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MEANS OF MECHANIZATION AND TECHNOLOGIES FOR MELONS PROCESSING

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ABSTRACT

The monograph provides an overview of equipment for processing and processing technology of melons. Until recent years, the primary processing of melons has no industrial production in the CIS countries and abroad. The all-round reduction or complete elimination of the share of manual labor due to the comprehensive mechanization of technological processes is acquiring particular relevance. However, when processing such crops as melons, it is impossible to completely exclude manual labor at the current level of development of agricultural and processing equipment. This is due to the specific properties of not only the plants themselves, but also the fruits. So the technologies for harvesting and processing melons include operations traditionally performed in whole or in part by hand. The mechanical and technological foundations for the calculation and design of machines for processing the fruits of melons for technical and food purposes are stated. The theoretical prerequisites for the creation of products based on melon are presented, the issues of rational use of melons for the production of long-term storage products are highlighted. Basic physical, mechanical and rheological properties of pumpkin, melon and watermelon fruits are given. Criteria equations for the processes of grinding in a closed environment, cutting, mixing are given. The proposed options for equipment and technological lines for the processing of fruits of watermelon, melon, pumpkin are presented. The technologies for processing the fruits of watermelon, pumpkin melon are described.

KEYWORDS

Watermelons, melons, pumpkin, technology, technique, processing, specifications, indicators, rheology, criterion equations.

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CIRCLE OF READERS AND SCOPE OF APPLICATION

The monograph is intended for the teaching staff and students of higher educational institutions, as well as employees of research institutes and specialists in the food and processing industry engaged in the research, development, production and sale of functional products of long-term storage from the fruits of melons. The monograph is interesting in regions where melons are grown. The monograph provides an overview of the works of domestic and foreign scientists on the development of equipment and technology for processing the fruits of melons.

INTRODUCTION

Melons (watermelon, melon, pumpkin) are of great nutritional, fodder, technical and agrotechnical importance. The products of these crops can be used both in natural form and in the form of processed products.

The fruits of melons are rich in vitamins, minerals and are very useful for human health. Melons are currently found in almost every garden plot. This is no coincidence. Moreover, the cultivation of pumpkins, zucchini, squash and melons is not particularly labor-intensive, and the plants themselves are relatively unpretentious to growing conditions, they are able to give a large yield of not only tasty, but also very useful fruits. Zucchini alone can be used to prepare all kinds of first, second and third courses.

The dietary and medicinal qualities of melons are very high. Eating them in food helps to improve the body's health, eliminate toxins and cholesterol, helps in the treatment of disorders in the gastrointestinal tract, urinary and cardiovascular systems, and normalizes metabolism.

The variety of vitamins allows pumpkin to be used as a preventive and therapeutic agent for various diseases. The refined pulp of melons can be widely used to obtain a concentrate of juice, jams, marmalades, candied fruits, the production of freeze-dried powder, baby food, puree, porridge, paste, and the rind after drying can be used to obtain pectin.

Modern agricultural production requires the solution of many problems, among which an increase in crop yields and an increase in the marketable output of high-quality products, while reducing overall costs and reducing losses, are of decisive importance. The all-round reduction or complete elimination of the share of manual labor due to the comprehensive mechanization of technological processes is acquiring particular relevance.

One of the main factors hindering the use of pumpkin in the food industry is the high labor intensity of post-harvest processing in order to obtain cleaned pulp. In this case, the issue of mechanizing the separation of seeds from pulp has not been practically resolved. The technology for removing the outer cover from the fruits of melons, as a rule, is based on the use of manual labor, since the existing constructive and technological solutions of machines for peeling fruits from rind do not provide efficient and high-quality work during the processing of melons.

To solve this problem, it is necessary, on the basis of an analysis of the features of the development of melons, to substantiate a rational technology and develop technical means for mechanizing the processes of processing pumpkin fruits for both technical and food purposes.

Not only domestic scientists, but also scientists from foreign countries are working on the problem of processing melons. The work is carried out in different directions and for different types of fruits: pumpkin (peeling, seeds, harvesting); melon (peeling, seed removal, processing of seeds for oil, etc.); watermelon (peeling, juice extraction, etc.).

Let's overview the foreign databases. For the processing of melon seeds, a peeling machine has been proposed to solve the problems associated with the peeling of melon seeds. Parameters evaluated include peeling efficiency, percentage of shelled and damaged seeds, throughput and machine productivity. The machine has been assembled and consists of a hopper, a frame, a peeling unit, trays and an engine. The peeling operation was carried out using melon seeds of three different moisture levels (6.99, 11.90 and 18.32 %) and at 2 peeling speeds of 2500 and 1500 rpm. The results obtained showed that a peeling speed of 1500 rpm and a moisture content of 18.32 % have the best peeling efficiency of 76.30 % and the lowest percentage damage to seeds of 22.60 % compared to a shelling speed of 2500 rpm and moisture content in seeds 6.99 %, which had a shelling efficiency of 70.0 % and a seed damage rate of 68.10 %. The productivity of the machine and equipment is 7.95 and 9.56 kg/h, respectively. Practical application: the built hulling machine is practically applicable for hulling melon seeds and then peeling it from chaff. This will solve a common problem associated with the processing of melon seeds, which limits their further use [1].

In the works of S. Vasilenko, M. Kopylov, A. Kairbaeva, it was deduced that the percentage of peeling for pressing oil from melon seeds is an important indicator, so when the seeds were husked and peel of husks, the oil yield was low, the machine tensed when extraction, with a percentage of 70/30 seeds and husks, the machine easily squeezed out the oil and the yield was high [2].

Also proposed is a machine for peeling melon from seeds and seedbed in whole melon. Based on the rectangular circulation diagram method, a seed melon pulping machine was designed. An improved swing cam was used for the melon feed mechanism, a 2-pin 4-channel wheel mechanism was chosen to realize the precise indexing movement of the melon saddle in the cork, and a flat bottom cam mechanism with an improved rod drive mechanism was used for the saddle lifting tool. An orthogonal experiment was carried out and the following optimal digging parameters were determined: the type of the digging tool – half-cycle, the speed of the digging tool – 240 rpm, the angle of installation of the digging tool – 15°. Repeated tests have shown that the degree of purification is more than 98 %, the degree of absence of grain seeds is more than 98 %, the degree of loss is less than 2 % and the degree of destruction is less than 1 %, respectively [3].

Marketing is conquering our lives everywhere and for the convenience of consumers, sliced fruits, freshly cut slices of watermelons and melons are offered. In [4], a machine for cutting watermelons and melons into slices is proposed for the convenience of selling in supermarkets. The machine cuts the fruits of watermelons and melons into discs, the results given in this work show that this type of cutting is convenient for consumers and, in order to preserve, is packed in a sealed package and can be stored for a week under refrigerated conditions. Improving the shelf life of freshly cut melons and watermelons is discussed in [5]. This study assessed the impact of post-harvest processing and packaging technologies on the consumer acceptability and flavor profiles of freshly cut watermelons. Changes in odor of samples stored at 3 °C were correlated with consumer sensory ratings for color, fresh appearance, firmness, aroma and taste. Freshly cut watermelon, sealed in non-perforated film and stored at 3 °C for 6 and 8 days, received the highest palatability and overall organoleptic scores compared to modified atmosphere (5 % O_2 and 10 % CO_2).

A machine for the extraction of juice from the fruit of a watermelon was proposed and designed [6]. The results of the analysis of productivity showed that the type of fruit and the condition of the rind significantly affect the yield indicators in the amount of 1 %. The percentage of juice yield from peeled and unpeeled watermelons was 89.5 % and 89.7 %, respectively. The extraction efficiency was 96.6 % for refined watermelons and 97.1 % for non-refined ones. Production losses were 2.9 % and 2.6 %, respectively. The proposed device is easy to use and maintain, so it is perfect for the needs of small fruit juice producers and can help to achieve economic efficiency for small production.

The mechanical properties of fruits and vegetables can be applied to improve the efficiency of processing equipment, including purifiers. Typically, the effectiveness of a mechanical cleaner depends on the effect of various forces on the performance of the machine. Beneficial forces such as tearing and cutting are deliberately used to peel; while unwanted forces such as impact and compression can reduce the effect of the previous forces. Unwanted exertion can also be a major cause of common problems such as bruising [7]. Knowing the mechanical properties of agricultural products will help designers apply force correctly.

Compression (force-strain) testing is used to study the mechanical behavior of fruits and vegetables for a variety of reasons:

– the force-deformation characteristics of the product in excess of the elastic limit can be used to simulate denting. Work [8] shows internal injuries in two varieties of watermelon using nonlinear models;

– the force-strain characteristics of a product within the elastic limit can also be used to predict attributes of touch texture such as maturity. Harker et al. [9, 10] showed that if the compressive force of two apples changes to 5 N, then their texture will be different;

– the mechanical properties of fruits and vegetables in various aspects, including rind, pulp and unpeeled foods, can be determined using compression tests. [11] Certain mechanical properties, including tensile strength, strength, cutting force, shear forces, and forces, are effective in designing a mechanical cutter for pumpkin varieties. Also Ohwovoriole et al. [12] investigated the mechanical properties of the cassava tuber, which will be used in the design of a mechanical knife. The properties were Poisson's ratio, shear stress, rind stress, cutting force and breaking stress for both peeled and unpeeled cassava tubers. Tensile testing can also be used for the same purposes. Recent studies have been conducted to show the accuracy of tensile tests versus compression tests [13]. Difficulty in making samples of the rind during testing and creating premature tensile failure during sample preparation of flaking. Compression tests of the rind can be carried out directly or indirectly. The latter exploits the difference in experimental results between the crude (as a whole) and the refined product [14, 15].

One publication by Harker et al. [16], which deals with the mechanical properties of melon, focuses on comparing instrumental (using puncture, shear and tensile strength) and sensory measurements of tissue strength and juiciness for some fruits and vegetables, including watermelon and cantaloupe. They studied only the cellular basis of the pulp to determine characteristics that affect sensory texture, signs of hardness and juiciness. Attempts to find any useful published data on the mechanical properties of melon varieties that could be used as a database for the design of a mechanical cleaner have been unsuccessful. The current study was carried out on three common varieties of melon, namely cantaloupe melon, honeydew melon and watermelon, with the aim of examining selected mechanical properties that will form a database for the design of peeling equipment. The mechanical properties of three common varieties of melon have been measured. These are strength, tensile strength, shear strength, maximum shear force, and cutting force. The role of the rind (%) for each property was also calculated as the relative contribution of the rind to the crude product. Rind-off resistance was statistically found to be the same ($p > 0.05$) for all grades. The same result was found for unrefined foods. The use of burst force was not recommended for peeling watermelon due to the close values of this property for peeling and unpeeled hull. The energy required for peeling all three melon varieties was determined to be 500 Nm. It is not recommended to rind melons with cutting tools [17].

The mechanical properties of three common pumpkin varieties were evaluated and statistically compared. Strength, tensile strength, shear strength and cutting strength were determined for grades Jarradale, Jap and Butternut. The study was conducted on three cases of pulp, leather and an unrefined product, ignoring the strength and breaking strength of the pulp. The relative contribution of leather to the untreated case of each property was evaluated. The grades were found statistically similar in tensile strength, toughness and maximum shear strength in the untreated cases. Also, the leather of the three grades showed the same shear strength ($p > 0.05$). The varieties Jap and Butternut showed similar values for some other properties. The maximum shear strength of the pulp-pulp, the shear strength of the untreated hull, and the relative contribution of leather to the shear strength of the untreated case were similar ($p > 0.05$) for these grades. Jarradale had no difference in pulp shear strength with the other two varieties. It was also similar ($p > 0.05$) to Yapo in the relative contribution of leather to shear strength, tear strength and toughness of the uncleaned casing [18].

In the following study, a Heavy-Weight Harvesting Robot (HWHR) was developed and evaluated. This robot consists of a robotic tractor as a mobile platform, a specially designed robotic arm for this application, a pumpkin end effector developed and a control system. The final evaluations focused on eight parameters, including workspace, system resolution, harvestable area, accuracy, repeatability, harvest success rate, cycle time, damage rate. The results showed that this robot has a harvest success rate and damage rate of 92 % and 0 %, respectively. The average cycle times in scenarios 1, 2 and 3 were 58.7, 41.9 and 35.1 s, respectively. The working space parameters of the final system, including the volume of the working space, the harvesting surface and the harvesting length, were 5.662×10^9 mm^3, 2.86×10^6 mm^2 and 800 mm, respectively, which was 70.6, 81.3 and 99 % of the required parameters in the design system, respectively. The accuracy and repeatability were 4.5 and 5.23 mm, respectively. The system resolution in the X, Y and Z directions was 1 mm, which had a tolerance of 75, 50 and 25 μm, respectively. These results indicate that the system has sufficient motion resolution, accuracy and repeatability for harvesting pumpkin. The harvest success of the HRHC system (100 %) was higher than the overall average harvest success of the previous studies between 1984 and 2012. During the experiments, no damage to the fruit was found. The result of the experiments meets certain requirements and the HRHC system, which is recognized as applicable for harvesting pumpkins in the field [19].

To automate the collection of melons, a mobile Cartesian robot has been developed, which collects melons according to previously known coordinates, the principle is based on Markov chains. Numerous experiments have proven the applicability of this robot for collecting melons [20].

Improving food quality and reducing mechanical waste in the food industry requires a comprehensive knowledge of the material's response to stress. While research has focused on the mechanical reaction of food material, post-harvest and processing waste is still quite high in both developing and developed countries.

The development and assessment of the basic model of the mechanical reaction of vegetables with a hard rind during post-harvest and processing operations is proposed in the following study [21]. The model focuses on both the tensile and compressive properties of pumpkin pulp and tissue rind, where the behavior of these tissues varies with various factors such as rheological response and cell structure. Both elastic and plastic responses of the tissue were taken into account in the modeling process, and finite elasticity was used to create the model in combination with the theory of pseudoelasticity. The results were then validated using published experimental work with pumpkin pulp and rind under uniaxial tension and compression. The governing coefficients for peeling during the tensile test were $\alpha=25.66$ and $\beta=-18.48$ MPa, and for meat $\alpha=-5.29$ and $\beta=5.27$ MPa. Under compression, the determining coefficients were $\alpha=4.74$ and $\beta=-1.71$ MPa for rind samples and $\alpha=0.76$ and $\beta=-1.86$ MPa for pulp samples. The constitutional curves accurately predicted strength values and are close to experimental values. The curves were fitted for the entire stress-strain curve, as well as for the portion of the curve up to the yield point of bioproduction. The simulation results showed good agreement with the empirical values, and the design curves are very similar to the experimental ones.

This study presents a comprehensive analysis of the available literature on the tensile properties of various food samples. The purpose of this review was to classify the available tensile test methods for crops and food materials to study the appropriate sample size and tensile test method. The results were then applied to tensile tests on pumpkin pulp and rind specimens, in particular on arc specimens with a constant loading rate of 20 mm/min^{-1}. The results showed that the maximum tensile stress of the pumpkin pulp and rind samples was 0.535 and 1.45 MPa, respectively. The modulus of elasticity of the samples of pulp and rind was 6.82 and 25.2 MPa, respectively, and the values of the modulus of destruction were 14.51 and 30.88 MPa, respectively. The results of tensile tests were used to develop a finite element model of mechanical peeling with a hard rind of vegetables [22]. This study carried out an empirical study of the mechanical properties of pumpkin rind. The test was part of an FE simulation and a simulation of the mechanical peeling step for vegetables with a tough rind. The compression test was carried out on a Japanese pumpkin variety. In addition, the stress-strain curve, bioavailability and strength of the pumpkin rind were calculated.

The energy required to reach the biological yield point was 493.75, 507.71 and 451.71 N/mm, for a feed rate of 1.25, 10 and 20 mm/min, respectively. The average value of the force at the biological yield point of pumpkin rind was 310 N [23].

There are various sources of stress that deform crop tissue, including impact, compression, and tension. Scanning Electron Microscope (SEM) is a common method of analyzing cellular changes in materials before and after these loading operations.

The article [24] investigates the structural changes in the rind and tissues of pumpkin under mechanical stress. Compression and indentation tests were performed on rind and pulp samples. Then the structure of the samples was fixed and dehydrated to capture cellular changes under SEM. The results were compared with images of normal rind and rind tissue. The findings suggest that normal pulp tissue had larger cells, while the cellular structure of the rind was smaller. Structural damage was clearly observed in the tissue structure after compression and indentation. However, the damage from the flat end indenter was much more severe than from the ball end indenter and compression tests. An integrated deformed tissue layer was observed in the compressed tissue, while indentation tests formed a deformed area under the indenter and left the rest of the tissue intact. On the walls of the hole, after the indentations at the flat ends, there was an obvious broken layer of cells, while the spherical indenter created a flattened layer around the hole. In addition, the effect of stress on the rind samples was less compared to the meat samples. Experiments have shown that the rate of tissue damage at a constant loading rate is highly dependent on the shape of the equipment. This fact and the observed structural changes after loading underscore the importance of tuning post-harvest equipment to reduce tissue damage in crops.

A review of scientific and technical information proves the relevance of the research given in the monograph. Although there are large gaps in research.

1 PHYSICO-MECHANICAL AND RHEOLOGICAL PROPERTIES OF MELON FRUITS

ABSTRACT

In this section, the structural features of the fruits of watermelon and pumpkin are given, the results of experimental studies of the physical and mechanical properties of both the fruits as a whole and their individual parts are given. Also, rheological models of fruits are given and criterion equations are obtained that can be used to determine technological parameters, both for melon pickers, where minimal damage to fruits is required, and processing machines, where it is necessary to destroy the fruit with minimal energy costs.

KEYWORDS

Watermelon, pumpkin, melon, rheology, size and mass characteristics, elasticity, modulus of elasticity, puncture, shear, stress, model of fruit.

The study of the technological process and the development of a machine, the operation of which is associated with the impact on agricultural materials, must necessarily be based on knowledge of the physical and mechanical properties of these materials. Academicians V. Goryachkin, V. Zheligovsky, G. Listopad and professor A. Gudkov pointed out this.

Much work on the study of physical and mechanical properties of gourds was carried out by I. Egorov, O. Terekhov, A. Tseplyaev, V. Abezin, P. Ovcharov, V. Fedorov, V. Maliukov, L. Chaban, S. Strekalov, E. Medvedkov, B. Erenova and others. Reference data covering the entire complex of physical and mechanical properties of melons is still scarce, and the available data are scattered and, moreover, very conditional data, which are not enough to calculate the technological process of seed extraction and substantiate the parameters of the working body for performing this operation. It is also necessary to take into account that the variety and growing conditions have a great influence on the physical and mechanical properties of melons: soil, weather conditions, cultivation technology, and so on.

1.1 STRUCTURE AND PROPERTIES OF WATERMELON

The fruit of a melon plant consists of a rind, pulp and seeds. The rind structure is complex: a single-layer epidermis is covered with a continuous cuticle, underneath is a belt of chlorophyll-bearing or colorless cells of 8–10 layers. Below this belt, the watermelon has a mechanical shell. It consists of thick-walled sclerenchyma cells with lignified walls. The shell determines the strength of the fruit (**Fig. 1.1**). Behind the shell is the rind pulp – the edible part of the fruit.

In a watermelon, the rind pulp grows together with the placenta so that it forms a monotonous edible pulp with them, in which seeds are interspersed, and there is no cavity in the fruit (**Fig. 1.2**).

The cuticle thickness of a watermelon varies slightly.

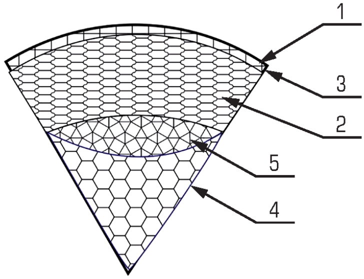


Fig. 1.1 The structure of the rind of melons: 1 – cuticle; 2 – epidermis; 3 – chlorophyll-bearing parenchyma; 4 – pulp parenchyma; 5 – mechanical shell

Fig. 1.2 Cross section of a watermelon

The epidermis of melons consists of square or elongated cells without colored contents. In a watermelon, the epidermal cells are almost square.

The epidermis of the fruit bears stomata, which are unevenly spaced. On the green stripes of the fruit, there are about 2 times less of them than on its light areas. This is explained by the fact that under the stripes there are rind vascular bundles, and most of the stomata develop in less watered areas.

The intensity of the green color of the fruit is due to the chlorophyll-bearing cells, which lie in layers (**Fig. 1.3**).

Behind the rind is the pulp of the fruit. The size of the cells of the parenchyma of the pulp of the fruit gradually increases towards its center. In parallel, their maceration occurs. The largest cells from the center of a ripe watermelon fruit reach 300–1500 microns and are visible to the naked eye.

This increase in cell size is due to the stretching of their walls from the solution of sugars in the cell sap, which increases the osmotic pressure. With a further increase in the concentration of cell juice, the cell walls break and a void forms in the watermelon (the fruit overripes).

Fig. 1.3 Types of watermelons: 1 – light-brown; 2 – bright stripe; 3 – mosaic; 4 – dark stripe

The color of the pulp in watermelons depends on the carotenoid type chromoplasts, from which some pigments turn into needle crystals.

The structure of the pulp in watermelons has crunchy properties and uniform density, only in table watermelon it is looser, juicy, and melts in the mouth [25].

Currently, 561 watermelon samples have been collected in the KazRIPWG gene pool [26]. The varieties of watermelons presented by KazRIPWG were studied: Mezhdurechensky, Krasnosemiannik, Zhetygen, Asar and Diskhim watermelon with yellow pulp. Information is given in **Table 1.1**.

Table 1.1 Varieties and yield of parts of the investigated watermelons

Watermelon variety	Mass, kg	Pulp, kg	%	Watermelon juice, l	%	Seeds, g	%	Rind, kg	%	Total
Mezhdurechensky	5.1	0.8	16.7	2.1	41.2	61	1.2	1.90	37.2	96.37
	5.3	0.8	15.9	2.0	38.7	73	1.3	2.10	39.25	95.32
	5.5	0.9	17.8	2.1	38.6	76	1.3	2.14	38.84	96.59
Krasnosemiannik	3.5	0.5	16.4	1.5	42.7	63	1.8	1.13	32.28	93.22
	5.2	0.8	16.7	2.15	41.3	80	1.5	1.80	34.61	94.25
	5.9	0.9	15.8	2.44	41.0	79	1.3	2.25	37.81	96.01
Zhetygen	6.0	0.9	16.0	2.55	42.5	80	1.3	2.10	35.00	94.88
	6.2	1.0	16.1	2.6	41.8	83	1.33	2.33	37.58	96.84
	6.5	0.9	15.2	2.7	41.6	88	1.35	2.51	38.61	96.81
Asar	8.0	1.5	19.2	3.7	46.4	128	1.6	2.18	27.21	94.48
	11.2	1.9	17.4	5.6	50.43	154	1.37	3.12	27.85	97.1
	10.3	2.0	19.9	4.8	47.08	129	1.25	2.90	28.15	96.4
Diskhim	2.7	0.7	25.9	0.7	26.3	41	1.52	1.10	40.74	94.5
	3.1	0.8	25.8	0.9	30.0	43	1.4	1.28	41.29	98.5
	3.6	1.1	30.5	0.9	27.5	47	1.3	1.35	37.50	96.5

The mechanical characteristics of the watermelon are important for the reduction of losses in the processing of the fruit, as well as for the design of the corresponding machines. For further research, watermelons with the same shape index were selected.

