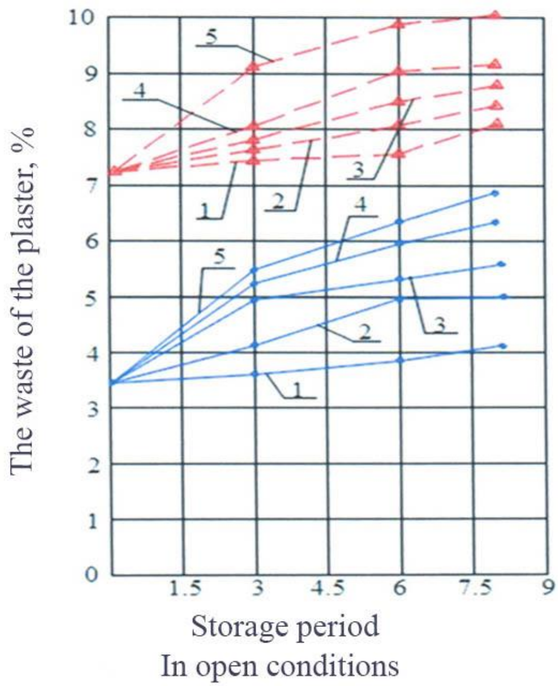
– • -- 70-day-old seeds



Graph 9: Variation in impurity percentage of seeds based on the density and storage conditions of raw cotton.

Raw cotton density: 1 - 700 N/m³, 2 - 1500 N/m³, 3 - 2000 N/m³, 4 - 2500 N/m³ ,5 - 3000 N/m³
-- Δ -- 50-day-old seeds
-- • -- 70-day-old seeds

Initially, the impurity percentage of seeds harvested from raw cotton in zone "A" was 1.3%, while the percentage from zone "C" was 6.5%. Over time, as the storage period increases, the impurity percentage also rises. It's noteworthy that as the density of raw cotton increases, the proportion of burned and semi-burned fractions in the impurities becomes higher. The quality of lint depends on the harvesting method, maturity level, density, and storage conditions of the raw cotton (Graph 10). Regardless of the maturity level or storage conditions of the raw cotton, an increase in density leads to a higher impurity percentage in lint



Graph 10: Variation in lint impurity percentage based on the density and storage conditions of raw cotton.

Raw cotton density: 1 - 700 N/m³ 2 - 1500 N/m³ 3 - 2000 N/m³ 4 - 2500 N/m³ 5 - 3000 N/m³
-- Δ -- Cotton from zone C
-- • -- Cotton from zone A

As the storage duration of raw cotton increases, the stack's volume density rises. When such cotton is passed through cleaning machines, the amount of separated impurities decreases, which leads to an increase in the percentage of impurities in the lint. Higher volume density in the stack reduces the airflow capacity of the cotton mass, negatively impacting seed quality, decreasing germination ability, and increasing the proportion of burned and semi-burned seeds. Conversely, raw cotton stored in smaller stacks with lower density shows higher seed germination percentages.

To ensure that the ripening process continues post-harvest while minimizing the decline in lint and seed quality, conditions must be created where the cotton mass allows unrestricted airflow. Experimental results from simulating storage conditions in industrial settings determined the following:

- Post-harvest ripening of raw cotton occurs faster at positive temperatures and lower densities.
- The storage duration significantly influences the quality of lint and seeds based on cotton density.
- Increased stack density leads to higher impurity percentages in both seeds and lint.

Storing raw cotton at low density and drying it with warm air intensifies the post-harvest ripening process

A three-factor matrix was used to plan a full-factor experiment. Input factors: x_1-density of baled raw cotton, x_2-shelf life, x_3-moisture content of raw cotton.

As the research parameters, y_1 -is the breaking length of the fiber, y_2 is the oil content of the seed, and y_3 is the seed yield percentage.

Analyzing the results of the study, we have derived a regressive equation that precisely expresses the change in parameters.

$$y_1 = 4.05 - 0.094x_1$$

$$y_2 = 83.06 + 3.94x_2 - 3.06x_1x_2 + 1.56x_2x_3 - 0.81x_2x_3 - 0.81x_1x_2x_3 \quad (2)$$

$$y_3 = 36.15 + 0.22x_3 - 0.16x_1x_2$$

Thus, using experimental and mathematical methods, the results were analyzed and the following conclusions were made:

- The storage of raw cotton is affected even by the density of raw cotton having low moisture content,

- Under certain conditions, the raw cotton seed can grow in the bale.

Dependence of the contamination degree of fibers and seeds, the growth energy and yield of the seed on the maturity, density in the bale, and storage conditions of raw cotton were studied.

The third chapter It is devoted to the study of the impact of the interaction between the working bodies of cotton processing machines and raw cotton on the quality of the product. It has been determined that the adhesion force between the trash particles and the lint increases when the cotton remains compressed in the stack for a long time, which leads to a decrease in the cleaning efficiency of the cleaning machines. It has been shown that studying the interactions between raw cotton and the working bodies of processing machines has great scientific and practical significance. It has been established that during the processing, raw cotton is subjected to mechanical effects such as compression and tension by the working bodies of machines and mechanisms. As a result, the impact on the lint increases, which leads to plastic deformation, fiber breakage, and a decline in quality.

Research has shown that when the working body enters the cotton mass at a certain speed, pressure, density, and temperature sharply increase. We propose the following formulas to calculate these parameters.

To calculate the density of cotton in the working environment:

$$\rho=\rho_0[1+\frac{1}{2}(\frac{U}{C})^2] \quad (3)$$

Here,

ρ – the density of raw cotton;

ρ_0 – the initial density of raw cotton;

U – the velocity of raw cotton movement;

C – the speed of sound propagation in the cotton medium.

To calculate the pressure generated during the interaction with the working body:

$$P_k = P_0 + q_0[1+\frac{1}{4}(\frac{U}{C})^2] \quad (4)$$

Here,

P_k – critical pressure;

P_o – initial pressure;

q_o – velocity pressure.

To calculate the existing temperature in the medium:

$$T_k = T_0\left[1 + \left(\frac{U}{C}\right)^2\right] \quad (5)$$

Here,

T_k – critical temperature;

T_o – initial temperature.

Calculations have shown that during the processing, compared to initial values, the density in the cotton mass increases by 1.6 times, pressure by 1.3 times, and temperature by 2 times. When the working body is positioned perpendicular to the direction of cotton movement, the pressure reaches its maximum value, and the seed gets damaged in this zone.

Based on the results of conducted experiments, it is proposed to calculate the seed damage degree (Z) using the following empirical expression:

$$Z = 0.015G, \quad (6)$$

where G – mechanical stress (kg/cm²).

The determination of pressure, stress, and velocity arising from the interaction between the working bodies and raw cotton makes it possible to determine the optimal parameters of the working bodies.

An analysis of the mechanics of interaction between the blades of the feeding drums of cotton processing machines and raw cotton shows that when the rotation speed of the feeding drum exceeds 12 m/s, the cotton seed gets damaged, and the trash content in the lint increases.

It has been determined that as the density in the stack increases, the adhesion force between the lint and the trash increases. For example, when first-grade raw cotton with a density of 150–200 kg/m³ is stored for one month, the adhesion force between the lint and large trash particles is 63–91 g-force, and with small trash particles is 714–1000 g-force; in third-grade raw cotton, these values are 76–96 g-force and 714–1267 g-force, respectively. [242][3]

During the processing of raw cotton, the mechanical damage of the lint by the rotor of the working body was studied using an

[3] Sailov R.A. Researchothe of into prosess of mechanical formation of the upper part of a raw cotton bundle // - Kharkov: Easten-European journal of enterprise technologies enterprise – 2017. № 4/1 (88), – s. 56-62.

experimental setup.

The results of the mechanical damage to the lint caused by the rotor of the working body are presented in Table 1.

Table 1

The effect of the rotor of the working body on the mechanical damage to the lint

Density ρ, kg/m³	Lint damaged by rotor, % (cleanliness level of rotor fingers: 2)	Lint damaged by rotor, % (cleanliness level of rotor fingers: 6)
150	0,68	1,9
200	0.9	2.4
250	1,25	3,7

As observed, when the rotor speed is 8 m/s and it interacts with cotton having densities of ρ = 150, 200, and 250 kg/m³, the working body with rotor finger cleanliness levels of 2 and 6 causes mechanical damage to the lint in the ranges of2 and 6 causes damage to the lint in the ranges of 0.68...1.9% and 1.25...3.7%, respectively.

This chapter includes a method for calculating the separating force of the feeding drums, taking into account the elasticity characteristics of raw cotton. As a result of the research, the elasticity modulus (E) of the deformed material and the stress values at the contact area in the compressed volume were calculated.

It has been determined that a high density in the cotton stack increases the adhesion force between the lint and the trash particles. Therefore, a density of 200–250 kg/m³ is recommended for stored cotton in stacks.

It has been shown that, for increasing the cleaning efficiency during processing, it is of particular importance to feed the cotton into the processing machines in equal amounts. In laboratory conditions, the first criterion for uniform feeding is considered to be the ratio of the area occupied by raw cotton on the belt (Sp) to the total area of the belt (So).

The second criterion is the filling of area Sp with a cotton mass Mp, and the third criterion is the ratio of Mp to Sp.

Thus, the criteria K_1, K_2, and K_3 can be used to evaluate the uniform feeding of cotton into processing machines.

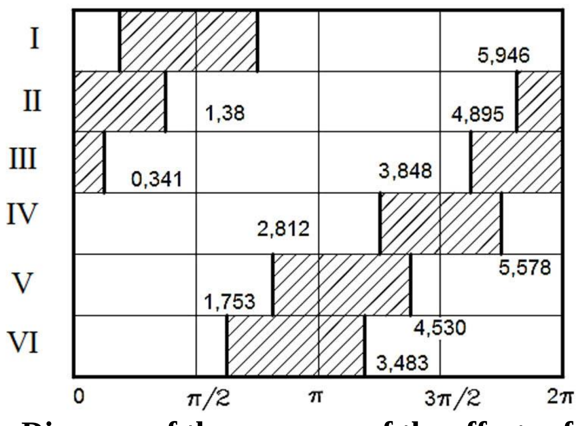
$$K_1 = \frac{S_P}{S_0} \leq 1 \; ; K_2 = \frac{M_P}{S_P} \; ; \; K_3 = \frac{M_P}{S_0} = K_M \cdot S \qquad (7)$$

As a result of such specific evaluation, it is possible to determine the mean mathematical statistical dispersion of the studied quantity.

Experimental results have shown that at a feeding speed of *n = 8 rpm* and a raw cotton density of *ρ = 72 kg/m³*, the area occupied by the cotton flow is *S = 0.54%* in louvered drums and *S = 0.808%* in fingered drums. Thus, in feeding machines equipped with fingered drums, the technological process is more efficiently supplied with raw cotton.

It has been shown that in order to evaluate the elasticity properties of cotton and the separating force, it is necessary to determine the moment of contact between the cotton and the blades. For this purpose, a cotton layer with a thickness of 170–380 mm and a width of 700 mm was compressed on a special device with a force of 3 kg, and the deformation of the cotton on the surface of the layer was investigated.

As a result of the conducted research, a diagram of the sequence of the effects of the cleaning drum blades on the cotton was constructed (Graph 11).



Graph 11. Diagram of the sequence of the effects of the drum blades on the cotton.

To improve the technological properties of cotton and to prevent damage to the seed and lint, the idea of improving the feeding mechanism of cotton processing machines has been proposed. Specifically, it is suggested to install the fingers of the feeding mechanism in an asymmetrical arrangement (Figure 3).

To study the impact of asymmetrically placed fingers on the cleaning efficiency of the machine, the following tasks have been addressed:

- The dynamics of the interaction between the feeding drum with asymmetrically placed fingers and raw cotton have been studied;
- A new feeder design has been developed to ensure the improvement of the technological properties of cotton.

As a result of analytical research conducted to determine the optimal technological parameters of the working bodies of the feeding mechanism, analytical expressions have been derived to calculate the length of the cotton layer directed from the feeding drums to the beater drums, the distance between the drums, and the cotton mass separated from the cotton layer.

$$l_1 = l_0\left[1 + c\left(\frac{v_2}{v_1} - 1\right)\left(1 - \frac{h}{l_0}\right)\right]; \qquad (9)$$

$$h = \frac{m_1}{\vartheta_1}\left[\frac{\vartheta_1}{\vartheta_0} - \left(1 - \frac{\vartheta_1}{\vartheta_0}\right)\Big/ c\left(\frac{v_2}{v_1} - 1\right)\right]; \qquad (10)$$

$$m_1 = h \cdot \vartheta_1\Big/\left[\frac{\vartheta_1}{\vartheta_0} - \left(1 - \frac{\vartheta_1}{\vartheta_0}\right)\Big/ c\left(\frac{v_0}{v_1} - 1\right)\right]; \qquad (11)$$

Here,

h – the distance between the feeding drum and the beater drum, mm;

m₁ – the mass of raw cotton separated from the cotton layer, kg;

c – coefficient accounting for the plasticity characteristics of cotton;

ε – relative deformation in the cotton layer;

w – deformation rate;

$\mathbf{v_1}$ – exit velocity of the cotton layer from the feeding drum, m/s;

$\mathbf{v_2}$ – rotational speed of the beater drum, rpm;

$\boldsymbol{\vartheta_0}$ – linear density of the layer exiting the feeding drum, g/cm;

$\boldsymbol{\vartheta_1}$ – linear density of the cotton separated from the layer, g/cm.

Based on theoretical and experimental studies, the construction of feeding machines has been improved to enhance the technological properties of raw cotton (Figures 3, 4, and 5). As a result, the cleaning efficiency of the cleaning machines has increased, and their overall efficiency has improved.