1.2 STRUCTURE, PROPERTIES AND RHEOLOGY OF MELONS: PUMPKINS

Pumpkin is an annual herb. The stem of the pumpkin reaches 8 m in length. At the base of the leaves, the stems are equipped with three-, five-part spirally twisted antennae. Leaves are alternate petiolate, five-lobed, toothed. The stem and leaves are covered with short, stiff hairs. The flowers are large, fragrant, dioecious, yellow. Fruit – «pumpkin» – polyspermous, obovate. Usually pumpkin varies greatly in size, shape, color. Peduncle with 5–8 scars and deep grooves. The pulp of the fruit is fibrous, yellow, with a woody rind. Seeds are flat, narrowed on one side with a pronounced groove. The seed has two shells: the upper one is dense, woody, yellowish-white in color; inner – filmy, greenish-gray. Pumpkin blooms in June-July. The fruits reach full maturity in August-October. Unknown in the wild. The homeland of the pumpkin is Mexico and the southern states of North America. The peoples inhabiting these countries have known pumpkin since time immemorial. As a garden and melon culture, it is widespread in many countries of the world. The plant contains energetic substances: fats, proteins and carbohydrates. Fatty and essential oils are found in the seeds. The fatty oil includes glycerides of linoleic, oleic, palmitic, and stearic acids; found phytosterol – cucurbitol, amino acids, resinous substances containing oxycerotinic acid, organic acids, vitamins C, B_1, carotenoids. The pumpkin pulp contains sugars (the main one is sucrose), fiber, potassium, calcium, magnesium, iron salts; trace elements: copper, cobalt, etc.; vitamins C, B_1, B_2, B_5, E and carotenoids. The leaves of the plant, in comparison with the fruits, contain significantly more vitamin C (up to 620 mg %). The flowers contain coloring agents, flavonoids and carotenoids (cryptoxacin, zeaxanthin, flavoxanthin). As a medicinal raw material in scientific medicine, seeds and pulp are used – pumpkin seed gruel, pumpkin seed decoction, pumpkin seed emulsion, pumpkin powder, pumpkin seed emulsion, pumpkin powder. These drugs are used to expel tapeworms – bovine, pork and dwarf tapeworms, broad tapeworm, etc. In terms of activity, pumpkin preparations are inferior to those of male fern, but they do not have a toxic effect on the body. Therefore, they are prescribed primarily to sick children and in old age, as well as to people who have had serious illnesses [27].

The pulp of pumpkin fruits is denser than that of watermelon and melon, as it contains 3…4 times more fiber and hemicellulose in comparison with them. The structure of the pulp of pumpkin fruits depends on the thickness of its cell walls and has a highly porous structure and a more developed coarse supply system. Nutrition of the rind part of the pulp of the fruit is carried out with the help of the peripheral system – the so-called vessels of the rind ring, and when it matures, light stripes appear above the vascular bundles. In pumpkin, the pulp is sharply separated from the placenta with the seeds (seed sac) in the fruit cavity (**Fig. 1.4**).

Fig. 1.4 Longitudinal section of the seed sac

The structure of the placenta in cross section resembles the letter «Z» in position with its open side towards the center of the fruit. Placentas are most often 4 (sometimes 3 and 5), they are located vertically from the stalk to the flower end of the fruit. The seed sac consists of a plexus of feeding vessels. Previously, these vessels were fed by the lobes of the stigma of the flower, so they are located from the peduncle to the receptacle, near which they are joined by the ends of the branches. The seeds are located on a branched system of vessels, in such a way that each seed is connected by a spout to a feeding vessel. The plexus of these vessels is the main skeleton of the placental pulp of the fruit.

In the study of the seed sac, such a pattern was revealed that in fruits of a smaller size, there is practically no overlap of seeds due to their small number, and in larger fruits, the seeds are located with an overlap, which varies widely and can reach 5 mm, since the number of seeds increases, and the dimensions of the seed sac in the cross section remain practically unchanged. The thickness of the interlayers between the seeds also depends on the size of the fruit and ranges from 0.2 to 1 mm.

1.2.1 DIMENSIONAL AND MASS CHARACTERISTICS OF FRUITS

Statistical processing of the experimental data makes it possible to reveal that the sizes of the fruits change according to the normal distribution law and are described by a continuous Gaussian curve.

Measurements showed that the diameter of pumpkin fruits of varieties Volzhskaya gray 92 and Krupnoplodnaya 1 varies from 261 to 352 mm and from 216 to 281 mm, respectively, with the average values being 311 mm and 255 mm (**Fig. 1.5**). Fruit height ranges from 191 to 235 mm and 175 to 224 mm, with the average values being 213 and 199 mm, respectively (**Fig. 1.6**). The shape of the fruit is usually characterized by the shape index. Experiments have shown that the shape index of fruits of pumpkin varieties Volzhskaya gray 92 and Krupnoplodnaya 1 was 0.75 and 0.8, respectively (**Fig. 1.7**).

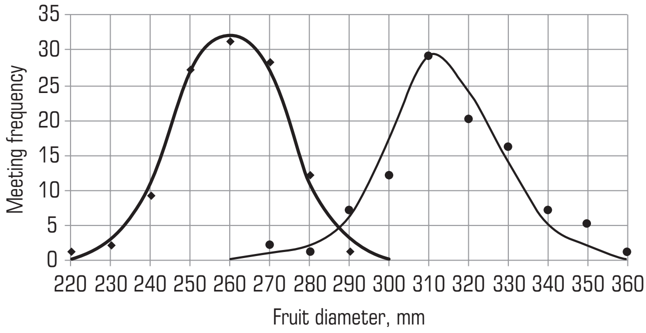


Fig. 1.5 Distribution of the diameters of the fruits of pumpkins Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (♦)

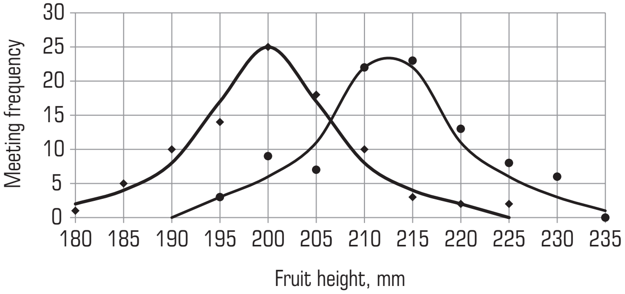


Fig. 1.6 Distribution of the fruit heights of the pumpkins Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (♦)

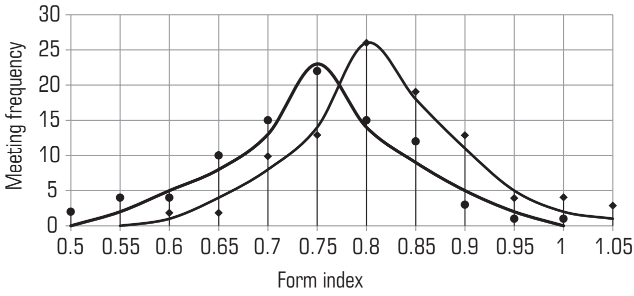


Fig. 1.7 Distribution of the fruit shape index values of pumpkins Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (♦)

Fruit mass is a necessary characteristic for all power calculations. As can be seen from the data obtained, the mass of pumpkin fruits of varieties Volzhskaya gray 92 and Krupnoplodnaya 1 varied from 5.9 to 8.3 kg and from 6.6 to 9.5 kg. The average weight of fruits was 7.1 and 8.1 kg (**Fig. 1.8**). The amount of kurtosis and asymmetry was determined for each variety, for each of the characteristics of the fruit. The values of these indicators in most cases differ slightly from zero.

Criterion χ^2 tests indicate a normal distribution.

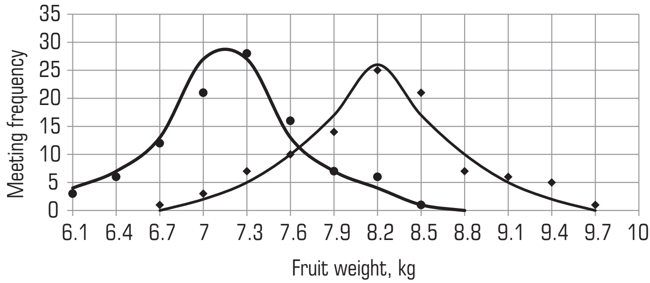


Fig. 1.8 Distribution of values of the mass of fruits of pumpkins Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (♦)

Determination of the rind thickness. The rind thickness is the starting point to be guided by when determining the boundaries of the layer to be removed, since the geometric parameters of the pile of brush drums directly depend on this property. The length of the pile will be determined by the maximum penetration depth into the fruit surface (**Fig. 1.9**).

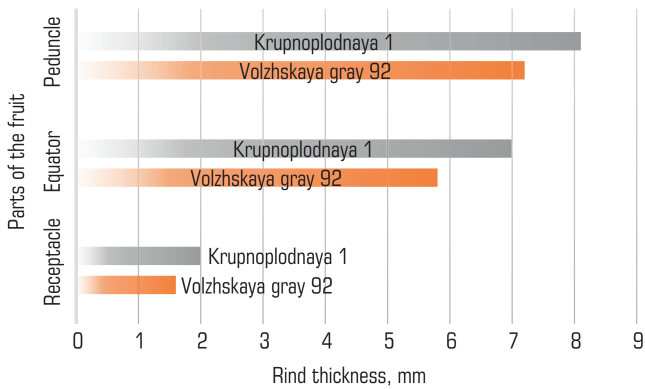


Fig. 1.9 Rind thickness in different parts of pumpkins Volzhskaya gray 92 and Krupnoplodnaya 1

Experimental data on determining the thickness of the rind showed that in the varieties Volzhskaya gray 92 and Krupnoplodnaya 1 it was h_e=5.8 and h_e=7.0 mm, respectively, in the part of the «equator», h_p=7.2 and h_p=8.0 mm in the peduncle part, h_r=1.5 and h_r=2.0 mm in the receptacle part (**Fig. 1.10–1.12**).

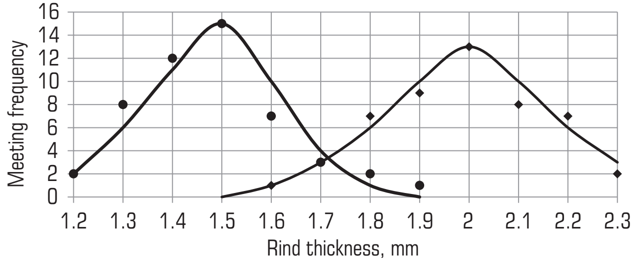


Fig. 1.10 Distribution of the rind thickness values in the part of the receptacle of the fruits of pumpkins Volzhskaya gray 92 and Krupnoplodnaya 1

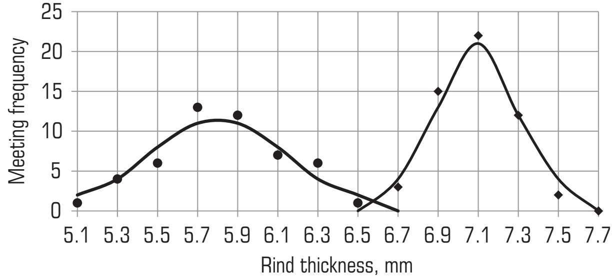


Fig. 1.11 Distribution of the rind thickness values in the part of the «equator» of the fruits of pumpkins Volzhskaya gray 92 and Krupnoplodnaya 1

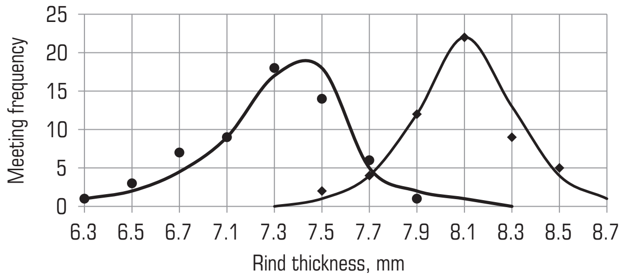


Fig. 1.12 Distribution of the rind thickness values of the fruits of pumpkins Volzhskaya gray 92 and Krupnoplodnaya 1

From the given experimental data it is clear that the rind thickness in the part of the «equator», the stalks differ slightly, and in the part of the receptacle it is 3.5...4 times less.

To test the hypothesis about the relationship between the size characteristics of pumpkin fruits and the rind thickness, according to the experimental data, relationships were built between the diameter of the fruit and the rind thickness (**Fig. 1.13**), as well as between the height of the fruit and the rind thickness (**Fig. 1.14**). In order to be able to accurately judge the experimental data, a linear approximation was carried out. At the same time, using the square of the correlation coefficient R^2, let's check the accuracy of the approximation, which in the first case ranges from 0.8671 to 0.9677, and in the second from 0.9108 to 0.9732. On this basis, it can be said that the experimental curves are fairly accurately described by the approximated curves.

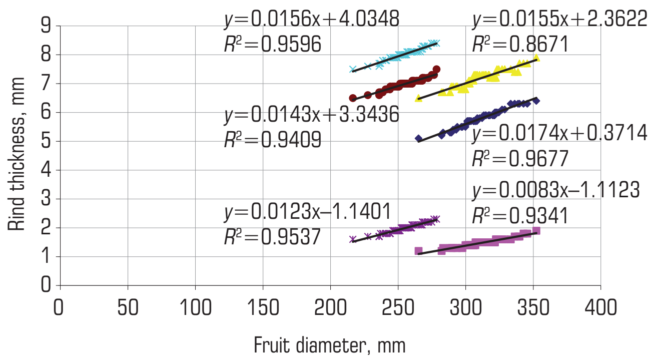


Fig. 1.13 Graph of the dependence of the rind thickness in different parts of the fruit on its diameter

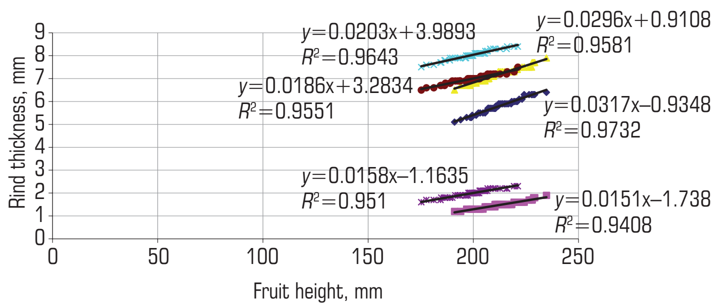


Fig. 1.14 Graph of the dependence of the rind thickness in different parts of the fruit on its height

The greatest relative variability of the rind thickness for the two tested varieties was noted in the part of the receptacle, since the minimum and maximum sizes in this part vary from 1.2 to 1.9 mm for Volzhskaya gray 92 and from 1.6 to 2.3 mm for Krupnoplodnaya 1 while the coefficient of variation was 10.25 % and 8.2 %, respectively.

Size and mass characteristics of seeds. Table 1.2 shows the results of a pumpkin seed study. The analysis of these data showed that the seeds have three pronounced indicators (length, width, thickness), significantly differing from each other even within the same variety. The most pronounced fluctuations in the size of seeds along the length and to the least extent in thickness. Since the thickness changes insignificantly, and in the length-width plane they have a clearly defined elliptical shape, their shape is called plane-elliptical.

Table 1.2 Dimensional characteristics of pumpkin seeds

Indicator		Variety	
		Volzhskaya gray 92	Krupnoplodnaya 1
Arithmetic mean, $\bar{x}$	Length, mm	17.8	18.7
	Width, mm	10.4	11.1
	Thickness, mm	3.9	4.3
Mean square deviation, σ	Length, mm	1.48	1.69
	Width, mm	0.94	1.28
	Thickness, mm	0.52	0.49
Coefficient of variation, V	Length, mm	7.83	8.85
	Width, mm	7.58	11.53
	Thickness, mm	11.06	12.89
Average error of experiments, Δ_{cr}	Length, mm	0.085	0.098
	Width, mm	0.054	0.074
	Thickness, mm	0.030	0.028
Variation interval, $\bar{x} \pm t\sigma$	Length, mm	14.5…23.2	14.6…22.8
	Width, mm	8.6…13.2	7.5…14.7
	Thi ckness, mm	2.7…5.1	3.0…5.6

Based on the data obtained, variation curves were constructed (**Fig. 1.15**), which vary according to the law of normal distribution and are described by a continuous Gaussian curve.

The results of the study of the dependence of the mass of seeds on the mass of the fruit are shown in **Table 1.3**. These data show that a favorable biological development of pumpkin fruits is observed when the weight of seeds in them varies from 160 to 200 g, since in this case the seed sac is most densely filled with seeds, which leads to their high-quality ripening. In addition, it can be concluded that with an increase in the weight of the fruit, the weight of the seeds also grows.

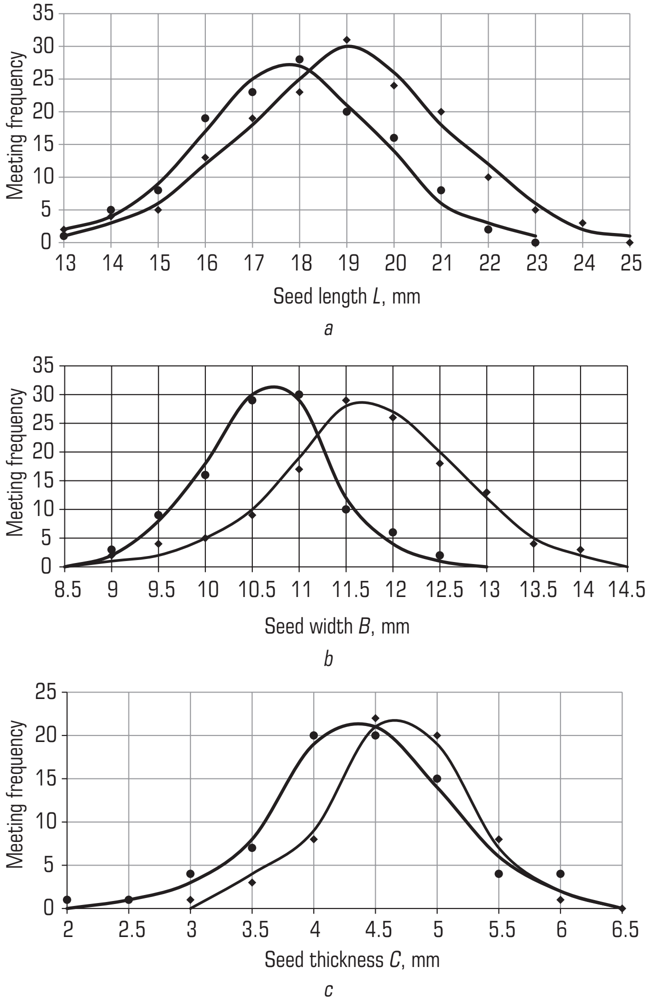


Fig. 1.15 Variation curves of the distribution of the dimensional characteristics of pumpkin seeds of Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (♦): *a* – in length; *b* – in width; *c* – in thickness

But this dependence is not directly proportional, since with an increase in the mass of the fruit, the seed sac is filled with seeds more densely, but most of them are empty.

Table 1.3 Dependence of the mass of seeds on the mass of the fruit of Krupnoplodnaya 1 pumpkin

Variation intervals of fruit weight, kg	The middle of the variation interval in the mass of fruits, kg	Number of fruits in the interval, pcs	Total weight of seeds in the interval, g	Average weight of seeds per fruit, g
5.0–7.1	6.05	15	2,505	167
7.1–9.0	8.05	15	2,687	179
9.1–11.0	10.05	15	2,745	183
11.1–13.0	12.05	15	3,006	200
13.1–15.0	14.05	15	3,064	204
15.1–17.0	16.05	15	3,167	211
17.1–19.0	18.05	15	3,229	215

1.2.2 FRICTIONAL PROPERTIES OF PUMPKIN FRUITS

The results of studying the frictional properties of pumpkin pulp and seeds on various surfaces (plastic, painted steel, polished steel, rubber sheet) were obtained on the basis of statistical processing of experiments and are presented in **Tables 1.4, 1.5**.

It follows from the tables that the coefficients of friction depend on the type of surface and are most important for rough surfaces. In addition, the coefficients of friction depend on the moisture content of the seeds themselves. Up to a moisture content of 30...35 %, the friction coefficients are influenced by the adhesion forces (stickiness), which leads to their increase. At a humidity of 40...60 %, the friction coefficients are sharply reduced, which is confirmed by our research.

Table 1.4 Coefficients of static friction

Pumpkin variety	Material	Friction surface	
		Polished steel	Rubber
Volzhskaya gray 92	Seeds	0.48	0.76
	Rind	0.26	0.56
	Pulp	0.98	1.39
Krupnoplodnaya 1	Seeds	0.47	0.74
	Rind	0.27	0.54
	Pulp	0.97	1.29

Table 1.5 Coefficients of movement friction

Pumpkin variety	Material	Friction surface	
		Polished steel	Rubber
Volzhskaya gray 92	Seeds	0.45	0.70
	Rind	0.24	0.33
	Pulp	0.59	0.73
Krupnoplodnaya 1	Seeds	0.43	0.71
	Rind	0.26	0.32
	Pulp	0.61	0.71

1.2.3 STRENGTH INDICATORS OF THE FRUIT

1. Breaking force of the spermatic cord.

The strength of the spermatic cord characterizes the ability of seeds to isolate from fruits and is estimated by the amount of effort required to break the bonds of seeds with feeding vessels. The obtained values of the breaking force of the spermatic cord are summarized in **Tables 1.6, 1.7**, and graphically presented in **Fig. 1.16**.

The results of the study of these data showed that the breaking force depends on the moisture content of the fruit at the time of processing. The least value of the breaking force is for fruits that were stored after harvesting (ripened) for at least 30 days, since this leads to a decrease in the moisture content, both in the fruits and in the feeding vessels. In this case, when loaded, they behave like a brittle material.

The analysis was carried out using the MS EXCEL software.

Table 1.6 Breaking force of the spermatic cord (Volzhskaya gray 92)

Indicator	Storage period				
	after harvest	in a week	in 2 weeks	in 3 weeks	in 1 month
Humidity, %	90	87	82	76	72
Force max, N	0.96	0.94	0.89	0.74	0.56
Force min, N	0.76	0.76	0.73	0.52	0.42
Average force, N	0.86	0.85	0.81	0.63	0.49

Table 1.7 Breaking force of the spermatic cord (Krupnoplodnaya 1)

Indicator	Storage period				
	after harvest	in a week	in 2 weeks	in 3 weeks	in 1 month
Humidity, %	89	85	80	76	69
Force max, N	1.05	1.02	0.95	0.79	0.61
Force min, N	0.88	0.86	0.79	0.63	0.50
Average force, N	0.96	0.94	0.87	0.71	0.56

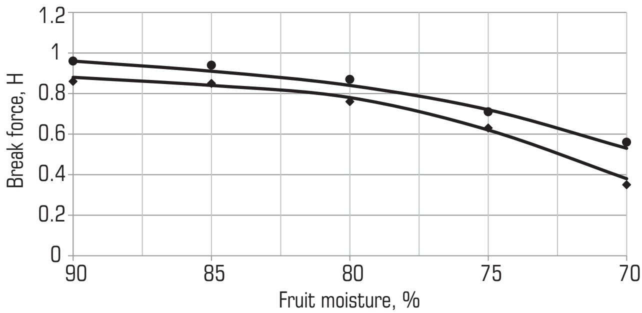


Fig. 1.16 Breaking force of the spermatic cord in fruits of pumpkins Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (♦)

2. Effort of separation of the seed sac from the pulp.

The data defining the force of separation of the seed sac from the pulp are presented in **Fig. 1.17** and are shown in **Tables 1.8, 1.9**.

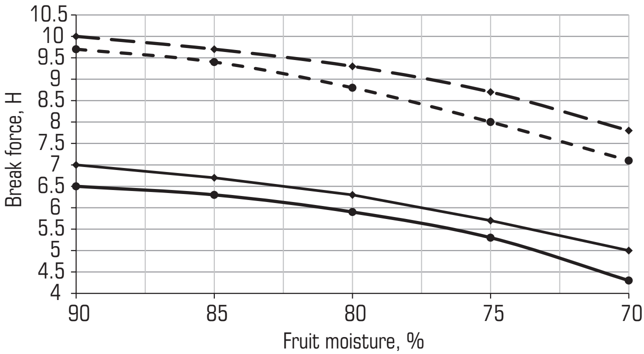


Fig. 1.17 Effort of separation of the seed sac from the pulp in the fruits of pumpkins Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (♦): in the middle of the sac (---), at the peduncle (- - -)

Table 1.8 Effort of separation of the seed sac from the pulp (Volzhskaya gray 92)

Indicator	Storage period				
	after harvest	**in a week**	**in 2 weeks**	**in 3 weeks**	**in 1 month**
Humidity, %	90	87	82	76	72
Breaking force at the peduncle, N:					
average	9.8	9.6	9.1	8.2	7.8
maximum	10.9	10.5	9.9	8.9	8.7
minimal	8.7	8.7	8.3	7.5	6.9
Sac breakout force, N:					
average	6.6	6.4	6.1	5.5	5.3
maximum	7.4	7.3	6.8	6.1	5.9
minimal	5.8	5.5	5.4	4.9	4.7

Table 1.9 Effort of separation of the seed sac from the pulp (Krupnoplodnaya 1)

Indicator	Storage period				
	after harvest	**in a week**	**in 2 weeks**	**in 3 weeks**	**in 1 month**
Humidity, %	90	87	82	76	72
Breaking force at the peduncle, N:					
average	9.9	9.8	9.4	8.5	8.2
maximum	10.6	10.7	10.3	9.5	9.4
minimal	9.2	8.9	8.5	7.4	7.0
Sac breakout force, N:					
average	6.9	6.7	6.4	5.9	5.7
maximum	7.8	7.5	7.4	6.9	4.7
minimal	6.1	5.9	5.4	4.8	4.8

The analysis of these data showed that the force of sac separation depends not only on the moisture content of the investigated fruits, and therefore on their storage period after harvesting, but also on the section in which the measurements were made. At the peduncle and receptacle, where fusion of the feeding vessels is observed, the pull-off force reaches its maximum value.

The analysis was carried out using the MS EXCEL software.

3. Determination of the density of the rind and subrind pulp.

According to the results of the experiments, the average value of the density of the pumpkin rind was 1.14 g/cm^3 for the Volzhskaya gray 92 pumpkin and 1.15 g/cm^3 for the Krupnoplodnaya 1 pumpkin. The density of the subrind pulp for the same varieties was 1.10 and 1.11 g/cm^3, respectively. Analyzing the data obtained, it is possible to conclude that the densities of the rind and subrind pulp are somewhat higher than unity, but at the same time they differ insignificantly (**Fig. 1.18**).

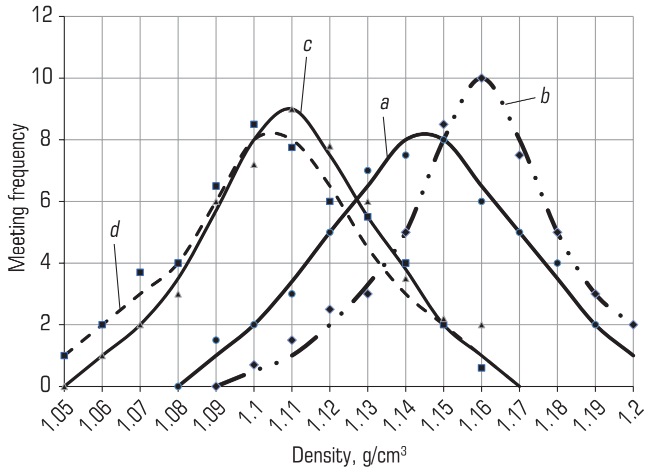


Fig. 1.18 Distribution of the density values of the rind and subrind pulp: *a* – rind of the Volzhskaya gray 92 variety; *b* – rind of the Krupnoplodnaya 1 variety; *c* – pulp of the Volzhskaya gray 92 variety; *d* – pulp of the Krupnoplodnaya 1 variety

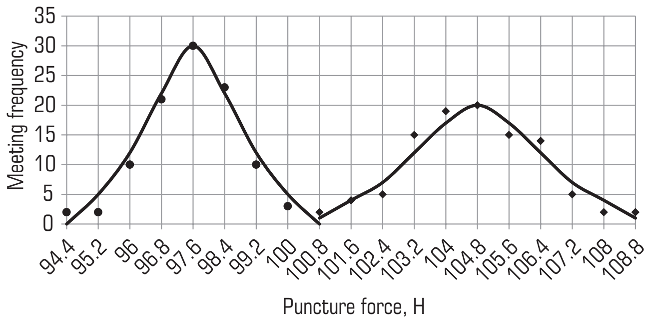
Thus, the rind is denser than the subrind pulp, and therefore more durable. This circumstance must be taken into account when choosing the permissible collision speeds of the brush elements during forward and reverse rotation of the brush drums. In the first case, elastic vibrations, which lead to the rind destruction, arise when the brush element hits the surface of the fruit, and in the second case, when the brush element hits the subrind pulp.

Evaluating the variability of the density of the rind and subrind pulp, it is possible to say that it is insignificant, since the coefficient of variation in all the experiments carried out does not exceed 10 % and varies from 1.99 % to 2.22 %.

The analysis was carried out using the MS EXCEL software.

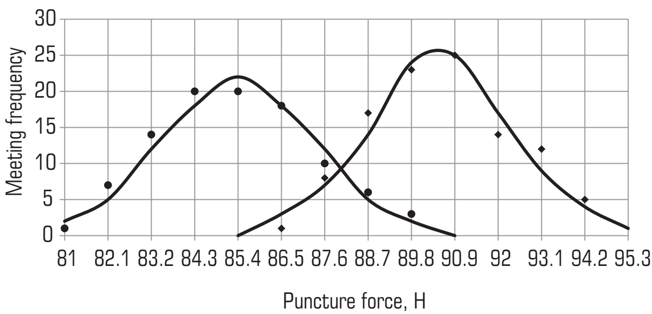
4. Determination of the puncture force and the hardness of the fruit rind.

As a result of research, it turned out that for the fruits of Volzhskaya gray 92 pumpkin, the average puncture force in the part of the peduncle is 97 N, in the part of the «equator» – 86 N, in the part of the receptacle – 45 N. For fruits of Krupnoplodnaya 1, the puncture force in the part of the peduncle – 104 N, in the part of the «equator» – 90 N, in the part of the receptacle – 51 N (**Fig. 1.19–1.21**). Analyzing the data obtained, let's find out that the puncture force in the part of the receptacle and in the part of the «equator» practically does not differ, but in the part of the receptacle it is almost 2 times less.



⬡ **Fig. 1.19** Distribution of the values of the puncture forces in the part of the peduncle in the fruits of pumpkins Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (♦)

Calculated on the basis of the data of the puncture force, the average hardness for the entire sample turned out to be, respectively, for the fruits of the Volzhskaya gray 92 pumpkin in the part of the peduncle 8.3×10^{-6} N/m^2, in the part of the «equator» 7.2×10^{-6} N/m^2, in the part of the receptacle 4.1×10^{-6} N/m^2, for pumpkin the fruits of pumpkin Krupnoplodnaya 1 in the part of the peduncle 7.7×10^{-6} N/m^2, in the part of the «equator» 6.8×10^{-6} N/m^2, in the part of the receptacle 3.6×10^{-6} N/m^2. The analysis was carried out using the MS EXCEL software.



⬡ **Fig. 1.20** Distribution of the values of the puncture forces in the part of the «equator» in the fruits of pumpkin Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (♦)

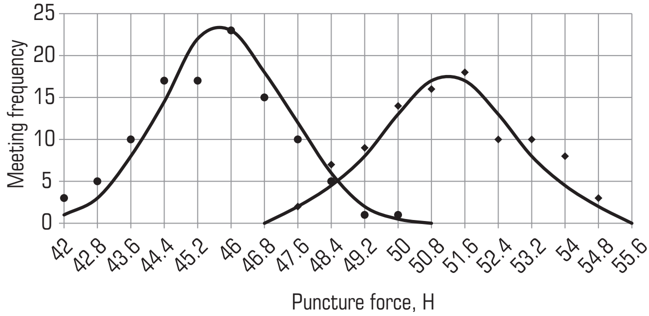


Fig. 1.21 Distribution of the values of the puncture forces in the part of the receptacle of the fruits of pumpkins Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (♦)

The analysis was carried out using the MS EXCEL software.

5. Determination of the shear force of the rind.

As a result of experiments to determine the effort at shear of the fruit rind of the Volzhskaya gray 92 variety, the following results were obtained:

a) in the part of the peduncle $P_p^{sh} = 96$ N;

b) in the part of the «equator» $P_e^{sh} = 90$ N;

c) in the part of the receptacle.

For the fruits of Krupnoplodnaya 1 pumpkin variety, they were:

a) in the part of the peduncle $P_p^{sh} = 94$ N;

b) in the part of the «equator» $P_e^{sh} = 88$ N;

c) in the part of the receptacle $P_r^{sh} = 47$ N (**Fig. 1.22–1.24**).

At the same time, the calculation of the shear stresses during the shear of the fruit rind led to the following results.

For pumpkin fruits of the variety Volzhskaya gray 92, they were:

a) in the part of the peduncle $\tau_p^{sh} = 4.2 \times 10^{-6}$ N/m^2;

b) in the part of the «equator» $\tau_e^{sh} = 2.5 \times 10^{-6}$ N/m^2;

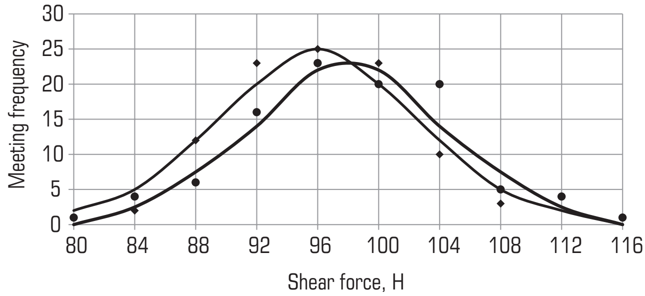
c) in the part of the receptacle $\tau_r^{sh} = 2.3 \times 10^{-6}$ N/m^2.

For the fruits of Krupnoplodnaya 1 pumpkin variety, they were:

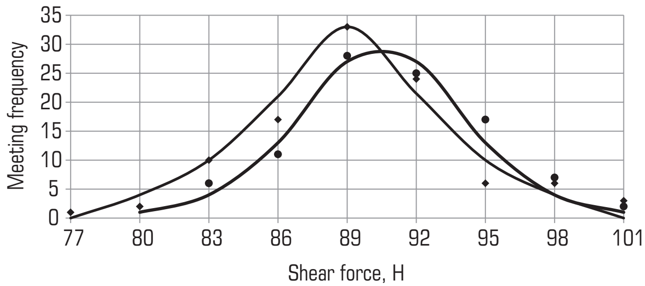
a) in the part of the peduncle $\tau_p^{sh} = 4.0 \times 10^{-6}$ N/m^2;

b) in the part of the «equator» $P_e^{sh} = 2.4 \times 10^{-6}$ N/m^2;

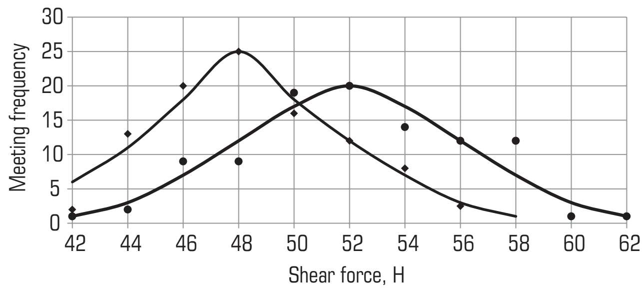
c) in the part of the receptacle $P_r^{sh} = 2.2 \times 10^{-6}$ N/m^2.



⬡ **Fig. 1.22** Distribution of the values of the shear force of the rind in the part of the peduncle in the fruits of pumpkins Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (♦)



⬡ **Fig. 1.23** Distribution of the values of the shear force of the rind in the part of the «equator» in the fruits of pumpkins Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (♦)



⬡ **Fig. 1.24** Distribution of the values of the shear force of the rind in the part of the receptacle in the fruits of pumpkins Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (♦)

6. Determination of the elastic moduli of the rind and pulp.

In the course of the research, the behavior under load of the rind and subrind pulp of various parts of the fruit was studied: in the part of the peduncle, the «equator» and the receptacle.

The results of the experiments showed that, under loading, the deformation of the sample increases to a certain limiting value, after which an almost instantaneous failure occurs. An analysis of the laws of loading shows that the rind and pulp at different points of the fruit have different strengths, but the compression process obeys Hooke's law.

The elastic moduli of the rind and pulp for the and Krupnoplodnaya 1 variety are equal:

a) $E_p^r = 15.2 \times 10^5$ N/m^2, $E_p^p = 4.9 \times 10^5$ N/m^2 in the peduncle;

b) $E_e^r = 13.7 \times 10^5$ N/m^2, $E_e^p = 4.5 \times 10^5$ N/m^2 in the «equator»;

c) $E_r^r = 8.9 \times 10^5$ N/m^2, $E_r^p = 1.72 \times 10^5$ N/m^2 in the receptacle, (**Fig. 1.25–1.30**).

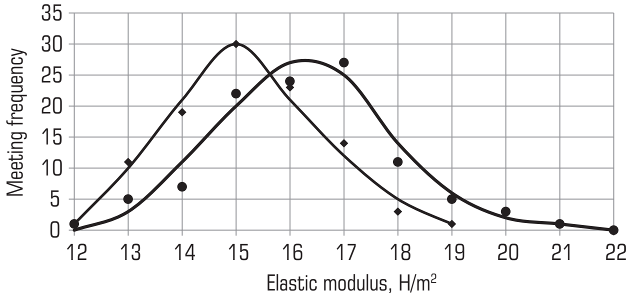


Fig. 1.25 Distribution of the values of the elasticity modulus of the rind in the peduncle in the fruits of pumpkins Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (♦)

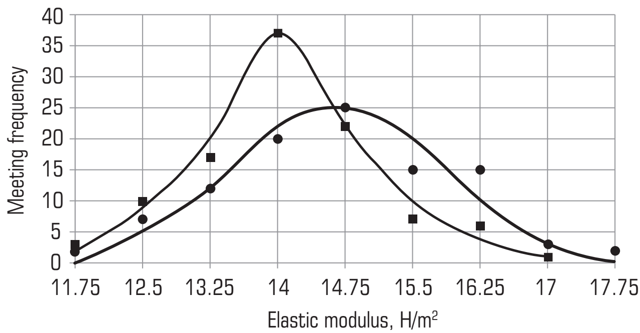


Fig. 1.26 Distribution of the values of the elasticity modulus of the rind in the «equator» in the fruits of pumpkins Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (■)

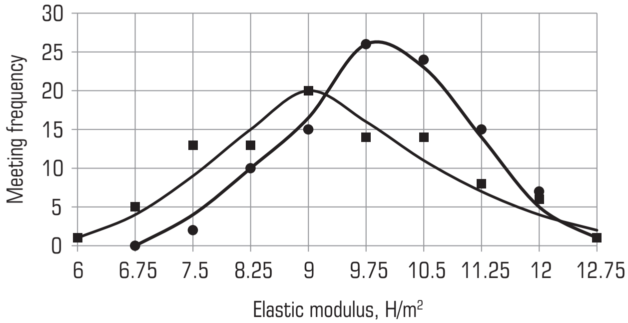


Fig. 1.27 Distribution of the values of the modulus of elasticity of the rind in the receptacle in the fruits of pumpkin Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (■)

The elastic moduli of the rind and pulp for the Volzhskaya gray 92 variety are respectively equal:

a) $E_p^r = 16.15 \times 10^5$ N/m^2, $E_p^p = 5.1 \times 10^5$ N/m^2 in the peduncle;

b) $E_e^r = 14.4 \times 10^5$ N/m^2, $E_e^r = 4.8 \times 10^5$ N/m^2 in the «equator»;

c) $E_r^r = 9.6 \times 10^5$ N/m^2, $E_r^p = 1.9 \times 10^5$ N/m^2 in the receptacle.

The analysis was carried out using the MS EXCEL software.

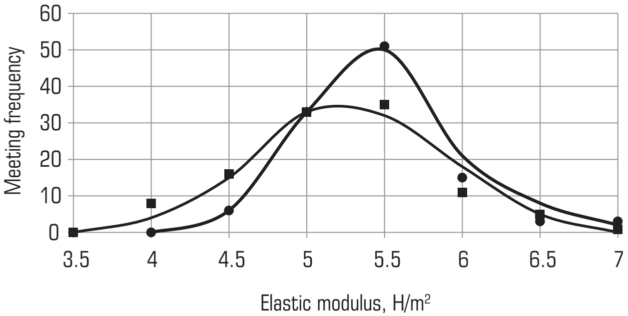


Fig. 1.28 Distribution of the values of the modulus of elasticity of the pulp in the peduncle in the fruits of pumpkins Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (■)

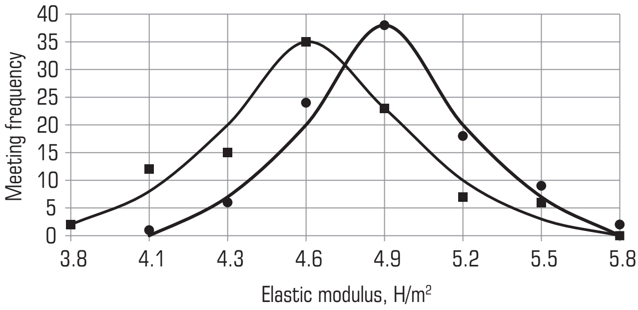


Fig. 1.29 Distribution of the values of the modulus of elasticity of the pulp in the «equator» in the fruits of pumpkins Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (■)

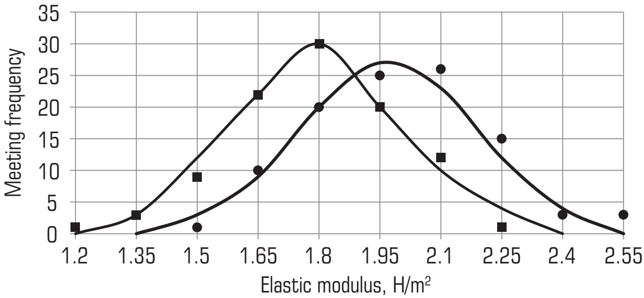


Fig. 1.30 Distribution of the values of the modulus of elasticity of the pulp in the receptacle in the fruits of pumpkins Volzhskaya gray 92 (•) and Krupnoplodnaya 1 (■)

1.3 STRUCTURE, PROPERTIES AND RHEOLOGY OF MELON

The characteristics of the main varieties of melons sold in the Almaty region, with an indication of the varietal affiliation to use for processing, are detailed in the interim report for 2015 [28].

1.3.1 GEOMETRIC CHARACTERISTICS OF MELON FRUITS, MASS OF THE CONSTITUENT PARTS OF THE FRUIT

Of great importance for determining the yield of products from a melon is the ratio of the parts that make up the fruit: pulp, rind, seeds and placenta. To determine this indicator, fruits were used, in which the linear dimensions were previously measured. The fruits were cut into slices and the rind was cut 5–10 mm thick, depending on the variety. The same components of the fruits of the same variety were combined and weighed on an electronic balance with an accuracy of 1 g. The data obtained are shown in **Tables 1.10, 1.11** [29–31].

Table 1.10 The yield of components when cutting melon fruits

Variety	Fruit weight, g	Pulp		Rind		Placenta		Seeds	
		g	%	g	%	g	%	g	%
Iliiskaya	1,210	765	63.22	360	29.75	46	3.8	39	3.22
Myrzachulskaya	5,575	4,000	71.75	1,370	24.57	133	2.39	72	1.29
Kolhoznitsa	1,150	793	68.96	290	25.22	42	3.65	25	2.17
Gurbek	4,225	2,645	62.6	1,320	31.24	210	4.97	50	1.18
Ameri	3,200	1,800	53.13	1,060	33.13	240	10.6	100	3.13
Inzhirnaya	3,460	1,890	54.62	1,210	34.97	270	7.8	90	2.6
Guliabi	4,175	2,645	63.35	1,320	31.62	135	3.23	75	1.8
Zhuldyz	1,990	1,310	65.83	570	28.64	67	3.37	43	2.16

Table 1.11 Characteristic parameters of melon

Variety	Shape index
Iliiskaya	0.92–0.96, average 0.94
Myrzachulskaya	1.80–1.90, average 1.85
Kolhoznitsa	0.96–1.00, average 0.98
Gurbek	1.20–1.25, average 1.23
Ameri	2.26–2.4, average 2.33
Sary Guliabi	1.55–1.60, average 1.57
Zhuldyz	1.20–1.25, average 1.23
Inzhirnaya	0.90–0.95, average 0.94

From **Table 1.10** it follows that the yield of pulp in different varieties of melon varies from 53.13 to 71.75 %, the highest – in Myrzachulskaya melon, low – in Ameri. The thickest rinds are in Inzhirnaya, Ameri, Guliabi and Gurbek, respectively 34.97, 33.13, 31.62 and 31.24 %. Basically, these are melons of late varieties, and mid-ripening varieties. More rind makes them more preferred for pectin production.

The seed content varies from 1.18 to 3.22 %. The dependence of the seed content on which class in terms of ripening the melons belongs to is not observed. This indicator depends only on the characteristics of the variety.

The analysis of the tabular data shows that the shape index in different varieties of melon varies widely: from 0.9 in Inzhirnaya to 2.4 in Ameri. The shape index is very important in the selection of devices for removing the rind from the fruit of the melon. The higher the shape index, the easier it is to mechanize the process of its cutting [3, 28].

1.3.2 DENSITY OF MELON PULP

As part of the research carried out in 2015, the results were obtained to determine the density of the layer adjacent to the rind and the inside of the melon of various varieties, which are shown in **Table 1.12**. The results of experimental data indicate that the density of the melon throughout the entire volume of the fruit is not the same and there is a decrease from the layers adjacent to the rind to the inner layers (in the center) [4, 28].

Table 1.12 Melon pulp density

Melon layer	Melon pulp density, $\rho \cdot 10^{-3}$, kg/m^3						
	Iliiskaya variety	Gurbek variety	Ameri variety	Myrzachulskaya variety	Guliabi variety	Inzhirnaya variety	Zhuldyz variety
Adjacent	1.26	1.28	1.24	1.29	1.30	1.32	1.30
Average	1.12	1.13	1.15	1.18	1.21	1.23	1.19
Interior	1.10	1.11	1.12	1.14	1.14	1.16	1.15

1.3.3 ADHESION PROPERTIES OF MELON PULP

The adhesion properties of melon pulp, in particular the stickiness of melons of various varieties, were determined using a ST-2 structuralometer, the experimental data are shown in **Table 1.13**.