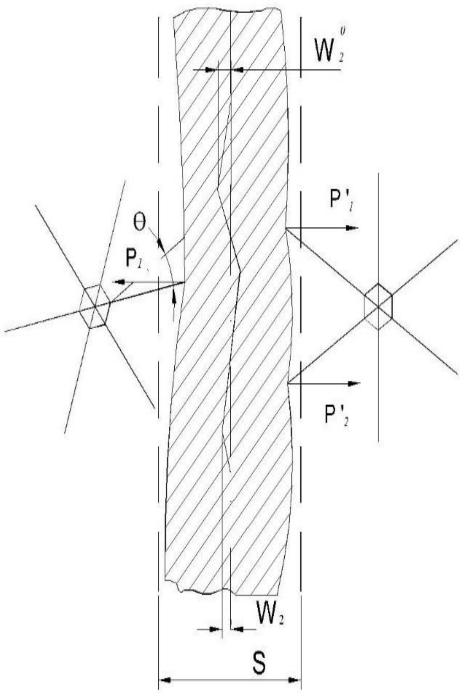


Figure 3. Schematic diagram of the asymmetrical arrangement of the feeder fingers

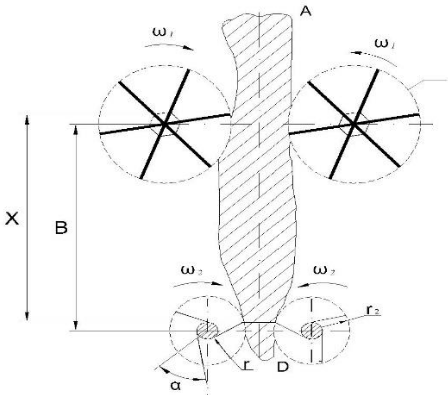


Figure 4. Diagram for calculating the technological parameters of the new feeding mechanism

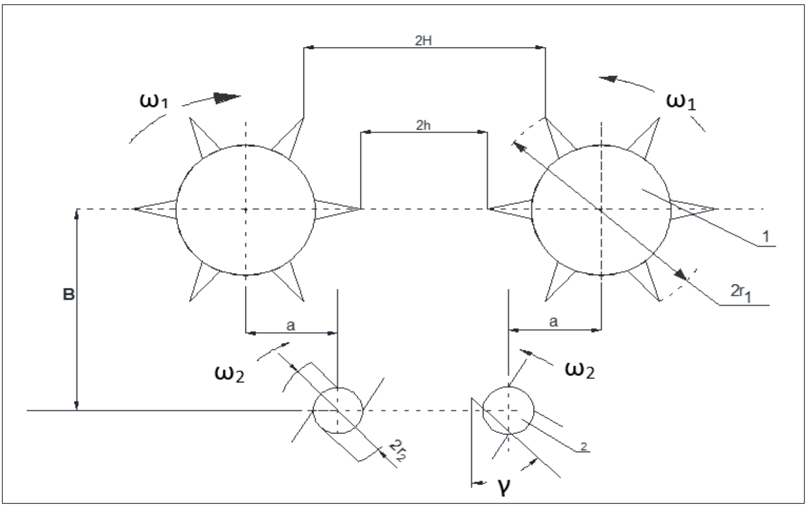
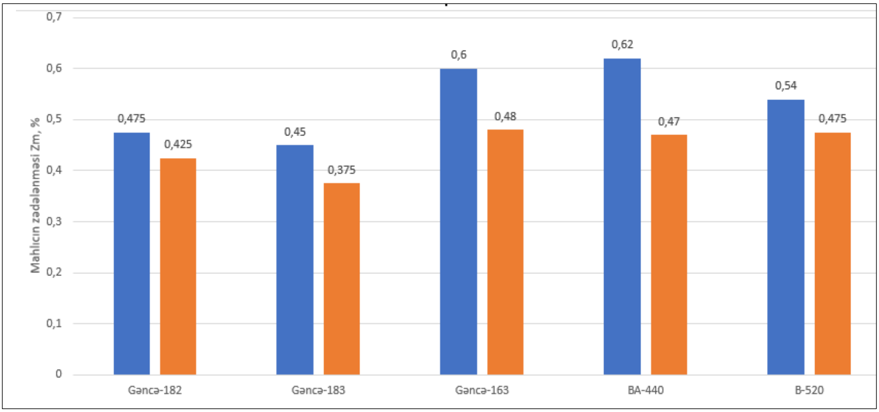


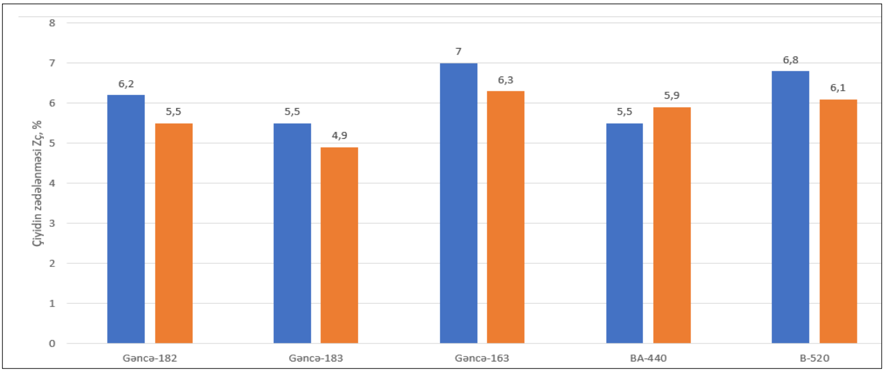
Figure 5. Diagram of the new feeding mechanism that improves the technological properties of raw cotton



Graph 12. Comparative diagram of lint damage of raw cotton from different cotton varieties.

— Damage in the new design machine, %;

— Damage in the existing cleaning machine, %.



Graph 13. Comparative diagram of seed damage of raw cotton from different cotton varieties.

— Damage in the new design machine, %;

— Damage in the existing cleaning machine, %.

The four chapter is dedicated to identifying the causes of the self-heating process of raw cotton during storage and to developing the theoretical foundations for predicting the process in advance. It has been shown that after being stacked at raw cotton procurement points, the cotton finds itself in a completely different environment. The accumulation of a large mass of cotton in a limited space changes the nature of its interactions with the surrounding environment, without altering the physical properties of the cotton. New conditions and opportunities arise for the course of biological, thermal, and chemical processes. Due to several factors, including moisture, ripeness, and the cotton's high heat retention capacity, self-heating occurs. The respiration of the seed is an energy source for various processes that can take place in raw cotton. Plants breathe only through individual cells. The process of cellular respiration involves the oxidation of organic compounds, resulting in the release of water and acid, accompanied by the release of heat [140][4].

The composition of the unripe raw cotton seed includes a lot of water, soluble carbohydrates, and nitrogen compounds. As the seed matures, the amount of water and soluble substances decreases. The proportion of insoluble components such as starch, proteins, and fats increases. As a result, the seed hardens. The maturation of the seed is accompanied by the formation of new and preserved cells. In oil-producing plants, the fat percentage in the seeds increases, while the amount of carbohydrates decreases. The reduced carbohydrates are consumed in the biosynthesis of fats during bioprocesses.

Various changes occur in the composition of the seed, and through biochemical processes, energy is obtained from internal resources. These changes occur through exothermic reactions, whereby complex bio-organic compounds are broken down into simpler compounds. These simpler compounds are converted into acids in the presence or absence of oxygen. Glucose serves as the primary material for the acidification process. The acidification reaction of glucose occurs through the hydrogen present in the air.