The data obtained indicate that the adhesion stress (stickiness) of all melon varieties lies in the range of 2.6–3.2 N/m^2, and for specimens of one variety, the fluctuations are much less and amount to 2.6–3.0 on average for mid-ripening varieties, for late-ripening – 2.9–3.2 N/m^2 [28].

Table 1.13 Determination of adhesion properties of melon pulp

Indicator	Melon varieties, layer						
	Early-ripening		Mid-ripening		Late-ripening		
	Sary Zhambylsha	Kyzyl Zhambylsha	Bos Kauyn	Kara Gurbek	Guliabi green	Guliabi orange	Kyzyl Guliabi
Adhesion stress, N/m^2	2.4–2.6	2.3–2.6	2.8–3.0	2.6–2.9	2.9–3.1	3.0–3.2	3.1–3.2

1.3.4 FRICTIONAL PROPERTIES OF MELON (COEFFICIENT OF FRICTION)

The data of experimental studies to determine the coefficient of friction are presented in **Table 1.14**. The results of these studies indicate that with an increase in the rind thickness with an adjacent layer of pulp, the coefficient of external friction decreases. Based on the results of the experimental data shown in **Table 1.14**, a graph of the dependence of the external friction coefficient on the melon rind thickness is built (**Fig. 1.31**).

Analysis of the nature of the curves indicates the presence of a general pattern: a decrease in the coefficient of friction with an increase in the rind thickness, and the decrease is more significant in melons of mid-ripening and late-ripening varieties.

Table 1.14 Dependence of the friction coefficient of a melon on melon rind thickness

Rind thickness, mm	Melon varieties (average)		
	Early-ripening	Mid-ripening	Late-ripening
3	0.31	0.24	0.23
5	0.28	0.23	0.21
7	0.25	0.23	0.19
10	0.23	0.21	0.19

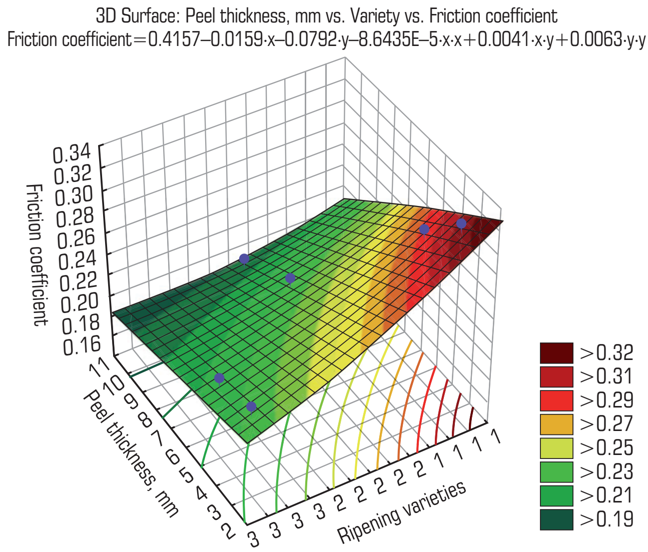


Fig. 1.31 Graph of the dependence of the external friction coefficient on the melon rind thickness

The linear model is most convenient for practical use. Mathematical processing of the experimental data results using Excel tools made it possible to obtain the regression equations, which are shown in the diagram.

Since the obtained value $R>0.9$, it is possible to talk about a high accuracy of the approximation [5, 27].

1.3.5 SPECIFIC CUTTING FORCE

The determination of the specific cutting force and physical and mechanical properties of materials under volumetric compression was carried out on a measuring complex based on the Structurometer-2 device, the readings of which were recorded into a computer [27] (**Fig. 1.32, 1.33**). The data obtained were processed using the Microsoft Office Excel program.

In this work, the values of the specific cutting forces of the layers of melon pulp adjacent to the rind were determined when separating the latter from the pulp of some melon varieties, united by ripening dates: early-ripening, mid-ripening and late-ripening.

Analyzing the given curves, which are typical for all grades, one can come to the conclusion that in the initial period of contact of the knife with the rind, the elastoplastic deformation of the latter occurs. In this case, the cutting force changes insignificantly; at the limiting value of deformation, an abrupt increase in the force occurs, which ends in the destruction of the material. When cutting the pulp, the cutting force remains almost constant as the knife moves inside the pulp [30–32].

The values of the specific cutting force for different varieties of melon and its average value are shown in **Table 1.15**.

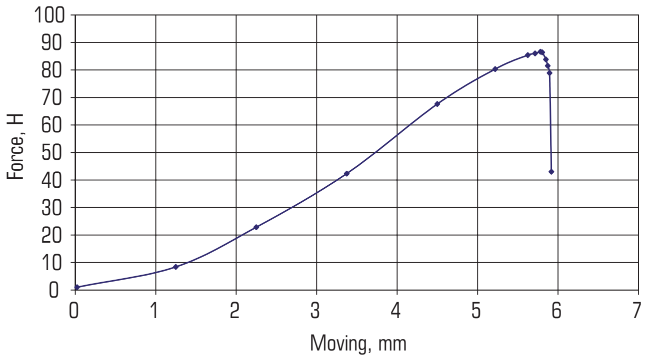


Fig. 1.32 Graph of the dependence of the cutting force on the movement of the knife when cutting the rind of the Ternek melon variety

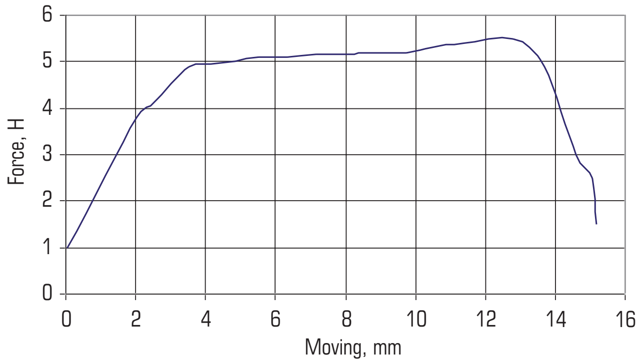


Fig. 1.33 Graph of the dependence of the cutting force on the movement of the knife when cutting the pulp of Ternek melon variety

Table 1.15 Values of specific cutting force for different varieties of melon

No.	Variety	Specific cutting force, N/m	
		Pulp	**Rind**
1	Iliiskaya	225	2,418
2	Myrzachulskaya	206	2,386
3	Kolhoznitsa	227	2,421
4	Gurbek	216	2,410
5	Ameri	236	2,479
6	Sary Guliabi	214	2,387
7	Zhuldyz	218	2,412
8	Inzhirnaya	234	2,485
Average value		222	2,424.75
Greater deviation		+6.31 %	+2.50 %
Less deviation		–7.20 %	–1.60 %

The table shows that the deviation from the average cutting force for certain varieties does not exceed the values (–7.20 %…+6.31 %) for the pulp and (–1.60 %…+2.50 %) for the rind.

Thus, the conducted studies allow to conclude that the average value of the specific cutting force for the studied melon varieties with an error not exceeding 7.2 % for the pulp and 2.5 % for the rind can be used in engineering calculations for various varieties, provided that the coefficient stock [33–38].

1.3.6 PIERCING FORCES OF THE MELON RIND

The determination of the piercing force of the melon rind was carried out using a ST-2 structurometer.

For plotting the graphs, a linear model was used, as the most convenient for practical application. The obtained dependencies are the initial data for calculating the energy consumption for piercing the melon rind when determining the engine power for the installation. **Fig. 1.34** shows the dependence of the rind breaking force of different melon varieties with the side surfaces of indenters of different diameters.

The results shown in **Fig. 1.34** show a directly proportional dependence of the breaking force on the diameter of the indenter rod. The degree of approximation *R* is close to 1, which indicates the applicability of the obtained dependences [14, 27].

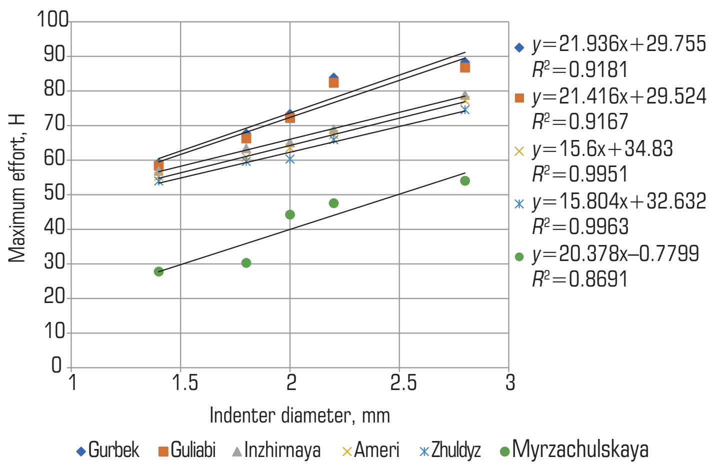


Fig. 1.34 Dependence of the breaking force on the diameter of the indenter rod

The next stage of our research was the construction of a nonlinear regression of the process of piercing the melon rind. Using the experimental design technique, the following quadratic regression equations were obtained for two variable parameters of a spike for piercing a melon rind. *Y* – piercing the melon rind, N.

$$Y = 10.07333 + 1.22767x_1 - 0.09300x_1^2 + 5.17933x_2 + 0.41800x_2^2 + 0.73200x_1x_2, \quad (1.1)$$

where x_1 – angle of sharpening of the indenter (spike), deg.; x_2 – indenter diameter, mm.

1.3.7 PHYSICAL AND MECHANICAL PROPERTIES UNDER VOLUMETRIC COMPRESSION

After processing the results of the experiments, the elastoplastic properties of melon pulp of various varieties were calculated, in particular, the varieties Myrzachulskaya and Ameri, the most common varieties of 2015. The analysis of the data allowed to conclude that such indicators as plasticity, softness, relative residual compression slightly decrease with an increase in the compression rate from 20 to 100 mm/min, while the recoverability and bulk modulus of elasticity increase (**Fig. 1.35**).

The graphs of the dependence of the change in the bulk modulus of elasticity on the compression rate for the melon of the above varieties are shown in **Fig. 1.35**. The dependence with a high degree of accuracy is described by the equations of a straight line, which are shown in the graphs, which also show the values of the reliability of the approximation.

The values of the latter indicate a good agreement of the equations with the experimental data.

The experimental data were used to calculate the values of the effective viscosity and the bulk modulus of elasticity for melon pulp of various varieties at different values of the compression rate. The equations describing this dependence, the reliability of the approximation and the deviation of the experimental values of these values from the calculated ones are given in **Table 1.16** [31, 39].

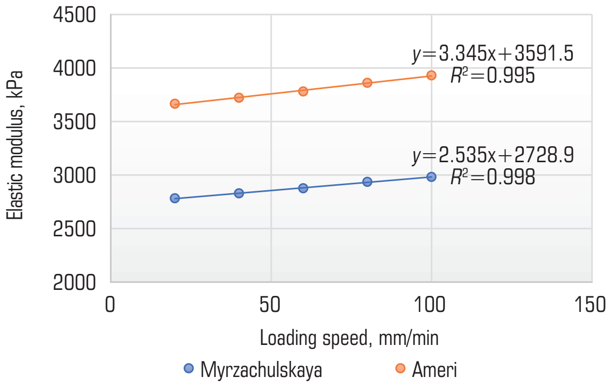


Fig. 1.35 Graph of the dependence of the elastic modulus of a melon on the loading rate

Table 1.16 Average values of effective viscosity and volumetric modulus of elasticity of melon pulp of various varieties with separation of 50 % drained juice

Index	Equation (v, m/s)	Approximation reliability	Deviation from the mean
Effective viscosity, kPa/s	2086+6.767v	0.97	(+5.3; –4.1) %
Bulk modulus of elasticity, kPa	5898+2.023v	0.96	(+3.2; –2.2) %

1.3.8 CHEMICAL COMPOSITION OF MELON FRUITS

Research work was carried out in the accredited testing laboratory «Food Safety» of the Almaty Technological University, where the following indicators of melon of late-ripening varieties were determined: mass fraction of dry matter, mass fraction of protein, mass fraction of fat, mass fraction of pectin substances, content of vitamin C, carotenoids, potassium, magnesium, iron, organic acids and antioxidant activity, using modern standard research methods [27].

The chemical composition of late-ripening melon varieties is presented in **Table 1.17**. The table confirms that the Myrzachulskaya melon variety is more balanced in composition, it has a higher content of vegetable protein by almost 3.8 times compared to the Zhuldyz variety and 1.9 times to the Ameri variety [40].

Table 1.17 Chemical composition of late-ripening melon varieties

Name of indicators, units	Late-ripening melon varieties		
	Zhuldyz	**Myrzachulskaya**	**Ameri**
Protein mass fraction, %	0.174	0.674	0.346
Mass fraction of fat, %	0.126	0.26	0.09
Mass fraction of pectin substances, g/100 g	0.53	0.42	0.375
Vitamin C, mg/100 g	13.97	16.75	10.14
Carotenoids, mg/100 g	0.12	0.1124	0.104
Potassium, mg/100 g	113.0	116.64	117.38
Magnesium, mg/100 g	10.43	10.812	10.846
Iron, mg/100 g	0.353	1.007	1.193
Organic acids: Malic acid, mg/kg Citric acid, mg/kg Succinic acid, mg/kg	 301.8 47.5 56.2	 290.0 27.0 62.0	 348.8 18.0 6.3
Antioxidant activity, mg/100 g	27.3	27.4	28.0

The Myrzachulskaya variety contains a higher amount of fat – 0.26 %, which is 0.134 % higher than that of Zhuldyz and 0.17 % higher than that of Ameri. In terms of the content of the mass fraction of pectin substances, the Myrzachulskaya variety is inferior to the Zhuldyz variety by 0.11 g/100 g, but slightly exceeds the Ameri variety – by 0.045 g/100 g.

The indicators of the Myrzachulskaya variety in terms of the content of ascorbic acid and vitamin C are 2.78 mg/100 g higher than that of the Zhuldyz variety and 6.61 mg/100 g higher than that of the Ameri variety. The content of carotenoids is approximately at the same level, with a small margin the Zhuldyz variety leads, then the Myrzachulskaya and Ameri varieties (0.12, 0.1124, 0.104 mg/100 g, respectively).

Melons are rich in potassium, magnesium and iron, which are essential for maintaining the tone of the cardiovascular system of the body.

The data in the table show that the Ameri variety has the best performance, it contains 117.38 mg/100 g of potassium, 10.846 mg/100 g of magnesium and 1.193 mg/100 g of iron. The second place is occupied by the Myrzachulskaya variety – 116.64 mg/100 g of potassium, 10.812 mg of magnesium and 1.007 mg/100 g of iron. In the Zhuldyz variety, respectively – 113.0 mg/100 g of potassium, 10.43 mg/100 g of magnesium and significantly lower iron content – only 0.353 mg/100 g.

In the Ameri variety, the malic acid content is 348.8 mg/kg, which is significantly higher than in the Zhuldyz variety by 47 mg/kg and by 58.8 mg/kg in the Myrzachulskaya variety. By the content of citric acid, the Zhuldyz variety differs – 47.5 mg/kg, then the Myrzachulskaya variety – 27.0 mg/kg and the Ameri variety – 18.0 mg/kg. Succinic acid is more contained in the Myrzachulskaya variety – 62.0 mg/kg, less in the Ameri variety, only 6.3 mg/kg, and in the Zhuldyz succinic acid variety – 56.2 mg/kg. The total antioxidant activity in the Ameri variety is 28 mg/100 g. In the Myrzachulskaya and Zhuldyz varieties, the level of antioxidant activity is practically the same, respectively, 27.4 mg/100 g and 27.3 mg/100 g.

Thus, given the rich chemical composition of late-ripening melon varieties, they should be used for the production of long-term storage products of increased nutritional and biological value in order to expand the range of products from non-traditional types of food raw materials with a high content of biologically active substances.

Caloric content was 34–36 kcal/100 g; nutritional value, g/100 g: proteins 0.4–0.6; fats 0.24–0.35; carbohydrates 7.3–7.5; dietary fiber 0.8–1.0; water 88–92; unsaturated fatty acids – less than 0.1; saturated fatty acids – less than 0.1.

The chemical composition, respectively, for the varieties Kolkhoznitsa and Myrzachulskaya: water – 6.0–6.2; lipids – 25.0–26.5; protein (N×6.25) – 22.5–25.5; starch and soluble sugars – 10.0–11.0; pentosans – up to 8.0; cellulose – 21.4–20.0; ash – 3.0–2.5. The kernel contains up to 30–50 % oil, and the husk – 0.5–0.6 %.

1.3.9 CONTENT AND STRUCTURE OF PECTIN IN MELON FRUITS

To study the content of pectin in melon fruits, the following varieties of melons sold in the Almaty region were taken: Inzhirnaya (sample No. 1), Guliabi (No. 2), Myrzachulskaya (No. 3), Gurbek (No. 4) and Ameri (No. 5).

Chemical analysis was carried out in the laboratory «The quality of functional food» Research Institute of Biotechnology of the Kuban State Agrarian University, performers of the topic under the guidance of laboratory staff. Melons of the aforementioned varieties brought from Almaty were taken for analyzes. The methods for the analysis of pectins are based on their physicochemical properties and structural features.

For the characterization of pectin, such indicators are important as: total ash content, molar mass, uronid component, degree of esterification, content of free carboxyl groups, binding capacity, etc.

The uronide component reflects the pectin content in terms of galacturonic acid and characterizes the purity of the pectin preparation. Determination of the uroid component is based on measuring the optical density of the colored products of the interaction of pectin hydrolyzate with carbazole at a wavelength of 530 nm. Determination of the degree of esterification is carried out by the titrimetric method. For a preliminary assessment of the ability of pectin to bind heavy metals, it is important to determine the content of free carboxyl groups. The property of pectin to interact with metal ions, binding them into insoluble complexes, reflects an indicator of the binding capacity, which is necessary to assess its detoxification properties.

In this work, we used the acidic method for extracting pectin from melon and pumpkin pulp, developed by L. Donchenko et al. The advantage of this method is a sufficiently high accuracy and reliability in the determination of pectin substances in plant raw materials.

Stages of pectin extraction in laboratory conditions:

1. Extraction of soluble pectin.
2. Extraction of protopectin.
3. Quantification.
4. Saponification.
5. Deposition.
6. Drying.

Extraction of soluble pectin. This process was carried out in two stages: the extraction of water-soluble pectins (hydratopectins) and the conversion of protopectin into a water-soluble form, followed by its extraction into solution.

The pulp was washed with water at a temperature of 40 °C, then kept in a water bath, filtered off. The solution is stored at a temperature not exceeding 10 °C for 6–7 days.

The results of the determination of pectin substances are presented in **Table 1.18**. The results of the analysis showed that the moisture content in different parts of the melon is not the same. Therefore, the highest moisture content was 88.6 % in the rind, and the smallest in the placenta 82.8. The moisture content of the pulp was 82.8 %. The mass fraction of pectin substances per absolutely dry matter in the rind of 10.9 % is more than 2 times higher than that in the melon pulp 5.09 %. The relatively high content of total pectin in the placenta is 7.44 %, which makes it a potential target for pectin extraction, possibly in the form of a middling product – liquid pectin, for use on site for the production of jams or pectin-containing beverages [41]. The content of pectins in the raw product due to its high moisture content does not exceed 1.28 % in the placenta and 1.18 % in the crust [42, 43]. An important indicator for the suitability of raw materials for processing in order to obtain pectin is the proportion of protopectin in the total content of pectin substances.

Table 1.18 The content of pectin substances in the Myrzachulskaya melon variety

Indicator	Sample number 3 – Myrzachulskaya melon		
	Rind	**Placenta**	**Pulp**
Moisture m.f., %	88.6	82.8	85.1
Pectin substances m.f., %	1.18	1.28	0.77
Hydratopectin, %	0.26	0.15	0.22
Protopectin, %	0.98	1.13	0.55
Pectin substances m.f. in terms of a.d.m., %	10.9	7.44	5.09
Hydratopectin, (a.d.m.), %	2.3	0.87	1.4
Protopectin, (a.d.m.), %	8.6	6.57	3.69
The share of protopectin in the total content of pectin substances, %	78.90	88.31	72.50

If the indicator is 70–90 %, then such raw materials can be used to obtain pectin. As can be seen from the table, the content of protopectin in all parts of the melon is included in this interval, and the proportion of protopectin in the placenta is 88.31 %. In the rind, this indicator is in the middle of the interval – 78.90 %, which once again confirms its suitability for extracting pectin, taking into account its high yield when processing melon. The content of protopectin in the pulp is close to the lower border of the interval, which makes it unprofitable for the production of pectin, but allows it to be used for pectin-containing products.

A similar picture is observed when researching melon of the Guliabi variety, the results of which are presented in **Table 1.19**.

Table 1.19 The content of pectin substances in the Guliabi melon variety

Indicator	Sample number 2 – Guliabi melon	
	Rind	**Pulp**
Moisture m.f., %	87.7	90.3
Pectin substances m.f., %	1.21	0.8
Hydratopectin, %	0.21	0.2
Protopectin, %	1.0	0.6
Pectin substances m.f. in terms of a.d.m., %	9.8	8.2
Hydratopectin, (a.d.m.), %	1.7	2.0
Protopectin, (a.d.m.), %	8.1	6.2
The share of protopectin in the total content of pectin substances, %	82.65	75.6

This melon has a more juicy pulp, its moisture content reaches 90.3 %, and the rind is slightly drier – 87.7 %.

The mass fraction of total pectin in the rind is 1.21 %, which, after conversion to absolutely dry matter, turns out to be 9.8 %, 1.1 % lower than that of the Myrzachulskaya variety. The share of protopectin in the total content of pectin substances in the rind is 82.65 %, which is higher than that of Myrzachulskaya and makes it no less suitable for pectin production.

The results of analyzes of the peel of the melon varieties Ameri, Gurbek and Inzhirnaya are shown in **Table 1.20**. For these varieties, only the rind was investigated as a more promising raw material.

Table 1.20 The content of pectin substances in the rind of melons of various varieties

Indicator	Sample number 1 – Inzhirnaya melon	Sample number 4 – Gurbek melon	Sample number 5 – Ameri melon
	(Rind)	(Rind)	(Rind)
Moisture m.f., %	82.4	89.1	87.4
Pectin substances m.f., %	1.67	1.41	0.78
Hydratopectin, %	0.37	0.2	0.029
Protopectin, %	1.3	1.21	0.75
Pectin substances m.f. in terms of a.d.m., %	9.5	7.43	6.13
Hydratopectin, (a.d.m.), %	2.1	1.83	0.23
Protopectin, (a.d.m.), %	7.4	5.6	5.9
The share of protopectin in the total content of pectin substances, %	77.89	75.37	96.25

The results **Table 1.20** show that the pectin content in the raw rind of Inzhirnaya melon is the highest of all five samples – 1.67 % due to the lowest moisture content of 82.4 %, in absolutely dry matter of this melon pectin is also quite a lot of 9.5 %, which is not significantly inferior to the Guliabi variety. The very low pectin content in the rind of the Gurbek melon is 7.43 % and especially in the rind of the Ameri melon is 6.13 %. However, in the latter variety, almost all of the pectin is protopectin. The share of protopectin in the total content of pectin substances is 96.25 %, which, taking into account its thick rind, the yield of which during cutting is 33.13 %, does not exclude the Ameri variety from the raw material for pectin production.

Studies have also shown that in all types of raw materials studied, pectins contain carboxyl groups esterified with methanol and do not contain carboxyl groups esterified with ammonia. In terms of the degree of esterification, the pectins contained in melon, as in pumpkin, are classified as low-esterified, in contrast to apple pectins, which are highly esterified. This indicates a lower water solubility of melon pectins compared to apple pectins.

According to [44], pectins with a degree of esterification of more than 66 % are readily soluble in water (for example, apple pectins), and less than 39.6 % are slightly soluble. By the degree of esterification of pectins of all varieties, melons are closer to the latter. The low methoxyl pectins found in melon are capable of forming sugarless jelly in the presence of small amounts of polyvalent metal ions. A high content of acetyl groups associated with hydroxyl groups of pectin substances was found in melon, which significantly impairs their gel-forming properties.

1.4 RHEOLOGICAL MODEL OF THE FRUIT OF PUMPKIN, MELON AND WATERMELON AS AN OBJECT OF MECHANICAL ACTION

To model the behavior of a complex rheological body, depending on the properties of its components, in engineering rheology, combinations are used in various combinations of the above simple ideal bodies, each of which has only one physical and mechanical property.

Models of simple ideal bodies can be combined by placing them in parallel, sequential, mixed (parallel and sequential). In combinations, the number of simple elements can be different – two, three, four or more, reaching 10–20. However, practice shows that the use of more than three or four elements in models significantly complicates the possibilities of visual observation of the behavior of bodies while simultaneously changing such a number of its properties. Therefore, most often complex models are used, in which the number of elements is no more than three or four.

For parallel connection of elements, it is assumed that the deformation of the elastic element is equal to the deformation of the viscous element, and the total stress is equal to the sum of the stresses of the elastic and viscous elements.

Any of the fruit processing technologies includes the operation of destroying the fruit.

When analyzing the process of fruit destruction, it is necessary to take into account its physical and mechanical properties, which it is advisable to generalize by creating a model of plant material, which makes it possible to reflect such fundamental properties of the material as elasticity, viscosity and plasticity. In rheology, for the mathematical description of the mechanical properties of a material, combinations of elements have been developed that reflect these properties with sufficient accuracy. For this, elasticity is usually depicted in the form of a spring, the deformation of which obeys Hooke's law, and viscosity – in the form of a cylinder with a viscous fluid, in which the movement of the piston is subject to Newton's law. Serial and parallel connection of these elements allows simulating the deformation of a material with very complex properties.

The model for melons is determined by the structure of the fruit rind, which consists of a hard skeleton and a semi-liquid, liquid or gaseous substance that fills the gaps between the solid elements of the rind and the inner cavity of the fruit.

Obviously, a more realistic model should contain more simple elements. But this will complicate the math. Therefore, let's compose the rheological model of the fruit so that it is simple and most accurately reflects the behavior of the material under load.

For seeds, the fruits of watermelon and pumpkin are mainly processed, which in many respects differ in their physical and mechanical properties, therefore, let's compose and analyze rheological models separately for the fruits of watermelon and pumpkin.

The basis of the watermelon fruit is water, which makes up 90 % of the total mass. It is almost in a free state and is enclosed in a thin shell of the fruit (rind). When the fruit ripens, gas interlayers may appear near the seeds.

Due to the hydraulic effect, the liquid base is a source of generation of destructive forces of a wave and shock nature, several times higher than the applied load, and the determining factor is the rate of application of the load to the fruit. Here, a rheological model of a watermelon fruit is also proposed, which is a series of ideally elastic and ideally viscous elements connected in series (**Fig. 1.36, *a***).

When a load is applied, the stresses σ in both elements are the same, and the deformation of the system consists of the deformation of individual elements. The rheological equation of this model:

$$\frac{d\varepsilon}{dt} = \frac{\sigma}{\mu} \cdot \frac{l}{E} \cdot \frac{d\sigma}{dt}, \tag{1.2}$$

where E – modulus of elasticity; μ – viscosity coefficient.

Solving this equation for an arbitrarily given deformation with the assumption that at the moment $l=0$ the material is in its natural state, let's obtain:

$$\sigma = E\varepsilon - \frac{E}{\tau}\int_0^{t_0} \varepsilon \, esp\left(\frac{t_0 t}{\tau}\right) \mathrm{d}t, \tag{1.3}$$

where t_0 – load application time; τ – relaxation time, $\tau=\mu/E$.

The pumpkin fruit has a different structure. The basis of the fruit is a rind with a high content of dry matter, which form a solid frame and a semi-liquid and liquid substance that fills the gaps between solid elements. The mass of the rind reaches 70 % of the total mass of the fruit. The inside of the fruit is filled with plastic pulp with seeds (50...60 % of the volume) and a gaseous substance. Therefore, the nature of the deformation of the pumpkin fruit is different than that of the watermelon fruit. To describe it, a rheological model is more suitable, containing three elements: two elastic and one viscous, with one elastic and viscous elements connected in parallel, and the second elastic element connected in series with them (**Fig. 1.36, *b***).

The rheological equation of stress versus deformation in this case:

$$\sigma = E\varepsilon + \tau H \frac{d\varepsilon}{dt} - \tau \frac{d\sigma}{dt}, \tag{1.4}$$

where E – long-term modulus of elasticity of the system, $E=E_1\ E_2/(E_1+E_2)$; E_1 and E_2 – elastic moduli of the elements; $H=E_2$ – instantaneous modulus of elasticity of the system; τ – relaxation time, $\tau=\mu/(E_1+E_2)$.

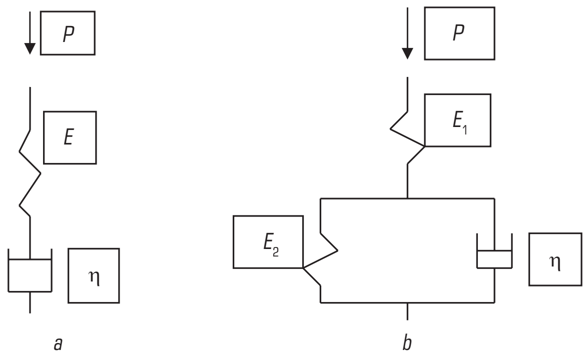


Fig. 1.36 Rheological models of the fruits of melons:
a – watermelon; *b* – pumpkin

Let's consider the process of destruction of the fruit of melons. The fruit can be destroyed in three ways: crushing, hitting and cutting. When crushing, the rate of application of the load is less than the rate of stress propagation in the fruit. This leads to the fact that when the working body acts on the fruit, internal stress spreads throughout its volume. Due to the anisotropy of the material, the fruit has weak sections, along which its chaotic destruction occurs, which does not coincide with the point of application of the load. All this leads to the fact that when crushing the fruit, great efforts are required for its destruction and it is impossible to obtain pieces of the required size.

The impact method of destruction is used in the IBK-5 and the seed dividing machine of the LSB-20 line. Its main advantage in comparison with crushing is that in the elastic-viscous material of the fruit, the speed of stress propagation is low and, at a high impact speed, the stress arising from it is concentrated at the point of contact of the working body with the fruit. This leads to local destruction with significantly less energy consumption.

In these machines, the fruit must be intensively chopped in order to separate the seeds from the rind and pulp. And according to the surface theory of material crushing, the energy spent on its destruction is directly proportional to the size of the newly formed surface. This means that the greater the degree of fragmentation of the fruit, the higher the energy consumption. In addition, the number of damaged seeds increases and the proportion of small pieces of rind, comparable to the seeds, increases, which complicates further peeling.

Thus, it is more expedient to use cutting to destroy the fruit. Moreover, the fruit can be cut into two halves or into pieces of a certain size. It depends on the type of working body for separating the seeds from the pulp.

At the present time, practically all developed working bodies for the selection of seeds cut the fruit into pieces. Let's take a closer look at this process. The best option is when the fruit is cut into equal pieces of a certain size, which is practically difficult to achieve. These pieces are best obtained using a knife grate. The power for grinding the fruit of the knife lattice has two components:

$$N_{gr}=N_{cut}+N_p, \tag{1.5}$$

where N_{cut} – energy consumption for cutting the fruit into pieces; N_p – energy consumption for pushing the pulp and rind through the lattice cells.

Upon further solution of the equation, let's obtain:

$$N_{gr}=\frac{Q}{\rho_d}\left[\frac{P_0}{\sqrt{b_d h_d}}+\frac{El_p}{b_k}\right], \tag{1.6}$$

where Q – productivity, kg/s; ρ_d – bulk density of fruits, kg/m^3; P_0 – specific resistance to cutting, N/m; b_d and h_d – distance between the horizontal and vertical knives, respectively; E – modulus of elasticity of the cut material, N/m^2; l_p – absolute axial deformation of the pushed piece, m; b_k – blade width.

The disadvantage of this grinding method is that energy is spent not only on cutting («live» energy), but also on pushing the pieces through the lattice cells («dead» energy).

Reducing the cost of «dead» energy is possible only by selecting the optimal parameters of the lattice knives (reducing the thickness of the knife and increasing the space), «living» energy – by increasing the size of the piece. But this parameter depends on the design of the working body for the separation of seeds. The second way is to reduce the specific cutting resistance.

Research has established that the determining factors affecting the energy performance of the cutting process: cutting speed, type of cutting, knife design. Cutting speed is the speed of the blade edge at a given point in the cutting direction. Based on the research, it can be concluded that with an increase in cutting speed, the energy intensity of the process decreases.

In the technological process, cutting with a blade to reduce the need for work is influenced by the sliding movement of the knife, which reduces the normal pressure of the knife on the material necessary to initiate the cutting process. Moreover, it is possible when the angle between the normal to the blade and the direction of its movement is greater than the angle of friction between the blade and the material. It is most advisable to use sliding cutting. However, its implementation at the lattice knives is associated with significant complications of its design. In addition, the variable cutting speed of the blade grid requires additional energy consumption.

Reiner proposed to evaluate the process of destruction of materials with elastic-viscous properties by the energy index of the critical specific work, equal to $A_{cr}=\sigma_p^2/2E$.

The equation of motion of an impinging body with mass M has the form:

$$M(d^2u/dt^2)=-P, \tag{1.7}$$

where u – magnitude of the absolute deformation.

Using the Laplace transform with respect to this equation, let's obtain:

$$Mp^2u - Mv_0 = -P, \tag{1.8}$$

where $v_0 = du/dt$ – initial impact speed.

Also, using the Laplace transform, let's find from the equation the value of the effort:

$$P(x,t) = F\eta p/(1+\tau p) \times (u/l), \tag{1.9}$$

where F – contact area of the colliding bodies; l – length of the deformed body.

Solving the equations together, it is possible to determine the maximum u_{max} and residual u_{res} deformation value, the maximum stress σ_{max} and the critical impact speed v_{cr}:

$$u_{max} = \frac{Mv_0 l}{\eta F}\left[1 - \left(\frac{1-k}{\sqrt{2k-1}}\right)\exp\left(-\frac{\pi}{\sqrt{2k-1}}\right)\right]; \tag{1.10}$$

$$u_{res} = \frac{Mv_0 l}{\eta F}\left[1 + \exp\left(-\frac{\pi}{\sqrt{2k-1}}\right)\right]; \tag{1.11}$$

$$\sigma_{max} = \frac{2Mv_0 l}{l\sqrt{2k-1}}\exp\left(-\frac{\pi}{\sqrt{2k-1}}\right); \tag{1.12}$$

$$v_{cr} = \frac{1}{\eta}\sqrt{\frac{A_{cr}\left(4\eta^2 Fl - El^2 M\right)}{2M\exp\left(-\frac{\pi}{\sqrt{2k-1}}\right)}}, \tag{1.13}$$

where $k = 2\eta F\tau/(Ml)$.

It is possible to see that the values of these quantities depend both on the kinematic parameters of dynamic interaction and on the physicomechanical and rheological properties of melons.

The obtained criterion equations can be used to determine the technological parameters of both melon combines, where minimal damage to fruits is required, and seed-dividing machines, where it is necessary to destroy the fruit with minimal energy consumption.

CONCLUSIONS TO SECTION 1

This chapter shows studies of the composition, properties, physical and mechanical properties of the fruits of melons: pumpkin, melon and watermelon.

The results of pumpkin research are presented, it turned out that the shape index of the fruits of pumpkin varieties Volzhskaya gray 92 and Krupnoplodnaya 1 was 0.75 and 0.8, respectively. Friction coefficients were studied for seeds; they depend on the type of surface and are most important for rough surfaces. In addition, the coefficients of friction depend on the moisture content of the seeds themselves. The strength of the spermatic cord characterizes the ability of seeds to isolate from fruits and is estimated by the amount of effort required to break the bonds of seeds with feeding vessels. The pulling force of the sac depends not only on the moisture content of the investigated fruits, and therefore on their shelf life after harvesting, but also on the section in which the measurements were made. At the peduncle and receptacle, where fusion of the feeding vessels is observed, the pull-off force reaches its maximum value. According to the results of the experiments, the average value of the density of the pumpkin rind was 1.14 g/cm^3 for the Volzhskaya gray 92 pumpkin and 1.15 g/cm^3 for the Krupnoplodnaya 1 pumpkin. The density of the subrindal pulp for the same varieties was 1.10 and 1.11 g/cm^3, respectively. Analyzing the data obtained, it is possible to conclude that the density of the rind and subrind pulp is somewhat greater than unity.

The results of research of fruits of a melon of Kazakhstan selection are presented. The yield of pulp in different varieties of melon varied from 53.13 to 71.75 %, the highest – in the Myrzachulskaya melon, the lowest – in Ameri. The thickest rinds are in Inzhirnaya, Ameri, Guliabi and Gurbek, respectively 34.97, 33.13, 31.62 and 31.24 %. Basically, these are melons of late varieties, and mid-season varieties. More rind makes them more preferred for pectin production. The seed content varies from 1.18 to 3.22 %. The dependence of the seed content on which class in terms of ripening the melons belongs to is not observed. This indicator depends only on the characteristics of the variety. Also, depending on the variety, the density of the melon pulp changes, the frictional properties of the seeds, just like pumpkin, depend on the surface and moisture of the seeds. Investigated the piercing of the melon rind for the implementation of a machine for peeling melon from the rind. The conducted studies allow to conclude that the average value of the specific cutting force for the studied varieties of melon with an error not exceeding 7.2 % for the pulp and 2.5 % for the peel can be used in engineering calculations for various varieties, provided that a safety factor is used. A rheological model of pumpkin and watermelon is presented.

The geometric parameters of the melon of eight domestic varieties have been determined, which are most realizable in Kazakhstan from the end of June to the end of October, they differ in ripening time, size and shape, the shape index varies for different varieties from 0.92 (spherical) to 2.4 (cylindrical). This requires the development of a versatile rind separation unit.

The physical and mechanical characteristics of various parts of the melon have been determined, which must be taken into account when developing or selecting mechanical equipment for preparing fruits for processing. Melon density 1.14–1.32 kg/m^3, adhesion stress for pulp 2.3–3.2 kPa, friction coefficient 0.19–0.31, specific cutting force 2,386–2,485 N/m, rind piercing force 3.22–33.87 N, depending on the diameter and angle of sharpening of the indenter, as well as the bulk modulus of elasticity in compression – 3,258–3,931 kPa.

It was found that the dependences of the elastic modulus on the compression speed, the specific cutting force on the speed and angle of sharpening of the knife, and the piercing force on the diameter and angle at the apex of the indenter are linear. The coefficients of the equations are determined. The R^2 index for all equations is close to unity, which indicates a high degree of reliability of the equations.

The chemical composition of the melon pulp of the most common melon varieties has been determined. It has been established that the melon pulp contains 82.8–90.3 % moisture, 0.8–1.0 % dietary fiber, vitamins A, B, C, E, PP, a wide range of macro- and microelements, which makes it suitable raw material for the production of functional food products. The seeds contain essential amino acids, fats, vitamins and trace elements that allow the seeds to be used to obtain oil. All investigated varieties of melon contain pectin, and its content in the rind is higher than in the rest of the fruit. The proportion of protopectin in the total content of pectin substances is in the range of 75.37–96.25 %, which makes it possible to economically process melon rind into pectin.

2 TECHNICAL MEANS FOR PROCESSING MELON FRUITS

ABSTRACT

In this chapter, possible technologies for processing melons are considered, an analysis of existing and prospective machines for the implementation of these technologies is given, as well as the results of the authors' research in this direction based on the analysis of scientific and technical information.

KEYWORDS

Technology, processing, rind, pulp, seed extraction, rind peeling.

2.1 DIRECTIONS FOR POST-HARVEST PROCESSING OF PUMPKIN FRUITS

Recently, there has been interest in the processing of melon products. For example, obtaining oil, medicines and dyes from seeds, as well as candied fruits, juice concentrates from the purified pulp of watermelon, pumpkin and melon.

For the further revival and development of the vegetable and melon industry, it is necessary to fully use the accumulated scientific potential and develop a strategy for its development. The wide field of application of the products of processing the fruits of melons requires the selection of the necessary machines to obtain a specific end product.

The choice of the required set of machines for harvesting and processing pumpkin is determined by the selected technology, which depends on the ultimate purpose of using the fruit. There are three main directions of fruit processing: for technical purposes, for seed material and complex processing.

When processed for technical purposes, the fruits are crushed and used for livestock feed. As a rule, seeds are preliminarily separated from the crushed mass, which go for further processing.

When processing for seeds, the main task is to maximize the extraction of seeds with minimal damage to them. The remaining waste (pulp, juice) is either disposed of or used as animal feed.

Integrated processing means obtaining seeds, pulp and juice after processing, which can be used for technical or food purposes. With the same technological operations, the structure of the production process takes on different forms depending on the quantity, combination, sequence and mutual influence of the operation. Technical and economic indicators largely depend on this.

Therefore, the first task is to substantiate the structure of the production process. When processing for technical purposes, there are currently two main directions in the technology of processing the fruits of melons: processing in the field with mobile machines and processing at stationary points (**Fig. 2.1**).

In the first case, after picking, the fruits are crushed, a large rind is released from the heap, which is thrown into the field, and the seeds, along with the pulp, are delivered to a stationary point for final processing.

In the second case, all processing is carried out at a stationary point, which makes it possible to organize the collection and further use of rind with pulp. If the fruits are processed for food purposes, then all operations are performed only at a hospital, where the necessary sanitary and hygienic requirements can be provided.

Each technology option may have its own advantages and disadvantages, and each of them requires its own sets of operations, technical means for their implementation, certain agrotechnical requirements, and so on, but the process of fruit processing is decisive (**Fig. 2.2**).

Depending on the purpose of processing, the fruits can be completely crushed, cut into pieces or halved. The method of grinding also determines the method of separating the seeds from the pulp. With intensive grinding, the seeds are immediately separated from the pulp and from the placenta of the seed sacs, but further separation of the heap is necessary to isolate the seeds from it. When the fruit is cut into pieces or in half, the seeds remain in the seed sacs and must be separated. The seeds are peel and immediately fed for standard processing. If the pulp is later used for food purposes, then the fruits are pre-cleaned from the outer cover. Thus, the methods of the processing process determine the technological scheme and design of the fruit processing machine.

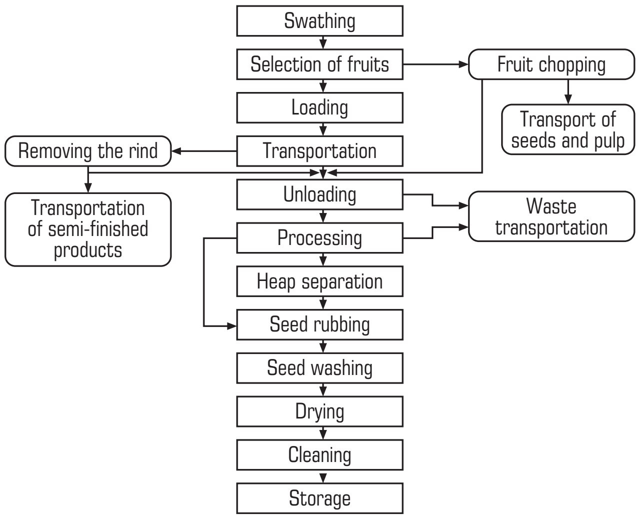


Fig. 2.1 Scheme of technologies for the primary processing of pumpkin fruits

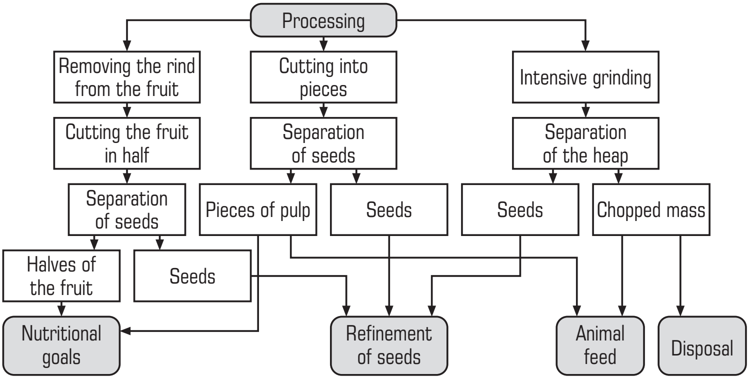


Fig. 2.2 Scheme of processing pumpkin fruits

2.2 MECHANIZATION OF SEED EXTRACTION

Farms specializing in melon growing use seed lines, or separators produced by industry, to perform this operation with large volumes of processed products.

Separators allow mechanizing only the process of crushing fruits and separating seeds, therefore they are mainly used in the processing of fruits for technical purposes.

The existing seed lines involve complex processing of fruits, since they allow almost completely mechanizing all operations from loading the fruit to utilizing the juice and rind. But the resulting processed products can only be used for technical purposes. In addition, for their efficient operation, it is necessary to process a large number of fruits (about 70...100 tons per shift), which is possible only in specialized seed farms.

The most widespread are the LSB-20 and LVS-30 lines. Line LSB-20 (**Fig. 2.3**) is intended for isolation, washing, drying and grinding of pumpkin seeds. The technological process of its work is as follows. The fruits of melons delivered from the field and loaded from the overpass into the tank of the receiving hopper 2, previously filled with water. With the help of the water flow created by the pump 19 and the unloading conveyor, the fruits are fed into the seed separator 3, where they are crushed. The crushed mass is fed to the sieves of the screens. Seeds, small rind and pulp pass through the openings of the sieves onto the pallets and together with water enter the collector 4. The large rind goes down the sieves into the trough with screws 5. The screws direct the rind to the scraper conveyor 6, which transfers them to the waste bin 7.

From the collector 4, the seeds with pulp and water by the fecal pump 8 are pumped into the rubbing machine 9. Here they first enter the upper pulp drum, and then into the lower one. Fine rind and pulp pass through the sieves of the drums and are removed together with the water into the sewer.