The respiration process ends with the production of gas and water, accompanied by heat release as a result of the reaction. In the absence

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[4] Michurin I.V. Seeds, Their Life and Preservation Before Sowing / I.V. Michurin, – Moscow: 1 M – OGIZ, – 1984. – 125 pages.

of hydrogen, the respiration process becomes anaerobic (similar to alcoholic fermentation). The acidification of glucose results in the formation of ethyl alcohol, carbon dioxide, and heat. A part of the released heat is used in intracellular processes. The remaining part is released externally. The release of gas externally causes the self-heating process in the raw cotton mass.

The causes of the self-heating process in the raw cotton mass include its high heat retention capacity, lack of air exchange, and uneven distribution of moisture in the raw cotton mass.

It is known that the biological activity of the cotton seed is an inertial biological process accompanied by heat release. The variability in ripeness determines the intensity of this process. The main indicator of the self-heating process is the heat released by the active biological environment, and the mathematical model of the process can be expressed by a non-linear kinetic equation:

$$c\rho \frac{\partial U}{\partial t} = \Delta(\lambda U) + f(U) - V_0 \frac{\partial u}{\partial x} \cdot \rho c \quad (12)$$

Where V_0 is the rate of heat spread in the cotton mass during self-heating, in m/hour.

Equation (12) expresses not the self-heating process itself, but only the heat loss. To ensure the development of the process, a nonlinear term must be added to the equation:

$$C\rho \frac{\partial u}{\partial t} = \Delta (\lambda U) - h (U - U o) + h_1 (U - Uo)^2 - V_0 \frac{\partial U}{\partial x} \cdot \rho \cdot c \quad (13)$$

Analytical studies have shown that there is an active zone propagating at speed V_0 in the self-heating process. Based on experimental research, a specific mathematical model of raw cotton heating has been developed, and an empirical formula has been derived to express the thermal-physical properties.

$$\lambda = [4 \cdot 10^{-2} + 4 \cdot 10^{-4} \cdot V + 1.1 \cdot 10^{-4} \cdot p + 10^{-2} \cdot 0.11 \{7\ \%-w\}] \quad (14)$$

Where **λ-** is the thermal conductivity coefficient of raw cotton, in kcal/m·hour.

Thus, based on analytical and experimental studies, a nonlinear differential equation was obtained to describe the heat distribution in the self-heating process of raw cotton. The center of the stack was taken as the starting point for the coordinates of the heating source, and the mathematical equation for heat distribution was derived. It has been shown that determining the heating source is of great practical importance for preventing the self-heating process in the cotton mass and increasing the effectiveness of preventive measures. Therefore, the classical theory of heat transfer—Fourier's law—was used to solve this problem:

$$\rho c U_t = \vec{\Delta}(\lambda \vec{\Delta})U + F(\vec{x}, t) \qquad (15)$$

Where $F(\vec{x},t)$ is the amount of heat released during the self-heating of raw cotton per unit volume in unit time.

Experimental research shows that as the temperature of the environment increases, the function F also increases. Expanding the function $F = F(\vec{x},t)$ around the point $U = U_0$ using Taylor series, we obtain the first linear approximation:

$$F = \beta (U - U_0) \qquad (16)$$

Where U_0 is the temperature at which the given area absorbs or emits heat.

By adding the Heaviside function $\Theta = \Theta(U^* - U)$, we can express it as:

$$F = \beta\, \Theta(U^* - U)(U - U_0) \qquad (17)$$

Equation (17) expresses heat release when heat absorption is equal to zero. The self-heating process is fully expressed by the following equation:

$$F = \beta\, \Theta(U^* - U)(U - U_0) - \gamma\, \Theta(U - U^*)(U - U_0) \qquad (18)$$

Where γ is the heat absorption coefficient analogous to the heat release coefficient, with $\beta > \gamma$.

As a result of the conducted analytical research, it was determined that the duration of the self-heating process of raw cotton is inversely proportional to the average temperature of the heating. When the heating process occurs at different points, the temperature inside the stack differs from the temperature at the outer edge of the raw cotton, depending on the temperature separation and absorption coefficients.

It has been established that, with the consideration of the dependence of the self-heating process on factors such as moisture, contamination, and other internal and external influences, the geometric dimensions of the heating source can be determined.

The purpose of the experiments to determine the heat release coefficient was to determine the impact of the dimensions of the stack on the temperature change. For this purpose, experimental stacks were made in the shape of cubes with the following dimensions: 1500 x 1500 x 1500 mm, 1000 x 1000 x 1000 mm, and 750 x 750 x 750 mm.

In the experiments, BA-440 selected cotton of the second type with 14% humidity was used. The cotton had 8.0% contamination and a density of 1050 N/m^3. The humid cotton was placed in the center of the experimental stack.

The studies showed that as the mass and dimensions of the experimental stacks increased, the temperature of the cotton also increased. The center of the cotton mass in the stack was taken as the starting point for the self-heating process. It was determined that the process was more intense when the heating source in the center of the cotton mass had an elliptical shape. The ratio of the minor and major diameters of the ellipse ranged between 1.6 and 1.8. The temperature in the cotton stack was measured using special thermocouples, and the ambient temperature ranged from 16-27°C.

To determine the self-heating coefficient, the thermal conductivity coefficient of cotton was used ($\alpha = 12.3 \cdot 10^{-3}$ m^2/hour). After determining the value of the β coefficient, further research can be conducted on larger macrovolumes. In real conditions, when the heat absorption coefficient $\gamma \neq 0$, external factors must also be considered.

Thus, in solving the heat-physical problems at hand, it is necessary to take into account the non-linearity of the thermal conductivity coefficient, properly choose boundary conditions, and functions. The transition from the point self-heating process to a broader area occurs due to the change in boundary conditions. As the temperature increases, the duration of the heating source decreases, and sufficient time is created for the heat to be released from the cotton mass.

It has been established through experiments that, after a certain geometric size of the cotton stack is reached, the temperature inside the stack increases rapidly. In smaller volumes, however, the intensity of heating decreases. Therefore, under certain conditions, it is possible to control the duration and intensity of the self-heating process.

It has been found that there are three possible scenarios during the heating process: the temperature may increase, remain almost unchanged, or gradually decrease. By applying a mathematical model and knowing the coefficients β and γ, as well as boundary conditions, it is possible to predict the self-heating process based on the values of β and α coefficients, according to analytical studies.

Therefore, special experiments were conducted under laboratory conditions to study the changes that occur during the storage of raw cotton. The density for cotton storage was varied between 800 and 1400 N/m^3, and the temperature was varied between 50°C and 55°C. In order to simulate the cotton storage process, the relationship between cotton volume density, humidity, contamination, and type with the rate of temperature increase was studied using modern equipment. Through experiments, the relationships between moisture, strength, temperature, and type changes in cotton, fiber, and seeds were analyzed. In accordance with the requirements of statistical analysis, the experiments were conducted 5-8 times with a 0.95% accuracy.

Based on the analytical and experimental results, the following conclusions can be made:

- The self-heating process is more intense when the volume density of cotton exceeds 1800-2000 N/m^3.
- As the temperature increases inside the cotton mass, the number of parasites in the cotton increases due to chemical and biological processes.
- The deterioration of the fiber quality in the cotton stack is not always related to the rise in temperature.

It has been shown that one of the key factors affecting the initial processing of raw cotton is its storage conditions. Therefore, by creating a model of the stack, it is of great importance to study the factors that affect the quality of raw cotton during storage by simulating the processes occurring in the stack.