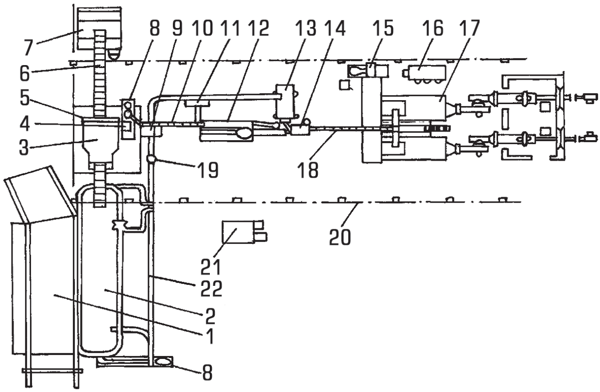


Fig. 2.3 Scheme of the seed line LSB-20: 1 – overpass; 2 – receiving hopper; 3 – seed separator; 4 – collection; 5 – screw; 6, 10, 18 – conveyors of rind, raw and washed seeds; 7 – bunker for rind; 8, 19 – pumps; 9, 14 – rubbing machines; 11 – compressor; 12 – machine for washing seeds; 13 – tank; 15 – grinding machine; 16 – seed peeling machine; 17 – drying equipment; 20 – canopy; 21 – control panel; 22 – pipeline

The seeds with the remaining impurities from the second wiping drum are fed to the scraper conveyor 10, which directs them to the machine for washing seeds 12. Air is supplied to the lower compartment of its bath from the compressor 11, which helps to remove the pulp adhering to the seeds of the peel and small rinds. Further, the seeds are carried away by water along the tray into the cyclones of the machine for washing seeds 12. Here, water is supplied tangentially to the cylindrical surface of the cyclone, swirling the water column in it. Seeds, which have a density of more than 1 g/cm^3, settle to the bottom of the cyclone and are carried by the auger into a single-drum rubbing machine 14. Impurities, together with water, are discharged to the sewer through a pipeline. If the seeds have a density of less than 1 g/cm^3 (pumpkin, zucchini), then a small rind settles to the bottom in the cyclone, which is removed by the auger into the sewer, and the seeds fall into the rubbing machine.

In the case when part of the seeds floats, and part drowns, both flows from the cyclone are redirected to the rubbing machine. From it, the squeezed seeds are fed to the reverse conveyor of the dryer 18, which directs them to one of the storage bins of the dryer 17. After filling it, the direction of movement of the conveyor belt changes, and the seeds are fed to another bunker. From the hoppers, the seeds are poured onto the mesh bottom of the drying trays and leveled.

After drying, the seeds are poured into the hopper of dry seeds by lifting the tray, then they are fed to the machine 15 for grinding by scraper conveyors. After that, the seeds are cleaned of impurity sediments on a seed peeling machine 16 and packed into sacs.

The productivity of the LSB-20 line (in terms of fruit) when separating seeds: watermelon – 21…25 t/h, cucumber – up to 10 t/h, pumpkin – up to 15 t/h.

The disadvantage of this line can be considered that for its placement it is necessary to allocate a rather large area on the ground. It has a large consumption of electricity and water for the processing of 1 ton of fruits. It becomes necessary to utilize a very large amount of juice, which requires the construction of special settling ponds. Irrecoverable loss of seeds is great, reaching 20 %.

All this sharply increases the cost of production on the LSB-20 line.

The LVS-30 line is also designed to isolate seeds from the fruits of melons (**Fig. 2.4**).

It works as follows.

The fruits are fed into the tank 2 by dumping conveyors. The reel 1, rotating, advances the fruits to the conveyor 4, which feeds them into the crusher 5. The crushed mass passes through the sieves of the screen 7, rinsing with water from the shower device 6. Seeds stand out from the mass and, passing through the openings of the sieves are collected in the pallet 8, from where they are fed into the wipe 17 by a fecal pump.

In the rubbing machines 17 and 15, as well as in the hydrocyclone of the machine for washing seeds 18, the technological process proceeds in the same way as in similar machines of the LSB-20 line.

The washed and wrung-out seeds are fed to a vehicle that transports them to the floor dryer.

The rind, descending from the sieves of the screen, is fed into the tank 9 of the seed catcher. Here, the seeds adhered to the rinds are separated, pass through the mesh and are collected in the lower part, and the rind is removed by conveyors 11 and 12 into the waste bin 13. From bath 9, the seeds are periodically pumped out into the pulverizing and washing machine, where they are washed and fed into the total mass of seeds. Such a catcher works effectively at a seed density of more than 1 g/cm^3 (cucumber, melon, watermelon).

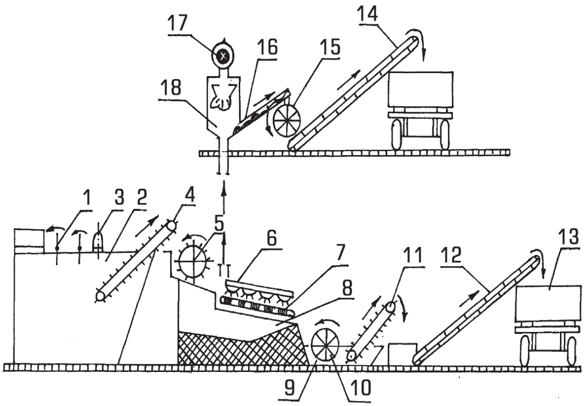


Fig. 2.4 Scheme of the seed line LVS-30: 1, 10 – reel; 2 – tank; 3 – pump; 4, 11 – unloading conveyors; 5 – fruit grinder; 6 – shower device; 7 – sieve screen; 8 – pallet; 9 – seed catcher; 12 – conveyor for rind; 13 – bunker; 14, 16 – scraper and screw conveyors; 15, 17 – rubbing machines; 18 – machine for washing seeds

The productivity of the line (by fruits) for one hour of the main work on the selection of seeds of cucumber and melon is 20...25 tons, watermelon – 30...35 tons, pumpkin – 18...20 tons.

The disadvantages of this line, as well as the LSB-20 line, are: large dimensions, attachment of the place allocated for the line to the presence of reservoirs, the resulting mass of the rind cannot be used by the fruit-processing industry, as well as the high energy consumption of the isolation process. Damage to seeds at the exit, after the completion of the entire process, is 10...18 %, loss of seeds in the exit «rind» 8...10 %.

Also, a similar type of line or sets of machines for performing all operations are currently produced by a number of enterprises (CJSC NPO Europe-Biopharm, Volgograd; JSC Elevatormelmash, Krapotkin, Krasnodar Territory).

In the process of obtaining seeds of melons, the most difficult and time-consuming operation is their isolation from the fruit. Its results not only affect the course of the technological process, but often determine one or another technology for further processing of the obtained seeds. For example, contamination of seeds with particles of fine rind and pulp leads to the need for additional wiping of raw seeds, and then peeling and sorting dry ones. It is known that the fruits of pumpkin crops contain only 0.8–2 % of seeds from the total mass, therefore, in the process of obtaining them, it is necessary to process a large volume of testis fruits, which, as a rule, are characterized by high mechanical strength (pumpkin, zucchini, etc.) [45, 46]. As a result, the process of separating seeds from fruits also accounts for the main share of energy costs in obtaining seed products. Currently, a wide range of machines and working tools are used to isolate seeds from fruits of pumpkin crops (**Fig. 2.5**).

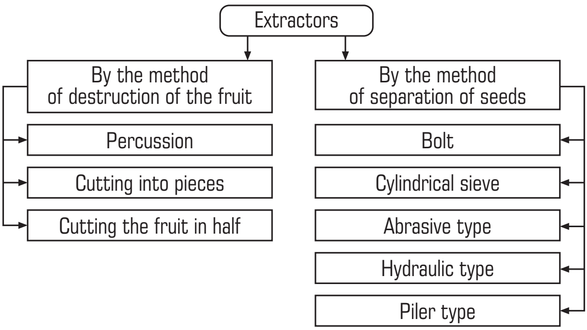


Fig. 2.5 Classification of emitters

The largest and most widespread group is made up of separators with impact separating devices, with separation of the heap on a vibrating screen.

These seed extraction machines are based on the principle of complete crushing of the fruit, which separates the seeds from the placenta and then separates them from the coarse rind on a screen. But if this principle of separation is acceptable when processing juicy fruits such as tomatoes, then when processing fruits of pumpkin, melon, zucchini, the loss of seeds reaches 18...23 %. This is due to the fact that in the heap obtained, up to 70 % are rind particles commensurate with the size of the seeds, which significantly complicates the subsequent separation of the seeds. At best, the crushed rind can be used for livestock feed, while in melons it is a valuable raw material for the confectionery and canning industry.

In addition, there is a high degree of injury to seeds, both during crushing and separating the seed heap. This adversely affects the quality of the seeds obtained.

The most common machine of this type in melon farms is the commercially available grinder of melons, cucumbers, zucchini and pumpkin IBK-5A (**Fig. 2.6**).

The versatility of this machine is explained by the simple technological scheme of its operation.

The machine is mobile and can operate both from the power take-off shaft of a 1.4 kN tractor, and from an electric motor with a power of 4.5 kW.

In the loading tray 1, the fruits are fed manually, and then the buckets of the conveyor 2 are fed into the receiving hopper 3, where they are captured by the pins of the drum 4 and crushed. The resulting mass goes to the screen 5. Seeds, small crumbs, juice pass through the screen of the screen to the bottom, through which they drain into the wiper 7. The large rind moves along the screen of the screen, and to the unloading conveyor 6, which feeds them into containers.

The four-blade drum of the rubbing machine, grinding the mass, moves the seeds to the unloading tray, and juice and small impurities through the holes in the drum casing fall on the pallet and pump 8 is removed from the machine. However, control tests by machine testing stations showed that seed losses during isolation reach 25 %, and the resulting seeds need additional peeling, since they contain up to 30 % pulp and 20 % crushed rind in their mass.

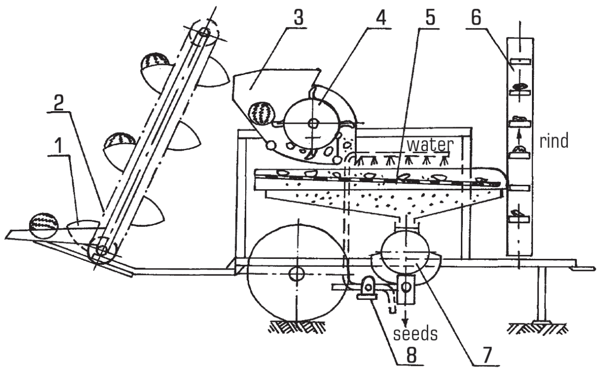


Fig. 2.6 Scheme of a melon crop grinder IBK-5A: 1 – tray; 2 – loading conveyor; 3 – bunker; 4 – drum; 5 – screen; 6 – unloading conveyor; 7 – rubbing device; 8 – pump

In addition, the productivity of the machine is low, which does not exceed 8 t/h in the processing of watermelon fruits, 4 t/h of zucchini and pumpkin, and 5 t/h of cucumbers. It is also necessary to point out the incompleteness of the technological process, the impossibility of using crushed rind and pulp for animal feed, juice in the canning industry.

Another separator of melons seeds VBL-20 (**Fig. 2.7**), installed in the LSB-20 line LSB-20, works in a similar way, but its technological scheme has a number of differences. It has a receiving tray 5 in the upper part of the frame 1 and the fruits from it go to two chopping drums, pin 4 and hammer 6 with receiving hopper 3. Seeds are allocated on two screens 9 with shower 8. This design can significantly increase the productivity of the machine.

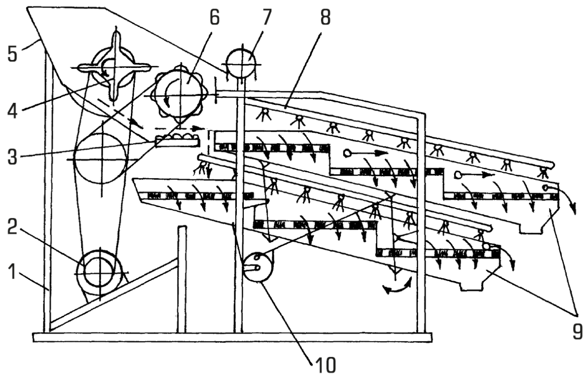


Fig. 2.7 Scheme of the VBL-20 seed extractor: 1 – frame; 2 – drive of drums; 3 – concave; 4, 6 – pin and beat drums; 5 – receiving tray; 7 – drive of screens; 8 – shower device; 9 – sieve screens

The highlighter has the following quality indicators of the working process when processing pumpkin fruits: irreversible loss of seeds in the «rind» yield – 8…10 %, the purity of the «seed» yield – 9…10 %, i.e. in the output – 90…91 % of the rind. Thus, although the quality of its work is better than that of the IBK-5A, the main disadvantages are the same.

The above machines have a screen type separator. However, with the development of semen technology, more and more preference is given to separators with a rotary separator. The technological process of these machines consists in separating the seeds from the crushed mass as a result of sifting it through the lattice surface of the rotating separator. Such separators have higher technical and economic indicators in comparison with the considered machines, since they are simple to manufacture, do not stick and have a high separating ability.

The technological scheme with a rotary separator is used to separate seeds from the fruits of melons in the Austrian combine KE 2000 MOTY (**Fig. 2.8**).

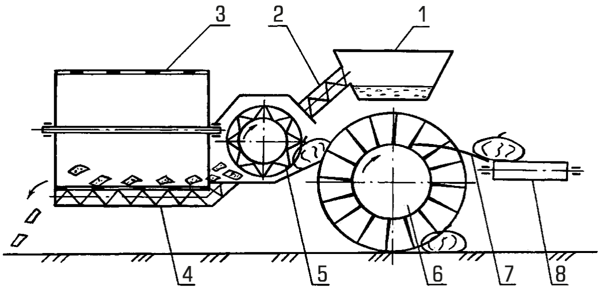


Fig. 2.8 Scheme of the KE 2000 MOTY combine for the extraction of seeds from melons: 1 – storage hopper; 2 – auger for feeding seeds; 3 – rotary separator; 4 – pallet; 5 – pressure drum; 6 – needle pick-up; 7 – puller plates; 8 – feeding conveyor

This combine extracts seeds from melons directly in the field. To supply fruits to the combine, a drum pick-up 6 is used, on the needles of which the fruits are pricked when the combine moves along the swath. Plates 7 are installed in the upper part of the pick-up, which serve as a fruit picker from the pick-up needles. The fruits to be processed are rolled from the stripping plates onto the feeding conveyor 8. The conveyor drives the fruits to the pressing drum 5, which crushes them into pieces by crushing.

The crushed mass after the pressure drum is sent to the rotary separator 3, where the seeds are directly separated. Passing through its lattice surface, the seeds fall into the pallet 4, from where the auger 2 is sent to the storage hopper 1. When the hopper is filled, the seeds are loaded into vehicles and delivered to stationary points for further processing (wiping, washing, drying).

The separator of seeds (**Fig. 2.9**) works according with a.p. USSR No. 1768126. Its peculiarity is a separator in the form of a hexagonal pyramidal rotor, in which the separation of seeds from the rind occurs as a result of active shaking and intense contact between neighboring parts of the fruit. The separated seeds are sifted through the rod sieves 11 and through the seed collection tray 9 are fed to the auger, which serves to feed them for further refinement [47].

Large pieces and a heap are removed from the separator along the tray for rind pan 8 and are used as feed for farm animals or disposed of as production waste.

This is the main disadvantage of this machine. In addition, there is a high contamination of seeds with small particles of the heap, which leads to the need to use special peeling devices, which complicates the technological process of seed extraction and leads to additional injury to the seeds. The machine for the extraction of seeds HH 5500 (USA) operates according to a similar scheme.

Seed separators of the conveyor type with abrasive working bodies are more effective.

The harvester for the extraction of seeds from the fruits of melons with working bodies of a brush type (RF patent No. 2301612) works more efficiently [48]. It includes (**Fig. 2.10**) a storage hopper, a feed conveyor, a chopping drum, a brush separator made in the form of rows of brush drums installed one above the other, a screen, a seed auger and a discharge conveyor.

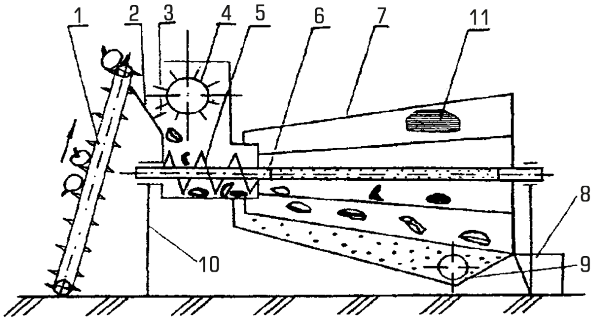


Fig. 2.9 Scheme of a seed separator with a rotary hexagonal separator according to author patent USSR No. 1768126: 1 – supply conveyor; 2 – grinding device; 3 – shear comb; 4 – pin drum; 5 – transporting auger; 6 – rotor shaft; 7 – hexagonal pyramidal rotor; 8 – tray for rind; 9 – seed collection tray; 10 – frame; 11 – rod sieves

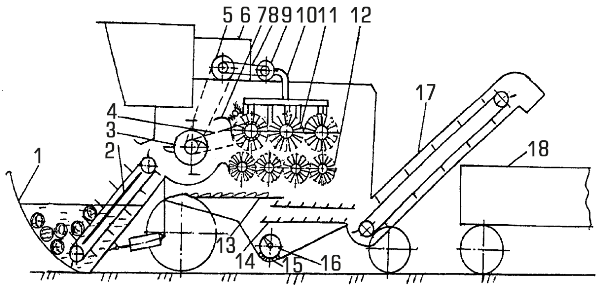
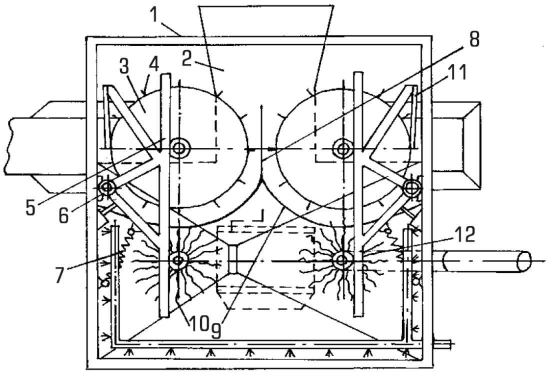


Fig. 2.10 Scheme of a combine for the extraction of seeds from the fruits of melons: 1 – storage hopper; 2 – feed conveyor; 3 – grinding drum; 4, 8 – drive; 6 – engine; 7 – shield; 9 – pump; 10 – pipeline; 11, 12 – brush drums; 13 – transport board; 14 – sieves; 15 – mesh casing; 16 – seed auger; 17 – unloading conveyor; 18 – vehicle

The workflow is as follows. The fruits from the storage hopper filled with water are fed into the grinding chamber, where they are cut into pieces of a certain size, and then fed into the gap between the upper and lower rows of brushes, which rotate towards each other, with each subsequent brush having a speed higher than the previous one. This achieves a relative movement of adjacent brush needles. As a result, the seeds are separated from the placenta and the pieces are moved between the brushes. The screen separates the seeds and the rind, which is fed into the vehicle by the unloading conveyor, and the seeds, passing through the screens of the screen, are fed into the hopper by the auger. A significant drawback of this machine is that the percentage of seeds injured by brushes is high.

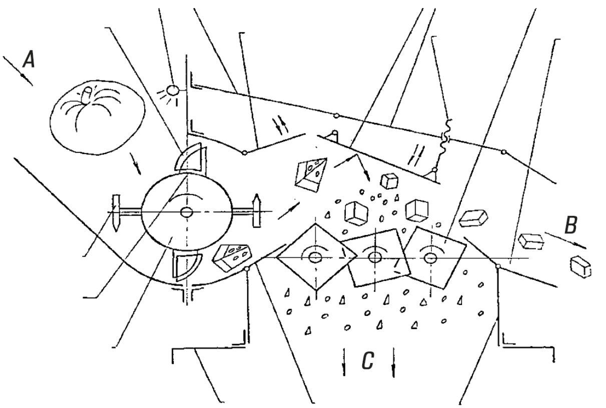
The separator of seeds from fruits (**Fig. 2.11**) allows to save the pulp for further processing according to a.p. USSR No. 827015 [49].



⬡ **Fig. 2.11** Scheme of a seed separator from fruits according to a.p. USSR No. 827015:
1 – frame; 2 – receiving hopper; 3 – drum grippers; 4 – needles; 5 – movable frame;
6 – pin; 7 – spring; 8 – knife plate; 9 – guides; 10 – elastic elements;
11 – puller; 12 – brush

It works in the following way. The fruits enter the receiving hopper 2, are pricked with the needles 4 of the drum grippers 3, installed on the movable frame 5, are pulled through the knife plate 8, which cuts them into two halves. Then the halves are bred along the rod guides 9 and fed under the influence of the elastic elements 10 of the shaped brushes 12, which separate the contents of the seed cavity from the pulp of the fruit. The processed halves are removed from the gripper needles with pullers 11. For the possible separation of seeds from fruits of different diameters, the frames 5 of the drum grippers 3 are spring-loaded. The disadvantage of this machine is that the round brush working body does not completely separate the seeds from the halves of fruits that are not spherical in shape and of different sizes. In addition, the brushes have an impact on the seeds, which leads to their microdamage and a decrease in field germination.

In addition, there is an extractor VSB-20 of the piler type (**Fig. 2.12**), the working body of which is a series of multifaceted drums rotating in one direction [50]. In the process of work, the crushed mass supplied to them by the edges of the drums is intensively thrown and hit against the baffle plate, due to which conditions are created for separating the seeds from the pulp and passing them through the gaps between the drums. But this design is inoperative when processing low-juiced fruits, for example, pumpkin fruits.



⬡ **Fig. 2.12** Scheme of the VSB-20 extractor: 1 – transverse knife; 2 – shower device; 3 – cover; 4 – guide curtain; 5 – reflective shield; 6 – screw; 7 – piler mechanism; 8 – unloading tray; 9 – frame; 10 – grinding drum; 11 – longitudinal knife

2.3 MECHANIZATION OF RIND REMOVAL

When developing a machine for removing rind from melons, it is necessary to take into account all the nuances associated with the biological, biochemical and physical-mechanical properties of the fruit.

For this purpose, a study was carried out of the most common methods of peeling plant materials from the outer cover. Unfortunately, at the moment, when processing melons, the operation to remove the rind is performed manually. For a number of reasons, almost all devices and machines have remained just experimental developments. They were not introduced into industrial production.

The greatest experience has been accumulated in the matter of peeling fruit and vegetable raw materials. Peeling is carried out to remove peels and inedible parts of raw materials such as stalks, seeds, seed nests from fruits, vegetables and tubers.

Removal of rind is carried out in various ways: mechanical, physical, chemical and combined (**Fig. 2.13**). This division is conditional. For example, the physical method includes both steam peeling by roasting, and water-steam and steam-water thermal. With the mechanical method, to increase the efficiency, the product is exposed to water, which softens the surface layer, and with the steam-water thermal method, mechanical action is used.

The creation of equipment for peeling led to the division of the process into two stages: peeling and additional peeling. Such a division has appeared because machines and devices that implement various methods of conducting the process do not completely remove the rind, therefore, a manual final peeling is necessary to remove the remnants of the rind, eyes and damaged areas. Actually an indicator of the quality of machine peeling, perhaps, the volume of additional treatment. The mechanical method is widely used for peeling potatoes, root crops – beets, carrots, white roots, onions, that is, raw materials that have a rough rind. The essence of the mechanical method is that the outer cover is peeled off against the rough surface of the working body and the walls of the working chamber of the machine. In this case, there should be a relative movement between the surface of the tuber, the rough surface of the working tool and the walls of the working chamber. At the same time, the tuber must be pressed against the rough surface with a certain effort so that the particles of the rough surface can go deeper into the tuber and, with its further movement, make micro-cuts (peeling off) of the pieces of the tuber surface. During peeling, water is supplied to the working chamber, which washes away the separated particles of the peel from the rough surface and the tubers to be cleaned and takes them out of the working chamber of the machine.

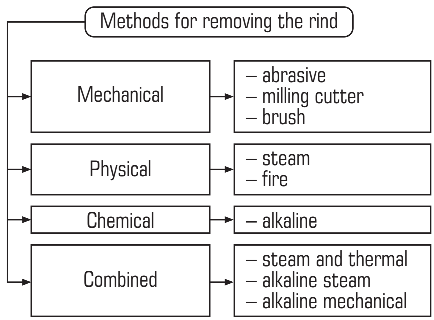


Fig. 2.13 Classification of rind removal methods

The uniformity of peeling will depend on the uniformity of contact of the entire surface of the tuber with the rough working surfaces of the machine, as well as on the intensity of pressing the tuber to these surfaces and the speed of relative movement between them. At the same time, too strong effect of tubers on the surface of the working body and the walls of the working chamber leads to product losses.

The essence of the physical (thermal), in particular steam, peeling method is that the tubers (roots) through the dosing loading device are fed into the working chamber of the steam peeling machine, in which they are exposed to hot water vapor at an increased pressure (0.4–1.1 MPa).

Depending on the variety and shelf life of potatoes and other root vegetables, the steaming time can be adjusted. When unloading, the tubers enter a special unloading device, where the pressure is rapidly reduced (released) to atmospheric. In some machine designs, the pressure drop occurs in the working chamber itself. Due to the increased temperature of the steam, a small surface layer of the tubers is boiled. Then the tubers enter the washing and peeling machine, where the peel and partially cooked layer are peeled off and washed off. At the same time, post-treatment is reduced to a minimum, and calibration is eliminated.

The steam peeling method has significant advantages: reducing the amount of waste, increasing the degree of peeling, reducing surface damage; elimination of preliminary calibration.

The steam-water-thermal method is based on the fact that the vegetable raw material is consistently exposed to the action of steam and water, as well as mechanical stress during friction of tubers during steaming and peeling. Here the product must be pre-calibrated in order to improve the blanching quality at the optimum processing time.

The physical method includes not only the steam peeling method, but also the so-called «fire» peeling method, the principle of which is that the tubers in thermo-units are fired for 8–10 seconds at a temperature of 800–1300 °C. At the same time, the peel is charred, moisture in the subcutaneous layer of the tuber almost instantly turns into steam, which separates the peel from the pulp of the tuber and breaks it, and the surface layer, in turn, is boiled to a depth of 0.6–1.5 mm.

Firing is carried out in rotating lined drums heated by natural gas burners or nozzles in which liquid fuel is burned (gas-thermal firing), or when moving with conveyor chain circuits in openwork trays in electric heating furnaces.

Subsequently, the tubers, processed in thermo-units, enter the washer-peeling machine, where, with the help of rotating brushes and rubber rollers, with abundant exposure to water, the peel and partially cooked layer are separated. Depending on the type and condition of the vegetables to be peeled, the time of their processing in the thermo-unit can be regulated.

The essence of the chemical peeling method is based on the processing of raw materials with an alkali solution. The technological process can be different. In some cases, the alkali solution is heated directly, in others – the tubers taken out of the solution. After treatment with an alkaline solution, the tubers are cleaned on roller machines and washed from alkali.

The equipment itself for carrying out alkaline treatment is carried out either in the form of a special bath with a perforated rotating drum, or a drum with a rotating auger. However, with this method, alkali is hardly washed from the surface of vegetables and it is necessary to use surfactants – wetting agents.

One of the most common combined methods is the alkaline steam method. It combines chemical and physical peeling methods. In this case, tubers or root crops are processed in chemical and steam units: first, the tubers are treated with a 12 % solution of caustic soda at a temperature of 75–80 °C for 10 minutes, and then with live steam at a pressure of 0.5–0.6 MPa in within 1 min.

After analyzing the above methods for removing the outer cover, we can conclude that the most preferred method for removing the rind from pumpkin fruits is the mechanical method of removing the rind. Among the machines for peeling the outer cover from fruit and vegetable raw materials, devices for removing the rind from the fruits of melons, which provide high productivity and good quality of peeling, there are very few.

Of particular interest is a device for peeling and washing root and tuber crops according to a.p. USSR No. 912131 (**Fig. 2.14**). It contains a bath 1, in the upper part of which, parallel to its loading and unloading ends, abrasive rollers 2 located on straight supports 3 and 4 are installed in one plane with the possibility of rotation in one direction. Rows of arranged rollers has an opposite winding. Instead of abrasive rollers, rollers with a corrugated screw surface can be installed. Above the abrasive rollers in the same plane are brush drums 5 mounted on movable supports 6 with the possibility of rotation in the direction opposite to the direction of rotation of the rollers, and equipped with a drive with a gear drive 7, and the threads of the drums are made with thickenings in the form of plates or nodes [51].

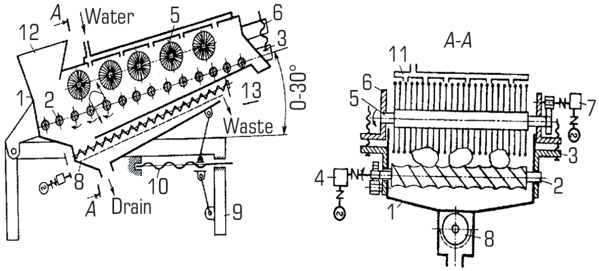


Fig. 2.14 Device for peeling and washing root and tuber crops according to a.p. USSR No. 912131: 1 – bath; 2 – roller; 3, 4 – supports; 5 – drum; 6 – support; 7 – gear transmission; 8 – auger; 9 – frame; 10 – lifting mechanism; 11 – collector; 12 – loading tray; 13 – unloading tray

The device works as follows. Potato tubers through the loading tray 12 fall on the rotating rollers 2. Passing between the rotating rollers 2 and the brush drums 5, they are processed in one layer. Due to the fact that each of the two rows of located rollers is equipped with an opposite winding, they, rotating in the direction of unloading the product, transfer to each tuber two degrees of freedom: rotation around an axis, parallel to the axes of the rollers, and rotation around an axis perpendicular to the axes of the rollers. In this case, each subsequent pair of rollers changes the rotation of the tubers around the axis perpendicular to them, as a result of which the tubers are forcibly oriented relative to the abrasive surface of rollers 2 and brush drums 5, due to which a more uniform peeling of the surface of tubers from rind and dirt is carried out. Brush drums 5, rotating in the direction opposite to the direction of rotation of rollers 2, with their threads remove impurities from deepened areas and cracks and promote tubers, and the teeth or knots on the threads increase the degree of peeling.

The removed mass of peeling is washed off from the brush drums 5, rollers 2 and potato tubers with water jets from the collector nozzles 11 and enters the auger 8, where the solid fraction of the waste is separated from the liquid. Peeled and washed potatoes are unloaded through tray 13.

For peeling the fruits of melons, vegetables and fruits, an installation has been developed (RF patent No. 2221465) consisting of a welded feed hopper 1, in the lower part of which there is an upper brush drum 2, designed to influence the fruit being cleaned 3. From the side opposite to the upper brush drum, in the lower part of the hopper there is an adjustable concave retaining brush 4. The position of the brush is changed using the adjusting rod 5 and the bracket on the brush (**Fig. 2.15**) [52].

Between the upper brush drum and the retaining brush, a lower brush drum 6 is provided, which is tangent to the surfaces of the upper brush drum and the retaining brush. The upper and lower brush drums are connected by a gear transmission 7, which drives the lower drum.

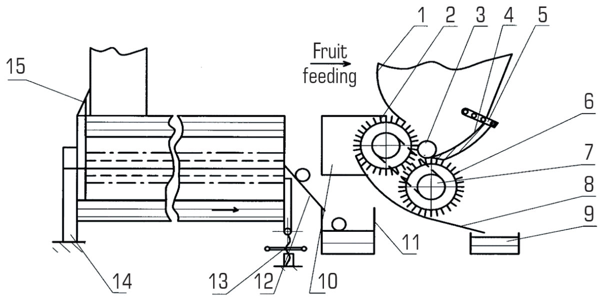


Fig. 2.15 Device for peeling fruits of melons, vegetables and fruits according to RF patent No. 2221465: 1 – feed hopper; 2 – upper brush drum; 3 – fruit; 4 – retaining brush; 5 – rod; 6 – lower brush drum; 7 – chain transmission; 8 – pitched board; 9 – conveyor of peeled rind; 10 – drive; 11 – conveyor of peeled fruits; 12 – tray; 13 – tray; 14 – movable support; 15 – frame

Under the brush drums, a pitched board 8 is fixed for removing the peeled rind, at the end of which a conveyor 9 for removing the peeled rind is mounted. The rotary motion to the upper brush drum is transmitted from the drive 10, the power source can be an electric motor or a tractor power take-off shaft. At the exit from the brush drums there is a conveyor 11 of peeled fruits, which are sent to it by a tray 12 for feeding peeled fruits. The inclination of the drums relative to the horizontal plane is adjusted by the screw mechanism 13. The front part of the frame of the brush drums is installed on a movable support 14. All units and parts of the installation are mounted on the frame 15.

The installation works as follows. The fruits to be cleaned are fed by a conveyor or manually into the feed hopper from the side indicated by the arrow. Rolling down the wall of the bunker, the fruits fall into the impact zone of the brush drums, the outer part of which has stainless wire needles. The rotation of the brush drums and the installation of the retaining brush ensure that the fruit slides relative to the brush surfaces and removes the upper rind from the fruit. At the same time, the fruit rotates and its surface is cleaned evenly. The movement of the fruit along the axis of the brush drums is due to the slope, which is regulated by a screw mechanism depending on the variety and their size. The adjustment of the position of the retaining brush also depends on the variety and size of the fruit. These adjustments are made during plant operation, with the decisive factor being the optimum peeling quality at maximum performance. The fruits that have passed along the entire length of the brush drums are rolled down the peeled fruit feed tray onto the peeled fruit feed conveyor, which feeds them for processing. The peeled peel from the fruit goes to the pitched board and, under the influence of its own weight, moves to the conveyor for removing peeled peel. As the size of the fruit to be peeled increases, the support brush moves clockwise on the adjustment rod. Due to the fact that the fruits of melons often have an irregular spherical shape, in order to ensure the completeness of removal of the rind, the working bodies of a number of machines are made with the ability to copy the surface of the fruit.

Such machines include a device for peeling fruits (**Fig. 2.16**), which contains a housing and a rotation unit 5 installed in it with the ability to move in a vertical plane and with the formation of a cell for the fruit, a clamping unit 3, a cutting unit 4 in the form of a package of cylindrical cutters located on a flexible shaft, strangulation devices 6 for flushing adhered parts, feeding 7 and 8 outgoing trays, feeder 9 and waste collector 10. Rotation unit 5 consists of two shafts 2, 11 and is located in the lower part of the cell for the fruit, and the clamping unit 3 is installed in the upper part of the cell for the fruit and includes a shaft with a bushing freely placed on it, which has a figured shape and is made of an elastic material.

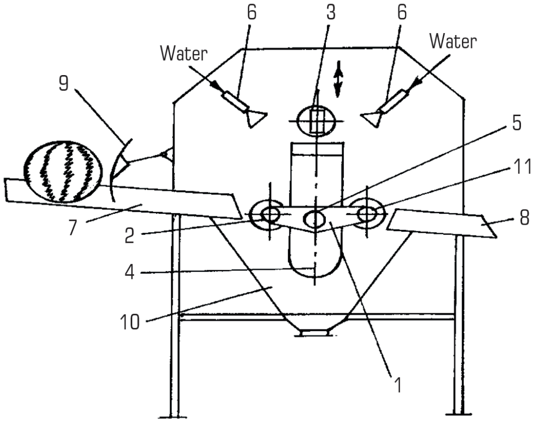


Fig. 2.16 Device for peeling fruits: 1 – rocker arm; 2, 11 – cutter shafts; 3 – pressure unit; 4 – cutting unit; 5 – rotation unit; 6 – choking device; 7 – supply tray; 8 – outlet tray; 9 – feeder; 10 – waste collector [52]

The clamping unit 3 is equipped with a means for limiting the movement of the shaft in the vertical plane, which contains a guide with a height-adjustable stop. To move in the vertical plane, one end of the shaft of the clamping unit 3 can be hingedly mounted, and the other is equipped with a carriage to interact with the guide.

The device works as follows. The fruits through the feeder 9 along the tray 7 are fed to the rotation unit 5, the shafts of which are preliminarily turned on the trunnions towards the fruits.

After placing the fruit on the shafts, the rotation unit 5 takes a horizontal position, and the fruit is fixed with a curly sleeve of the clamping unit 3. In this case, rotation from the unit 5 is transferred to the fruit in the cell, and the rotating cutters of the cutting tool 4 remove the peel layer from it.

After finishing the processing of the fruit, the rotation unit 5 is turned towards the discharge tray 8 and the fruit is moved to further processing.

Articulating one end of the shaft and equipping the other end with a carriage to interact with the guide ensures reliable fixation of a fruit of any size. The supply of the rotation unit 5 with the rocker 1 facilitates the feeding and removal of each fruit before and after processing.

The working body in the form of cutters mounted on a flexible shaft does not provide a copy of the surface of the pumpkin fruit. To peel them, a machine is proposed consisting of a frame 1 (**Fig. 2.17**) of a welded structure, on which two pairs of horizontally located brush drums 2, 3 are mounted, and the lower drums are located perpendicular to the upper ones 2, 3. Each of the drums is a cylinder, on the outer part of which the brushes are fixed, and the needles of the brushes have different lengths, which increase from the middle to the edges. In the center of the drums, on bearings, needle discs 5 are installed, which ensure the rotation of the fruit 16 in the process of peeling it. Drum 2 is fixed on levers 6 and held in the upper position by springs 7. Drum 3 has a needle disc driven by an electric motor 9 by means of a drive shaft 10, a V-belt 19 and chain drives 20, 21, as well as sprockets 4, 8.

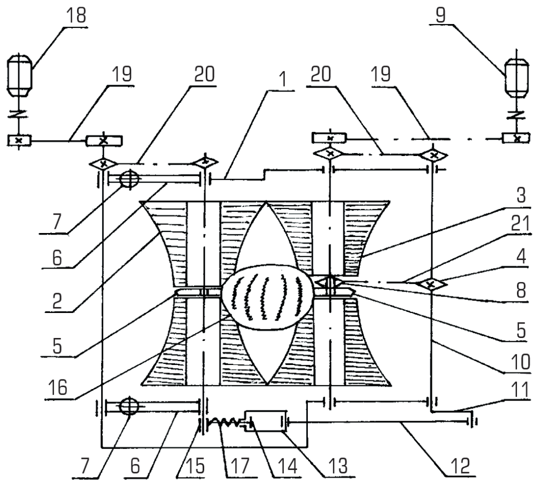


Fig. 2.17 Diagram of a machine for peeling the rind from the fruits of melons:
1 – frame; 2, 3 – brush drums; 4, 8 – sprockets; 5 – needle disc; 6 – levers; 7, 17 – springs; 9, 18 – electric motors; 10 – drive shaft; 11 – crank; 12 – connecting rod; 13 – compensator; 14 – thrust; 15 – latch; 16 – fruit; 19 – V-belt transmission; 20, 21 – chain drive

The drums are driven by electric motors 9, 18 using V-belt 19 and chain 20 gears. The machine has an automatic device that moves the fruit 16 from the upper drums to the lower ones, depending on the time of peeling the fruit from the rind. The automatic device includes cranks 11, a connecting rod 12, a compensator 13, a rod 14 with a latch 15.

The machine works as follows. Fruits 16 are fed from the top one at a time by a dosing device and fall on the upper brush drums 2, 3. As soon as the fruit makes one revolution of the crank 11 through the connecting rod 12, the compensator 13 and the rod 14 unlocks the latch 15. Drum 2 will go down under the influence of the weight of the fruit and the fruit 16 will fall on the lower pair of brush drums 4. Springs 7 return drum 2 to its original position, and it is fixed by a latch 15 returned to its original position by spring 17. A new fruit is fed to the upper drums. The lower drums 4 are arranged in the same way as the upper ones and work in the same way.

The fruit is processed in a circle in two mutually perpendicular directions. This ensures complete removal of the rind from the entire fruit of the melons. Uniform and high-quality peeling of the fruit is carried out due to the shock-combing effect on its rind. The speed of movement of the fruits along the vertical axis from top to bottom is regulated by changing the length of the crank. Springs 7 are adjustable according to the fruit weight. The performance of the machine depends on the type and size of the crop being cleaned.

2.4 MECHANIZATION OF MELON CUTTING

Analysis of literature sources shows that all existing machines for peeling fruits and vegetables, including melons, have a number of disadvantages. In our opinion, the most convenient machine for peeling melons and cutting them into pieces is the design proposed by A. Imanbaev [54]. However, this device has a number of disadvantages: a complex cutting unit with a clamping mechanism, which causes a relatively large material consumption, as well as unreliable operation of the cam mechanism.

Therefore, the goal was set for us: to create a more simplified design of a machine for peeling melons and cutting them into pieces, in which it is proposed to design a cutting unit, replacing a knife that reciprocates in a vertical plane using a cam mechanism with a block of rotating radial knives, which will significantly increase the reliability of the unit, as well as reduce material consumption by eliminating the complex clamping mechanism from the design.

The research objective was to develop a simple and reliable equipment for cutting and peeling melon fruits.

The technical result, an increase in the productivity and quality of the finished product, is achieved by the fact that the melon cutter containing the body and radially mounted knives for cutting the pulp, according to the invention, is equipped with a knife for cutting the peel, a roll with spikes for the peel and a scraper for peeling the peel from the spikes, and radially installed knives for cutting the pulp are fixed on the shaft, while the knife for cutting the peel is located between the roller with spikes and radially mounted knives. The unit diagram is shown in **Fig. 2.18**.

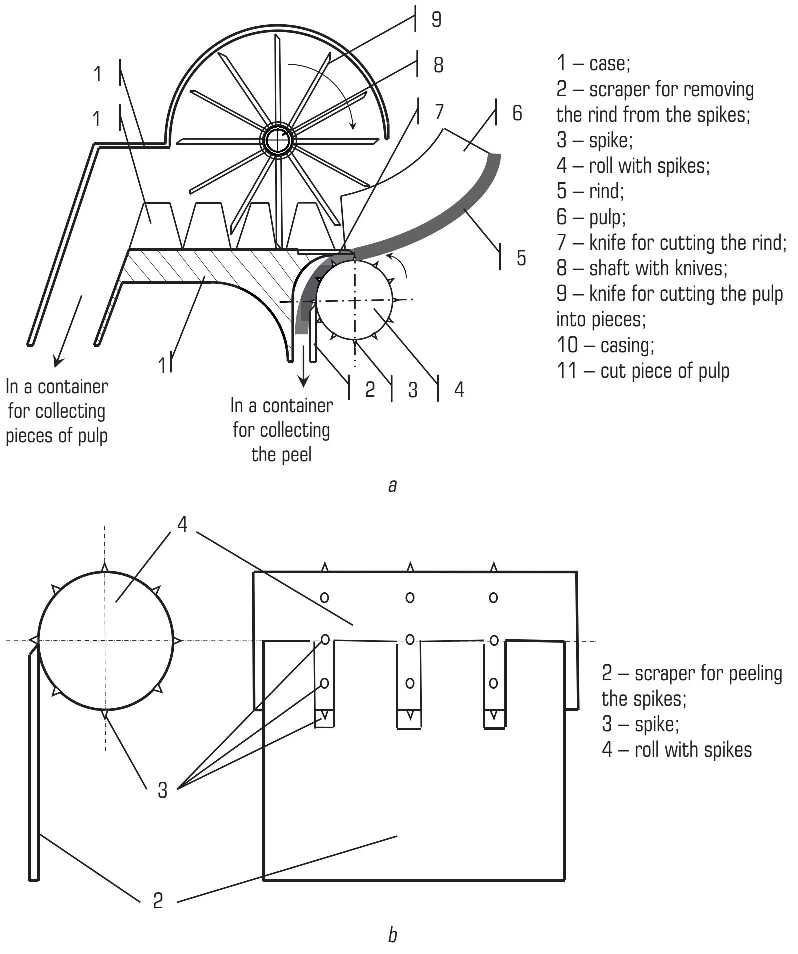


Fig. 2.18 Diagram of a melon cutter (machines for peeling and cutting round-shaped fruit pulp): *a* – device diagram; *b* – scheme of a scraper for peeling from spikes

The design is illustrated by drawings, where in **Fig. 2.18**, ***a*** shows a longitudinal section of the device; in **Fig. 2.18, *b*** – roll with spikes and scraper.

The cutter contains a supporting frame 1, a cutting device for pulp 6, consisting of radially mounted knives 9, which are fixed on a shaft 8, a knife 7 for cutting off a peel 5, a fixing element for a peel made in the form of a roll 4 with spikes 3, a scraper 2 for removing peel from spikes 3. Knife 7 for peeling the peel is located between the roll 4 and radially mounted knives 9. The cutter has a protective cover 10, peeled pieces of melon 11 enter the container for collecting the finished product.

The device works as follows.

A slice of melon down with its peel 5 is fed into the gap between the roll 4 and the fixed knife 7. In this case, the rind 5 is pricked onto the spikes 3, and then by the rotating roll 4 moves towards the knife 7 and is cut off. The cut rind 5 is removed from the spikes 3 with a grooved scraper 2 and removed into a container for collecting the peel (not shown). A slice of melon peeled 5 is cut by knives 9 radially mounted on the shaft 8 into pieces while rotating the shaft 8. The length of the pieces 11 corresponds to the distance between the ends of the knives 9. The pieces of melon are sent to a container for the finished product (not shown).

2.4.1 METHOD FOR DETERMINING THE POWER OF THE POWER PLANT

The total power required to drive the unit can be calculated using the equation:

$$N_e = 1.2(N_1 + N_2 + N_3 + N_4 + N_5)/\eta_e \eta_g, \tag{2.1}$$

where N_1 – power required to cut the rind with a flat knife, W; N_2 – power required for cutting the pulp into pieces, W; N_3 – power required to move the melon slice during cutting, W; N_4 – power required to rotate radial knives, W; N_5 – power required to pierce the rind, W; η_e – electric motor efficiency; η_g – gear efficiency; 1, 2 – power reserve.