These factors include the maturity of raw cotton after harvesting, changes in its physical-mechanical properties, and the opportunities for comparative analysis. In the creation of the model, factors such as the storage conditions of cotton, stack density in the bunk, height of the stack, temperature changes in the stack, the system’s heat retention capacity, air permeability, heat transfer, etc., must be considered.

According to the conducted studies, in the lower layers of the stack, the density of cotton is ρ = 3000-3500 N/m³, and in the upper layers, it is ρ = 800-1100 N/m³. The amount of cotton with this density was determined in the model.

For the research, BA-440 variety cotton with 6-7% contamination and 10% humidity was used. In the model, depending on the height, the density was ρ = 3200 N/m³ in the lower layer, ρ = 2200 N/m³ in the middle layer, and ρ = 1500 N/m³ in the upper layer. To create the stack model and achieve the desired density, a small mechanical press was used. The dimensions of the press compression chamber were 500 x 350 x 300 mm.

During the experiments, the temperature of the raw cotton in both the stack and the model was measured. According to the sample collection scheme, the containers were stacked in small stack shapes, and the raw cotton was covered with a tarpaulin to isolate it from the environment.

After the experiments, samples were taken from different points for analysis. The quality indicators of the samples were determined in accordance with the requirements of State Standards.

To plan a full factorial experiment, a 3-factor matrix was applied. The input factors were: x_1 - the density of the raw cotton in the stack and container, x_2 - storage time, x_3 - the moisture content of the raw cotton. The moisture factor was controlled but not managed. The research parameters were: y_1 - the breaking length of the fiber, y_2 - the oil content of the seed, y_3 - seed yield percentage. The planning of the research was based on the short duration of the harvest period and the long processing time of the results.

By analyzing the results of the studies, we obtain a regression equation that expresses the change in the parameters.

$$y_1=4.05-0.094x_1$$

$$y_2=83.06+3.94x_2-3.06x_1x_2+1.56x_2x_3-0.81x_2x_3-0.81x_1x_2x_3 \qquad (19)$$

$$y_3=36.15+0.22x_3-0.16x_1x_2$$

The Fisher criterion was used to check the adequacy of the model, which confirmed its validity. The regression analysis shows that $\mathbf{y_1}$ is significantly affected only by $\mathbf{x_1}$, the density of the raw cotton. As the density of the raw cotton in the stack increases, the strength of the fiber decreases. This is explained by the fact that when the cotton is stored at a density higher than 3000 N/m³, its breaking length changes. Referring to the studies, it can be said that an increase in density leads to the fibers getting closer to each other, creating favorable conditions for the development of the microflora in the cotton.

Thus, the analytical and experimental studies carried out have shown that the primary cause of the self-heating process is the moisture content of the raw cotton. There are two reasons for the moisture content in raw cotton: first, the incomplete maturation of the cotton, and second, the moisture absorption from the environment once the cotton is stacked.

One of the main ways to prevent moisture absorption from the environment is by ensuring the stack has an optimal shape. It is necessary to ensure that water, which accumulates on top of the stack due to rain and snow, drains quickly. As a result of numerous studies, the optimal shape for the top part of the stack has been suggested, and a specially designed mechanism has been applied to implement this.

The fifth chapter, theoretical and practical research conducted on optimizing the storage process of cotton, considering its air, heat, and moisture permeability, is presented. It has been shown that to ensure the quality storage of raw cotton, a scientifically substantiated and efficient technology must be developed, and the parameters of the technological process must be optimized. To achieve this, the air, heat, and moisture permeability of cotton were studied both theoretically and experiment-tally. The existing technology for drawing hot air out of the stack to prevent the self-heating process resulting from the moisture in the stored cotton was analyzed.

In the experiments, the passage of air through cotton layers of various thicknesses, the air velocity, and the hourly consumption depending on the cotton layer density were determined. For the research, the second type of raw cotton was used. Cotton with a density of 1800 N/m³ was subjected to air pressure of 300, 600, 1200, and 1500 Pa, while cotton with a density of 2500 N/m³ was subjected to 550, 2000, and 2400 Pa air pressures. The experiments showed that as air passes through the raw cotton layer, the pressure decreases, and the ability of the air to pass through the layers weakens. Initially, the air permeability and pressure change significantly. As the density and pressure of the cotton increase, the resistance to air flow also increases.

Based on the results of the research, the following hypothesis can be proposed: in raw cotton of varying densities, air is a key component of the “raw cotton mass” system. From this perspective, the decrease in the air pressure applied to the cotton mass can be considered a process where the energy is spent overcoming the resistance of the components interacting with the raw cotton's mass. To substantiate this hypothesis, the process of air passage through raw cotton with varying densities was studied through experiments.

The research findings show that even with the lowest density of raw cotton, the “air-cotton system” is not open for air flow. Studying the passage of air flow through the “air-cotton” system in different conditions is of special importance.

The optimized parameter for the experiments was the pressure of the air flow passing through the raw cotton mass (Y). The influencing factors were X_1 – the bulk density of raw cotton (700-2200 N/m^3), X_2 – air pressure (500-2500 Pa), and X_3 – the thickness (height) of the cotton layer (0.1-1.0 m). Based on the experimental methodology, air was passed through raw cotton masses of different densities. The initial air pressure and the change in air pressure when passing through various thicknesses of raw cotton were measured using pneumological transducers and a Pitot tube.

It was determined that as air passes through the cotton layer, the air flow pressure decreases, and the ability of the air to pass through the layer weakens. Initially, the air permeability and pressure change significantly. As the cotton density increases, the resistance to air flow increases.

It has been shown that the air within the raw cotton mass of varying densities is a key component of the “air-cotton mass” system. Even at the lowest density of cotton, the air-cotton system is not open to air flow.

To study the resistance of the system to air flow, specific experiments were conducted. In these experiments, the output parameter was the pressure of the air flow passing through the cotton mass (y), with the process parameters being: X1 – bulk density of the raw cotton, X2 – air pressure applied to the raw cotton mass, and X3 – thickness of the raw cotton layer.

Based on the results of the experiments, the following regression equation was derived for the resistance to air flow of cotton masses with different densities:

$$У=12,8-3,2X_1+8,0X_2 -8,6X_3 – 1,6X_1X_2+ 1,8X_1X_3- 5,4 X_2X_3+0,54X_1X_2X_3 \quad (20)$$

The resulting mathematical model shows that the reduction of aerodynamic resistance when air passes through cotton is possible under the condition that y→maxy \rightarrow \text{max}y→max.

It has been established that the largest pressure drop occurs at the boundary layers of the system at the beginning of the process. For example, when the cotton layer thickness is 0.1 m, the pressure drops by 95-96% relative to the initial value. To determine the dependence of aerodynamic resistance on the cotton layer thickness, a mathematical analysis of the research results was conducted using the least squares method.

An empirical expression was obtained to characterize the effect of cotton layer thickness on its air permeability. It was found that in freely dropped cotton (density of 70-80 kg/m^3), the pressure drop is 95%. The change in the direction of the air flow does not affect the value of aerodynamic resistance. To determine the dependence of aerodynamic resistance on the sample's density, the least squares method was used, and a functional dependence was established.

By analyzing the obtained results, the maximum and minimum density ranges of the module can be identified. It should be noted that raw cotton practically does not allow air flow at a density of 2700 N/m^3. To study the influence of complex factors on the air flow through raw cotton, the optimization of parameters is necessary.

As the output parameter, the pressure of the air at the exit of the cotton module (y) was taken, with the free factors being the pressure (X1) in the range of 1013–10130 Pa and the density of cotton (X2) in the range of 500–2200 N/m^3. Based on the mathematical analysis of the experiments, the regression equation characterizing the air flow passing through the module was derived:

$$У =24,9-6,9 X_1-21,8X_2- 5,4 X_1X_2 \quad (21)$$

It has been determined that to intensify the air exchange process in the cotton mass, the density of the cotton mass must be reduced, and the pressure of the air flow must be increased. The combined effect of these factors allows for the aerodynamic resistance of the cotton mass to be controlled as a process. For this purpose, special research has been conducted to assess the air permeability of cotton masses with varying densities, by regulating the speed and consumption of air flow under production conditions.

The methodology of the research involves passing air flow with pre-determined parameters through cotton masses of varying densities, stacked in cubic modules. Unlike previous experiments, this study also examines the air permeability of cotton at different horizontal heights, air flow pressure, cotton density, air consumption, and air speed.

The research material used was second-grade 3038 variety cotton. In the first phase, air flows with pressures of 300, 600, 1130, and 1500 Pa were passed through a cotton mass with a density of 1800 N/m^3. In the second phase, air flows with pressures of 480, 1400, and 2590 Pa were passed through a cotton mass with a density of 2500 N/m^3.

It has been found that the air flow passing through the cotton mass at different heights and densities loses speed. In the initial stage, the pressure of the air flow sharply decreases at the upper part of the module. Analysis of the obtained results suggests that cotton can be characterized as a material with significant aerodynamic resistance, depending on its density.

To direct the results of the theoretical research on the air permeability of cotton towards solving technological problems, it is necessary to correlate the heat exchange processes in cotton masses stacked in modules under various air conditions. For this purpose, the conditions for modeling the heating process of raw cotton mass have been determined as follows:

1. The fibrous mass consists of two components: a) The mass of the pulp that forms the “solid matrix” has a specific porosity (f) and Young's modulus (k). b) The air filling the pores of the “matrix” and each component of the cotton have distinct mechanical and heat-physical properties; in other words, the fibrous mass consists of two mixtures that differ in their physical-mechanical properties.

2. Each component undergoes deformation separately.
3. The heating of each component occurs due to heat displacement within the component and heat exchange between the components.

Taking these conditions into account, the heat conduction equation for the “cotton mass–air” system can be written as follows:

$$\rho_1(1-f)C_1\frac{\partial T_1}{\partial t} = k_1\frac{\partial^2 T_1}{\partial x^2} - \rho_1(1-f)C_1\vartheta_1\frac{\partial T_1}{\partial x} - F(T_1 - T_2) \qquad (22)$$

$$\rho_2 f C_2\frac{\partial T_2}{\partial t} = k_2\frac{\partial^2 T_1}{\partial x^2} - \rho_2 f C_2\vartheta_2\frac{\partial T_2}{\partial x} - F(T_1 - T_2)$$

Here, T_1 and T_2 represent the temperatures of the matrix and air, respectively;

ρ_1, C_1, k_1, ρ_2, C_2, k_2 are the corresponding thermal-physical parameters;

f- is the porosity;

ϑ_1, ϑ_2 are the velocities of each phase;

$F(T_1 - T_2)$ is a function that characterizes the heat exchange between the components.

To model the heating process of the fibrous mass in various cases, we examine the possibilities of using equation (22) and determine the temperatures of the matrix and air. For this, we accept the following conditions:

- The fibrous mass is subjected to external influence: when the cotton mass is compressed, intensive heat transfer occurs between the fibrous mass and the heat carrier; when the external influence stops, heat transfer occurs at the constant temperature of the heat carrier.
- In each stage, the heat transfer coefficient between the cotton mass and air is considered a constant value.
- When using equation (22), it is assumed that each stage is short-term.

$T=T_1(t)$; $T=T_2(t)$;

$\frac{dT_1}{dx} = 0$; $\frac{d^2T_1}{dx^2}=0$; $\frac{dT_2}{dx}=0$ $\frac{d^2T_2}{dx^2}=0$ if we accept, then

The equation (22) can be written as follows:

- For the compression process observed with intensive heat transfer.

$$\rho_1(1-f)C_1\frac{dT_1}{dt} = -h(T_1 - T_2) \qquad (23)$$

When $0<t<t_0$

$$\rho_2 f C_2 \frac{\sigma T_2}{\sigma t} = h(T_2 - T_1) \tag{24}$$

Here, t_0- is the compression duration.

For the discharge process.

$$\rho_1 (1-f) C_1 \frac{dT_1}{dt} = -h(T_1 - T_2) \tag{25}$$

When $t_0 < t < t_1$, $T_2 = T_1$

Thus, the temperature of the cotton mass rises to the temperature of the heat carrier. At the same time, the temperature of the air is restored to the initial temperature due to the heat coming from the outside. This process continues until the temperature of the cotton mass equalizes with the temperature of the air. Once the temperatures are equalized, the “compression-expansion” cycle practically does not affect the temperature change of either component.

Thus, the results of theoretical and experimental studies have proven that the main factor in heating and cooling the cotton mass through air flow is the density of the cotton mass.The investigation of factors affecting the heat and air permeability of cotton mass and experimental research have shown that when mechanical vibrations are applied to the cotton mass, its drying time is significantly reduced.

It has been shown that the initial processing of cotton is highly sensitive to the material’s moisture content. Even slight changes in moisture during processing significantly affect the quality of the fiber and seed. Therefore, studying the analytical dependencies of the drying process kinetics is of great importance. The kinetics of the drying process refers to the change in average moisture content and average temperature over time. The laws of the drying process kinetics allow us to calculate the amount of moisture evaporated from the material and the heat consumption during drying.

To determine the drying kinetics of raw cotton, the applicability of the drying rate method proposed by Q.K. Filonenko has been considered. It should be noted that in this method, raw cotton is considered a uniform material. Kinetic equations are not used to describe the drying kinetics of fibers and seeds [188][5].

To determine the parameters involved in the kinetic equations, the graph-analytic method proposed by L.V. Likov is used. However, this method leads to errors and significant difficulties in calculations. To describe the entire drying process of raw cotton, it is more appropriate to use a generalized kinetic equation that includes both the constant and falling drying rate periods.

Thus, the next theoretical studies have covered the following:

1. The construction of kinetic curves and kinetic equations during the heating period.
2. Determining the drying kinetics of raw cotton and its components.
3. Developing new methods for calculating the drying kinetics of raw cotton and its components based on unified generalized equations.
4. Development of analytical methods for determining the parameters included in kinetic equations.
5. Derivation of empirical formulas for calculating the heat-physical coefficients based on the initial indicators of the cotton mass stored in the bales.

Thus, to determine the relationship between drying rate and moisture in the drying process of raw cotton and its components, the following known equation can be used:

$$\frac{\mathrm{d}w}{\mathrm{d}\tau} = \mathrm{k}(\mathrm{W_c} - \mathrm{W_t})^{\mathrm{m}}\ ; \mathrm{W}/_{\tau=0} = \mathrm{W_b}$$

Where W_c, W_b, W_t, are the current, initial, and equilibrium moisture content, respectively.

To use this known equation, the constant mmm must be determined experimentally. Based on the conducted experiments, the values of the constant mmm were found as follows:

$$\mathrm{m} = \begin{cases} 2 - \text{seed cotton} \\ 3 - \textit{raw cotton} \\ 4 - \text{fiber} \end{cases} \tag{26}$$

After determining the constant m experimentally and the drying coefficient k analytically, the following formulas for the drying rate of

[5] Filonenko G.K. Drying of Food Plant Materials / G.K. Filonenko, – Moscow: 1992. – 327 pages.

raw cotton and its components are obtained:

$$g_{x.p} = -\frac{dW_{x/p}}{d\tau} = k_{x.p}\left[\frac{W_b - W_t}{1 + k_{x.p}(W_b - W_t)\cdot\tau}\right]^2$$

$$g_m = -\frac{dW_m}{d\tau} = k_m\left[\frac{W_b - W_t}{1 + k_{\frac{x}{p}}(W_b - W_t)^2\cdot\tau}\right]^2 \qquad (27)$$

$$g_ç = -\frac{dW_ç}{d\tau} = k_ç(W_b - W_t)\exp(-k_ç\tau)$$

Where $k_{x.p}$,, k_m and $k_ç$ are the drying coefficients for cotton, mahlıc, and seed, respectively.

It should be noted that the proposed method for determining the parameters of the kinetic equations can also be used to determine the drying kinetics of other moist materials.

The analysis of the conducted theoretical and experimental studies has shown that the proposed method and equations for calculating the drying kinetics of raw cotton and its components adequately express the moisture exchange in raw cotton.

The sixth chapter is dedicated to the methods, technologies, and technical means for ensuring the quality of raw cotton during storage, as well as the measures for implementing them in production.

According to the existing technological regulations, raw cotton with a moisture content of less than 18% is not subjected to any preventive measures before storage. The proposed method involves heating the raw cotton mass to a temperature of 45-55°C, drying the moisture on the surface of the cotton mass, and then cooling it down to the surrounding temperature. The initial heating operation should be carried out with a heat carrier at a temperature of 100-150°C, which is the accepted static condition for raw cotton in practice. The new method ensures the drying of the moisture on the surface of the cotton without heating the seeds of the raw cotton.

The difference between the proposed method and the existing method (i.e., drying raw cotton in drum dryers at 250-280°C) is that, in the new method, the opposite flows of moisture transfer and thermal moisture transfer currents are eliminated. The first current directs from the inner layers of the material to the outside, creating moisture outflow, while the second current is directed from the outside to the inside, driven by the resulting temperature gradient.

Since raw cotton is a multi-component material with various structures, the time spent on its initial heating is longer than the time spent in drum dryers. During this time, the different moisture levels within the raw cotton mass are evenly distributed and balanced among the components. In the proposed method, during the initial heating of the raw cotton, the moisture is distributed among the components of the cotton mass, which results in an intensification of the drying process.

During drying in the drum dryer, a low-temperature (100-150°C) heat carrier is used. 40-50% of the energy of the drying agent is consumed during this operation. Practically, the temperature gradient in raw cotton is at its minimum level. The moisture is directed from the inside to the outside, leading to the drying of the raw cotton.

The proposed method ensures the efficient drying of raw cotton without compromising its quality. One of the advantages of the method is that during the drying process, the cotton seed does not overheat and maintains its viability. According to the research by B.C. Fyodorov and F.M. Mayer, cotton seeds retain their viability when heated up to 55-60°C [186][6].

The proposed method can be implemented in cotton warehouses and special storage areas. For this purpose, cotton storage platforms with air channels, 2CB-10 brand dryers for drying pre-heated cotton, and СЧ-02 brand cleaners can be used. The proposed method can currently be implemented with the help of machines and mechanisms used in cotton cleaning factories in the following sequence:

The supplied raw cotton is gathered in a storage platform with special channels. The raw cotton, freely placed, is heated with warm air at 100-110°C for 3-4 hours, resulting in the cold air mass between the cotton fibers being compressed and removed as the raw cotton is heated to a certain temperature. The cotton is then moved to the drying

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[6] Fedorov V.S. The Study of Cotton and Its Primary Processing / V.S. Fedorov, – Moscow: MashGAZ, – 1999. – 126 pages.

drum using transport mechanisms. In the drying drum, the raw cotton is mixed, softened, and dried using a heat carrier at a temperature of 100-150°C. The temperature of the heat carrier is sufficient to remove the loosely bound moisture on the surface of the raw cotton and the seeds. An analysis of the raw cotton drying process using the new method has shown that the amount of moisture released is much higher than the amount released during conventional convective drying.

The temperature of the heat carrier drops to the raw cotton temperature in 2.0-2.5 minutes. The dry raw cotton is then transferred from the drying drum to the cleaner. During the transfer, the temperature of the raw cotton starts to decrease. The temperature decreases rapidly in the cleaner. The high-moisture air in the raw cotton mass is replaced by dry air.

As the moisture release process continues, the cooling of the seeds occurs three times faster than their heating. It has been determined that during the drying of raw cotton with the new method, the amount of moisture released increases by 2.0-2.5 times, while the energy consumption decreases by 30-35%. The product loss is reduced by 0.5-1.0%, and the quality of the cotton increases by 4-5%. After the drying process is completed, the raw cotton can either be processed according to the plan or stored in the storage platforms.

The implementation of the proposed new method and technological tools not only ensures the preservation of raw cotton without loss of quality but also eliminates the need for preventive measures such as digging tunnels in the cotton stacks (tayas), extracting air, or periodically opening and closing tarpaulins to improve air exchange within the stack.

As a result of extensive theoretical and experimental studies, a new technological regulation has been developed to ensure the safe storage of raw cotton without loss of quality.

According to the existing technological regulation, if the initial signs of self-heating are detected in raw cotton stored in a stack, hot air is extracted through a tunnel. However, the approach in the newly proposed technology is completely different.

In the new method, when the raw cotton starts to be stacked into a taya and the height of the stack reaches 1.0–1.5 meters, hot air is introduced through special channels to heat the cotton mass to 45–55°C, after which the dried cotton is cooled down to ambient temperature. During drying, the temperature of the heat carrier should be 100–150°C to avoid excessive heating of the cotton seeds.

Technical and technological developments aimed at improving the procurement, storage, and initial processing of raw cotton have been tested under industrial conditions. At this stage, experimental trials were conducted in both standard and newly designed stacking platforms (bunt areas) to test a cotton aeration technology and a mechanism for mechanizing the stacking of raw cotton, both based on theoretical and experimental research results.

The proposed technology includes:

- Mechanized stacking of cotton into stacks or special storage areas;
- Installation of air channels for hot air flow;
- Laying of special air ducts from heating units in drying-cleaning facilities to the stacking platforms;
- In cases where drying-cleaning units are absent, the installation of heating radiators.

In the stacks and special warehouses, the air transmission channels are placed below ground level, under the floor. Mechanical stacking ensures uniform density between the layers, and since cotton is freely poured into special warehouses, density remains nearly equal throughout the space.

To allow free air inflow into the stack, the air channels should be covered with metal sheets in such a way that no more than 40–45% of the channel surface is obstructed. Central air channels can consist of steel pipes with a diameter of 40–45 cm or concrete channels with iron sheet coverings.

The raw cotton storage technology begins from the moment of acceptance. The acceptance is carried out using conveying mechanisms (ХПП+КЛП-650 +rotor distributor). When the thickness of the cotton layer reaches 1000–1200 mm, hot air at a temperature of 50–60°C is blown into the stack for 3–4 hours depending on the moisture content of the raw cotton. During this time, the surface free moisture of the raw cotton evaporates. Blowing hot air does not adversely affect the quality of the cotton or its components.

The total height of the stack may reach 6–7 meters, with a total raw cotton weight of about 180–190 tons.

To confirm the theoretical studies, experiments were conducted using raw cotton with varying moisture content stored in warehouses and stacking areas (bunt platforms). The initial experiment was carried out with raw cotton loosely stored in a warehouse. The cotton had a moisture content of 12.1%, a stacking height of 3 meters, and an average density of 870 N/m^3. During the experiments, hot air was applied for 2 hours, followed by cold air for 1 hour.

In addition, experiments continued using raw cotton that had been stacked and slightly compressed in bunt platforms.

1. In the first experiment, the raw cotton had a moisture content of 10.1%, a stacking height of 1.7 meters, and a density of 850 N/m^3. The experiment lasted 5 hours, with hot air applied for 3 hours, followed by cold air for 2 hours.
2. In the second experiment, the raw cotton had a moisture content of 10.6%, a stacking height of 2.0 meters, and a density of 881 N/m^3. The experiment lasted 6 hours, with hot air applied for 4 hours and cold air for 2 hours.
3. In the third experiment, the cotton's moisture content was 11.1%, stacking height 1.5 meters, and density 730 N/m^3. The experiment lasted 5 hours, with 4 hours of hot air and 1 hour of cold air.
4. In the fourth experiment, the moisture content was 12.5%, stacking height 1.2 meters, and density 750 N/m^3. The experiment lasted 6 hours, with 5 hours of hot air and 1 hour of dry air applied.

During the experiments, the air permeability of the raw cotton stack was studied. For this purpose, air parameters were measured using a manometer at different heights of the stack and along the length of the air channel — at the beginning, middle, and end. The results of the studies were presented in graphical form. Since the results of measurements at different points were similar, the graphs were constructed using average values.

From the graph, it can be seen that pressure drop, which indicates air permeability in the stack, reaches 80% at a height of 2 meters.

The results obtained through these experiments were also verified under laboratory conditions. For this purpose, raw cotton of various moisture levels, types, and densities stored in stacks and special warehouses was dried using the new technology and then stored for three months.

For comparison, raw cotton was also stored using the current technology over the same period. Afterward, both batches of cotton were processed. During processing, samples of lint and cottonseed were taken every hour to evaluate quantitative and qualitative characteristics.

The quality indicators of the lint obtained from raw cotton stored using the new technology were determined using organoleptic and mechanical methods in accordance with international standards. As a precise method, the manual separation of trash was used. Although somewhat challenging, this method is widely applied in Central Asia and Azerbaijan. It was developed by the Central Cotton Research Institute.

According to this method, when determining the trash content in lint:

- A 10 g sample is taken from lower-grade raw cotton,
- A 50 g sample is taken from higher-grade raw cotton.

The selected sample is manually sorted, and the separated trash mass is weighed on a precise electronic scale.

In the mechanical method, to determine the amount of trash in lint, a 100 g sample is taken and passed twice through an AX-2 analyzer.

In foreign countries, to determine the trash content in lint, an automated measurement system known as AFIS (Advanced Fibre Information System) is used. This system is produced by the Zellweger Uster company.

The AFIS system determines the following characteristics of lint:

- AFIS N – content of neps,
- AFIS L+D – diameter and length,
- AFIS T – trash content.

A comparative analysis of experimental results with those obtained through the AFIS system showed that the application of the new technology improves the quality indicators of raw cotton, lint, and cottonseed. Additionally, the lint yield percentage increases, and the loss percentage decreases.

The obtained results fully comply with the current regulatory and technical documentation requirements.

MAIN RESULTS

1. Research was conducted on a physical model simulating the post-harvest state of raw cotton. Comparative analysis of the results showed that the experimental data closely matched practical indicators. It was determined that as the density of cotton in the bundle increases, the quality of its components—lint and seed—decreases. High density negatively affects seed germination ability and oil yield percentage [20][7].
2. As a result of the conducted research, a new technology and methodology for drying raw cotton were developed. The implementation of this new technology helps prevent the self-heating process. Theoretical aspects of the passage of the heat agent through raw cotton in accordance with Darcy's law were studied, and it was established that laminar heat flow occurs within the mass of raw cotton. Analytical expressions were derived to determine the thermal conductivity of raw cotton under various boundary conditions [25][8].
3. A new technology was developed to ensure the storage of raw cotton without quality degradation, based on moisture content and maturity indicators. This technology significantly reduces the need for preventive measures during storage and improves the quality of raw cotton and its components [40][9].
4. The machines and mechanisms proposed in the new technology were tested in both experimental and industrial conditions, and their designs were improved. Noticeable improvements in the

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[7] Sailov R.A., Vəliyev F.Ə. (2014). Study of the effect of raw cotton density on air permeability. – Baku: International Scientific-Practical Conference, pp. 352–354.

[8] Sailov R.A., Vəliyev F.Ə. (2016). Effect of air flow on the drying process in a raw cotton bundle. – Baku: Theoretical and Applied Mechanics, No. 2, pp. 45–47.

[9] Sailov R.A., Həbibov F.H. (n.d.) – Device for forming ventilation channels in cotton and hay stacks, International Patent No. 045690.

quality indicators of pre-processed raw cotton and its components were observed with the enhanced technical means [36][10].

5. As most of the procured raw cotton is subject to preventive measures during storage, a new storage technology was developed. The machines and mechanisms designed to implement this technology were successfully tested [10][11].

6. The mechanics of interaction between the blades of the feeding drum of cotton cleaning machines and raw cotton, as well as the deformation characteristics of the cotton layer, were studied. The extrema of total deformation were identified. To improve productivity, asymmetric placement of the fingers in the feeding system was proposed, and the forces acting on the fingers were evaluated [44][12].

7. It was found that when the working organ enters the cotton mass at a certain speed during processing, both internal pressure and density within the mass sharply increase, leading to damage to the lint and seed. Therefore, processed raw cotton should have minimal and uniform density. The working organs in cleaning machines—beaters and the fingers of the feeding drum—must maintain a high degree of cleanliness [32][13].

8. The results of the theoretical and experimental studies were implemented in several cotton processing plants across the country. A substantiated concept for the storage and processing of raw cotton was developed. Scientifically grounded technical and technological solutions can be used in the design of cotton processing machines and equipment. The application of the proposed technology in a plant with a production capacity of 20,000 tons can yield a techno-economic benefit in the range of 350,000 to 400,000 AZN.

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to co-authored works:

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