The power required to cut the rind with a flat knife is calculated as the product of the cutting force F_{c1}, N and the cutting speed determined by the feed rate of a melon slice with a spiked roll $v_{c1,}$ m/s:

$$N_1 = F_{c1} v_{c1}. \tag{2.2}$$

The cutting force F_{c1} can be calculated as the product of the specific cutting force of the melon pulp when cutting the rind F_{c1}, N/m by the linear size of the contact zone of the knife with the material l, m:

$$F_{c1} = f_{c1} l. \tag{2.3}$$

The feed rate of a melon wedge into the cutting zone can be calculated in two ways: through the number of revolutions per second of the spiked roll n_1 and the number of revolutions per second of the radial knives n_2:

$$v_{c1} = \pi d_s n_1 = \pi d_{rk} n_2, \tag{2.4}$$

where d_s and d_{rk} are the diameters of the spiked roll and the block of radial knives, respectively. Expressed in meters. Substituting equations (2.3) and (2.4) into formula (2.2), let's obtain:

$$N_1 = f_{c1} l \pi d_s n_1 = f_{c1} l \pi d_{rk} n_2. \tag{2.5}$$

The power required for cutting the pulp with radial knives is calculated as the product of the cutting force F_{c2}, N and the cutting speed v_{c2}, determined by the rotational speed of the radial knives v_{c2}, m/s:

$$N_2 = F_{c2} v_{c2}. \tag{2.6}$$

The cutting speed in this case is defined as the quotient of dividing the depth of immersion of the knife into the melon pulp h by the time 1/4 of the turn of the radial knife block. Taking into account the fact that two knives come into contact with the melon pulp at the same time, the cutting speed can be determined by the equation:

$$v_{c2} = 0.5 h n_2 = 0.5 h n_2, \tag{2.7}$$

where h – height of the pulp layer in the melon slice, m.

The depth of immersion of the knife into the pulp of the melon wedge is achieved in 1/4 turn of the radial knife block. The cutting force F_{c2} can be calculated as the product of the specific cutting force of the melon pulp F_{c2}, N/m, and the linear size of the contact zone of the knife with the material l, m:

$$F_{c2} = f_{c2} l. \tag{2.8}$$

Substituting equations (2.7) and (2.8) into formula (2.6), let's obtain:

$$N_2 = 0.5 f_{c2} l h n_2. \tag{2.9}$$

The power to move one melon slice is calculated by the equation:

$$N_3 = F_m v_m, \tag{2.10}$$

where F_m – effort to move a melon wedge, N; v_m – speed of movement of a melon wedge, m/s.

The movement force can be calculated using the formula:

$$F_m = m_s g, \tag{2.11}$$

where m_s – mass of a melon slice, kg; g – acceleration of gravity, m/s.

Movement speed:

$$v_m = \pi d_s n_1 = \pi d_{rk} n_2. \tag{2.12}$$

Taking into account (2.10) and (2.11), equation (2.12) takes the form:

$$N_3 = m_s g \pi d_s n_1 = m_s g \pi d_{rk} n_2. \tag{2.13}$$

The weight of a melon slice is determined by weighing. Taking into account the maximum weight of the melon fruit and the fact that it is divided into 12 parts, it is possible in the calculations to take the mass of the slice equal to 1 kg. Rotational power of the unit of radial knives:

$$N_4 = m_{br} g v_r, \tag{2.14}$$

where m_{br} – mass of the unit of radial knives, kg; v_r – rotation speed of the radial knife block, m/s.

The speed of rotation of the unit of radial knives can be taken equal to the speed of movement of the melon wedge according to equation (2.1). Rind piercing power:

$$N_5 = F_{pr} v_{pr}, \tag{2.15}$$

where F_{pr} – piercing force of the melon rind, N; v_{pr} – piercing speed, m/s.

The piercing force of the melon rind is calculated taking into account the number of spikes simultaneously in contact with the rind:

$$F_{pr} = f_{pr} N, \tag{2.16}$$

where f_{pr} – specific piercing force, H, value of which is determined by the empirical equation (2.1); N – the number of spikes simultaneously piercing the melon rind.

The piercing speed is defined as the product of the height of the spike h_s and the rotational speed of the spiked roll:

$$v_{pr} = h_{pr} n_1. \tag{2.17}$$

2.4.2 DETERMINATION OF DEVICE PERFORMANCE

The productivity of the projected device depends on the feed rate of the melon wedge, which is determined by the rotational speed of the drive roll with spikes and the amount of transported product [55]. In our case, it will be one piece of melon:

$$Q = \frac{m}{l}v, \quad (2.18)$$

where v, m/s – linear speed of movement of the melon wedge; m, kg – average mass of a melon slice moved through a given section; l=0.4 m – average length of a melon wedge.

The mass of a melon slice is determined by the equation:

$$m = \rho bh, \quad (2.19)$$

where ρ=1020 kg/m^3 – density of the melon; h=0.05 m – height of the slice; b=0.05 m – width of the slice in the middle part of the height.

$$m = 1020 \times 0.05 \times 0.05 \times 0.4 = 1.02 \text{ kg}.$$

Then the productivity of the machine will be:

$$Q=1.02\times0.5/0.4=1.275 \text{ kg/s}.$$

Taking into account the intermittent supply of melon slices, the calculation for the machine's productivity will be equal to 1.275 : 1.5 = 0.85 kg/s.

2.5 DEVICE FOR THE SIMULTANEOUS PEELING OF THE FRUIT OF A MELON FROM THE RIND AND CUTTING IT INTO PIECES OF A GIVEN SIZE

In this section, let's present some calculations.

The electric motor transmits rotation to the drive shaft, and the intermediate to the radial blade unit using belt drives. The linear speed on the outer parts of the drive roll (at the end of the spike) and radial knives must be the same and equal to the speed of movement of the melon wedge:

$$v_s = v_{dr} = v_r = v. \quad (2.20)$$

Let's accept this speed of 0.5 m/s.

Then the rotational speeds of the roll and radial knives will be respectively equal:

$$n_{dr} = \frac{v}{\pi d_{dr}} \text{ and } n_r = \frac{v}{\pi d_r}. \quad (2.21)$$

The roll diameter is d_{dr}=40 mm, radial knives d_r=150 mm. The last dimension is determined by the height of the cut layer of pulp (no more than 50 mm).

Then

$$n_{dr} = \frac{0.5}{\pi \cdot 0.04} = 4s^{-1},$$

$$n_{r} = \frac{0.5}{\pi \cdot 0.15} = 1s^{-1}.$$

Let's take the engine speed as 800 rpm or 13.3 s^{-1}.

The drive roll must rotate in the opposite direction with the radial knife, therefore we install the intermediate shaft, which meshes with the drive roll using a gear drive. The diameter of the gears does not matter.

Let's calculate the gear ratios of the belt drives.

The ratio of the diameters of the pulleys on the engine and the drive shaft:

$$i_1 = \frac{n_e}{n_s} = \frac{d_{pds}}{d_{pe}} = \frac{13.3}{4} = 3.3.$$

Intermediate shaft and radial blade unit:

$$i_2 = \frac{n_s}{n_r} = \frac{d_{pr}}{d_{pi}} = \frac{4}{1} = 4.$$

If a pulley with a diameter of 0.01 m is installed on the engine, then on the drive shaft:

$$d_{ps} = i_1 d_{pe} = 3.3 \times 0.01 = 0.033 \text{ m}.$$

If a pulley with a diameter of 0.01 m is installed on the intermediate shaft, then on the unit of radial knives [56, 57]:

$$d_{pr} = i_2 d_{pr} = 4 \times 0.01 = 0.04 \text{ m}.$$

As a result, the design of a machine for peeling melon slices from the rind and cutting the pulp was proposed.

2.6 PIERCING THE MELON RIND

Melons of the following late-ripening varieties were taken as objects of research: Kok-Guliabi, Ak-Guliabi and Kara-Guliabi, since it is the late-ripening melon varieties that are used for processing and production of various products of long-term storage according to the classification of melon varieties proposed by A. Admaeva [58]. In addition, these varieties of melon have a high degree of keeping quality, in comparison with early and late-ripening varieties, which allows to extend the processing time of raw materials, and, consequently, to increase the efficiency of the line for processing melons. It is these varieties that have an oval-elongated shape, which makes it possible to mechanize the process of peeling the melon to the maximum extent with its simultaneous cutting into pieces of a given size (**Table 2.1**).

The experimental technique consists in justifying the choice of the studied parameters, technical means of measurement, measuring instruments and parameters of the process under study. Experimental studies were carried out in the laboratories of the Department of Machines and Apparatus for Food Production of the Almaty Technological University.

Analysis of the literature data [59–62] shows that a number of scientists have investigated the process of cutting melons, and also were engaged in the determination of various geometric and rheological characteristics (structural and mechanical properties) of the melon: stickiness, density, frictional properties, etc.

However, according to literary sources, no one was involved in the determination of the piercing force of the melon peel, therefore this indicator is the basis for the development of a new design of a machine for peeling melon from the peel and cutting it into pieces at the same time.

Melon samples were taken at the technical maturity stage.

2.6.1 DETERMINATION OF THE PIERCING FORCE OF THE MELON RIND

Different varieties of melon have different characteristics in terms of the hardness of the rind and the shape of the fruit. To select a melon variety for further research, 3 varieties of domestic melons were selected and studied. The data are summarized in **Table 2.1**.

Table 2.1 Characteristics of late-ripening melon varieties used for processing

No.	Variety	Characteristics		
		shape	**rind**	**pulp**
1	Kok-Guliabi	oblong-ovoid, almost cylindrical	rough, thick and dense	white, medium thickness (5–6 cm), sugar content – 14 %, dense, medium fiber, juicy, no aroma
2	Ak-Guliabi	ovoid	rough, hard	6–7 cm thick, white, dense, low-fiber, juicy, sweet (16 % sugar), with vanilla aroma
3	Kara-Guliabi	ovoid	rough, semi-hard	5–6 cm thick, white, very dense when removed, medium-fiber, juicy, sweet (14 % sugar), with a weak aroma during physiological maturation

The determination of the piercing force of the melon peel is carried out using a device – a structurometer.

The structure meter is designed to determine the quality indicators of recipe ingredients, semi-finished products and finished products in various branches of the food industry by their classical and conventional rheological characteristics: elastic and plastic deformations; the work of elastic deformation; rigidity; ultimate strength; ultimate shear stress; modulus of elasticity; ultimate loading force; viscosity; adhesive stress; depth of implementation, etc.

The calculation of the length of the sharpening of the spike is carried out according to the formula:

$$L = r/\mathrm{tg}\alpha, \quad (2.22)$$

where L – length of the spike sharpening, mm; r – radius of the spike, mm; α – spike sharpening angle, deg. The data for calculating the sharpening length are entered in **Table 2.2**.

Table 2.2 Calculation of the length of the spike sharpening depending on the radius and the specified sharpening angle

α, deg	tg	*L*, mm			
45	1	2	1.5	1.15	1
35	0.7	2.9	2.1	1.6	1.4
30	0.577	3.5	2.6	2.0	1.7
25	0.466	4.3	3.2	2.5	2.1
10	0.176	11.4	8.5	6.5	5.7
–	–	d=4 mm	d=3 mm	d=2.3 mm	d=2 mm
–	–	r=2 mm	r=1.5 mm	r=1.15 mm	r=1 mm

To determine the piercing force of the melon rind, let's use the mode of operation of the structure meter No. 2.

Specified values: touch force F_0=0.5 N; movement speed v=100 mm/min.

2.6.2 RESULTS OF EXPERIMENTAL STUDIES

Experimenting. To characterize the piercing force of the melon rind, compression tests were performed at a constant speed of 100 mm/s.

After selecting the mode, the indicator displayed the value of the initial force, from which the table movement begins, F_0=0.5 N. Next, press the /VKL/ button, while the value F_0=0.5 N is entered into the device's memory. At the same time, the indicator displays the value of the table movement speed «V=20 mm/min». Let's set the required speed value v=100 mm/min. Pressing the /VKL/ button, let's enter the new speed value into the device memory, while the indicator displays the force value to which the sample will be loaded during the experiment. This completes the setting of the parameters. The indicator displays the set values of force and displacement F and N.

Sample preparation. For research, let's prepare the necessary samples of the investigated product. To do this, take a piece of melon of any size and cut off the layer of pulp, leaving the rind with an adjacent layer of pulp 10–5 mm thick. From the obtained sample, we cut out a number of square samples with dimensions of 30×30 mm for research. Each test is numbered, taking into account the experiment for each angle of sharpening of the spike in five repetitions. Thus, 25 samples were prepared for each spike diameter.

Mode testing. Press the «START» button, while the values of *F* and *H* are reset to zero. The table moves upward at a given speed. At the moment the tool touches the sample surface, the force acting on the tool begins to increase. Loading occurs until the material is completely pierced. Next, the table moves downward at maximum speed. The indicator displays the *F* and *H* values at the time of piercing.

Successively changing the indicators (spikes), we carry out a series of experiments for each spike diameter in 5 replicates for each melon variety.

After conducting a series of experiments with the following melon varieties Kok-Guliabi, Ak-Guliabi and Kara-Guliabi, let's found that the data obtained for different melon varieties differ insignificantly (the difference does not exceed 5 %), therefore, data on the Kok-Guliabi variety are given.

The obtained data on testing melon peel for strength when piercing is entered in the table (**Tables 2.3–2.5**). After the end of each series of experiments, let's determine the average value of the piercing force N for each angle of spike sharpening.

Table 2.3 Determination of the piercing force of the melon peel with a spike diameter $d=4$ mm, penetration rate $v=100$ mm/min

Sharpening angle, deg.	Piercing force, N					
	Repetition number					
	1	2	3	4	5	average
15	9.6	9.7	9.76	9.9	9.64	9.72
30	21.64	21.68	21.75	21.73	21.55	21.67
45	33.82	33.8	33.69	33.71	33.88	33.78

Table 2.4 Determination of the piercing force of the melon peel with a spike diameter $d=3$ mm, penetration rate $v=100$ mm/min

Sharpening angle, deg.	Piercing force, N					
	Repetition number					
	1	2	3	4	5	average
15	8.43	8.14	8.31	8.78	7.59	8.25
30	16.48	16.29	16.32	16.5	16.61	16.44
45	24.85	25.3	25.24	25.08	25.13	25.12

Table 2.5 Determination of the piercing force of the melon peel with a spike diameter *d*=2 mm, penetration rate *v*=100 mm/min

Sharpening angle, deg.	Piercing force, N					
	Repetition number					
	1	2	3	4	5	average
15	6.37	6.21	6.34	6.28	6.05	6.25
30	10.76	10.41	10.54	10.52	10.67	10.58
45	15.54	15.59	15.78	15.74	15.6	15.65

According to **Tables 2.3–2.5**, let's plot a graph of the dependence of the piercing force of the melon peel on the sharpening angle of the spike of the structurometer (**Fig. 2.19**) and the graph of the dependence of the piercing force of the melon rind on the diameter of the spike of the structurometer (**Fig. 2.20**).

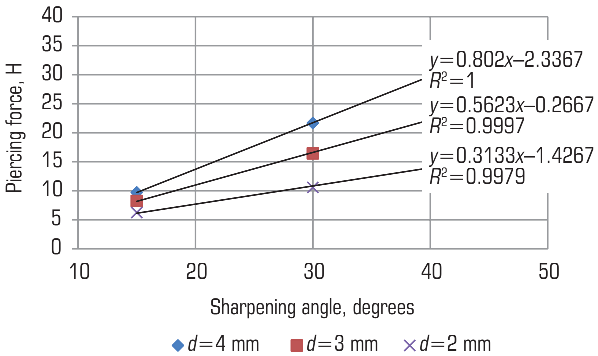


Fig. 2.19 Graph of the dependence of the piercing force of the melon rind on the sharpening angle of the tool (spike) of the structurometer

From the graph of the dependence of the piercing force of the melon peel on the sharpening angle of the tool (spike) of the structurometer, it was found that with an increase in the sharpening angle of the spike, the piercing force increases, i.e. the smaller the sharpening angle of the spike, the less effort is required to pierce the peel for all the studied melon varieties.

A similar pattern is observed in the dependence of the piercing force on the diameter of the spike.

For plotting the graphs, a linear model was used, as the most convenient for practical application. Further, the mathematical processing of the data was carried out in the Excel system. This allowed to obtain the regression equations shown in **Fig. 2.20**.

A high degree of approximation is confirmed by the obtained *R* value, which is close to 1.

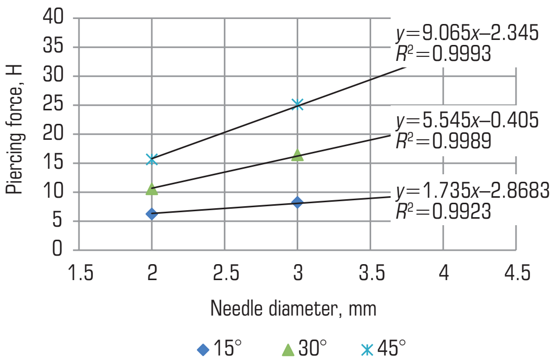


Fig. 2.20 Graph of the dependence of the piercing force of the melon peel on the diameter of the instrument (spike) of the structurometer

The data obtained are the initial data for calculating the energy consumption for piercing the melon peel when determining the engine power for the unit.

2.6.3 EXPERIMENT DESIGN AND MATHEMATICAL DATA PROCESSING

To establish the influence of various factors on the process of piercing the melon peel, we use the method of mathematical modeling. In this case, let's use orthogonal compositional planning of the experiment. This method is applied taking into account the results of a full factorial experiment, followed by experiments at additional points corresponding to the orthogonal plan (orthogonal planning) [37].

As a result of preliminary experiments, it was found that the main factors influencing the piercing process are the sharpening angle of the working tool (spike) and the diameter of the spike. Other factors have an insignificant effect on the piercing process.

When studying the influence of factors, the following limits of factors were selected: the angle of sharpening of the working tool (spike) – 15–45°, the diameter of the spike – 2–4 mm.

To compile the orthogonal planning matrix, let's define the factors on a natural scale:

– for the angle of sharpening of the working body:

$$z_1^0 = \frac{15+45}{2} = 30;$$

$$\Delta z_1 = \frac{45-15}{2} = 15;$$

– for the spike diameter:

$$z_2^0 = \frac{4+2}{2} = 3;$$

$$\Delta z_2 = \frac{4-2}{2} = 1.$$

For a two-factor experiment, the regression equation has the form [57]:

$$y = b_0 + b_1x_1 + b_2x_2 + b_{12}x_1x_2 + b_{11}x_1^2 + b_{22}x_2^2, \qquad (2.23)$$

where b_0 – free term; b_1, b_2 – linear coefficients; b_{12} – coefficients of pair interaction; b_{11}, b_{22} – quadratic coefficients; x_1, x_2 – measured and controlled parameters.

The number of experiments in this case is calculated by the formula:

$$N = N_0 + 2k + n_0, \qquad (2.24)$$

where N_0 – the number of trials of the full factorial experiment 2^k; k – the number of factors; n_0 – the number of experiments in the center of the plan:

$$N = 9.$$

The orthogonal planning matrix is shown in **Table 2.6**, the matrix for calculating the regression coefficients is shown in **Table 2.7**.

Table 2.6 Matrix of orthogonal planning of the experiment for the sharpening angle of the spike and the diameter of the spike

Experiment number	Factors in a natural scale		Factors in a dimensionless coordinate system		
	z_1	z_2	x_1	x_2	x_0
1	2	15	–1	–1	1
2	4	15	1	–1	1
3	2	45	–1	1	1
4	4	45	1	1	1
5	3	30	0	0	1
6	4	30	1	0	1
7	2	30	–1	0	1
8	3	45	0	1	1
9	3	15	0	–1	1
Total	–	–	6	6	9

Table 2.7 Matrix for calculating regression coefficients (extended orthogonal planning matrix)

Experiment number	x_0	x_1	x_2	$(x_1')^2$	$(x_2')^2$	x_1x_2	y
1	1	–1	–1	0.33	0.33	1	6.25
2	1	1	–1	0.33	0.33	–1	9.72
3	1	–1	1	0.33	0.33	–1	15.65
4	1	1	1	0.33	0.33	1	33.78
5	1	0	0	–0.67	–0.67	0	16.44
6	1	1	0	0.33	–0.67	0	21.67
7	1	–1	0	0.33	–0.67	0	10.58
8	1	0	1	–0.67	0.33	0	25.12
9	1	0	–1	–0.67	0.33	0	8.25
Total	9	6	6	2	2	4	147.46

In this case, the values of the coefficients $(x_1')^2$ and $(x_2')^2$ are calculated by the formula:

$$(x_1')^2 = x_1^2 - \frac{\sum x_1^2}{N},\ (x_2')^2 = x_2^2 - \frac{\sum x_2^2}{N}. \tag{2.25}$$

Let's calculate linear coefficients, quadratic coefficients and coefficients of pair interaction:

$$b_1 = \frac{\sum(x_1y)}{6},\ b_2 = \frac{\sum(x_2y)}{6},$$

$$b_{11} = \frac{\sum(x_1x_2y)}{6},\ b_{22} = \frac{\sum(x_2x_2y)}{6},$$

$$b_1 = \frac{\sum(x_1x_2y)}{4},\ b_0 = \frac{\sum(x_0y)}{6} - 0.67b_{11} - 0.67b_{22}. \tag{2.26}$$

Substituting data into expression (2.23), let's obtain:

b_1=6.02, b_2=8.39, b_{11}=–0.57, b_{22}=–0.01, b_{12}=3.67, b_0=16.38.

Based on the results of the calculation, a regression equation was obtained for the dependence of the piercing force on the sharpening angle and the spike diameter:

$$P=16.38+6.02(d-3)+8.39(\alpha-30)/15+$$
$$+3.67(d-3)(\alpha-30)/15-0.57[(d-3)^2-0.67]-0.01\{[(\alpha-30)/15]^2-0.67\}, \tag{2.27}$$

where P – piercing force of the melon peel, N; α – sharpening angle of the spike, degrees; d – spike diameter, mm.

Fig. 2.21 shows the resulting surface, built on the basis of the regression equation, in **Fig. 2.22, 2.23** – the dependence of the piercing force of the melon peel on the sharpening angle of the spike and the diameter of the spike, built according to the calculated data.

Comparative analysis of the data (**Table 2.8**), obtained by calculation and experiment, shows that the discrepancy is no more than 5 %.

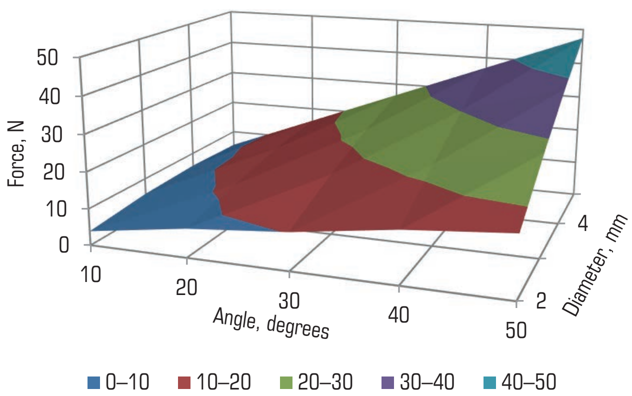


Fig. 2.21 Response surface of melon rind piercing force versus sharpening angle and spike diameter

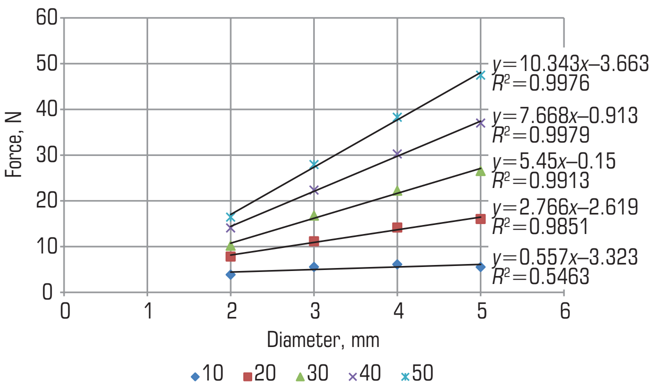


Fig. 2.22 Graphs of the dependence of the melon rind piercing force on the spike diameter (calculated data)

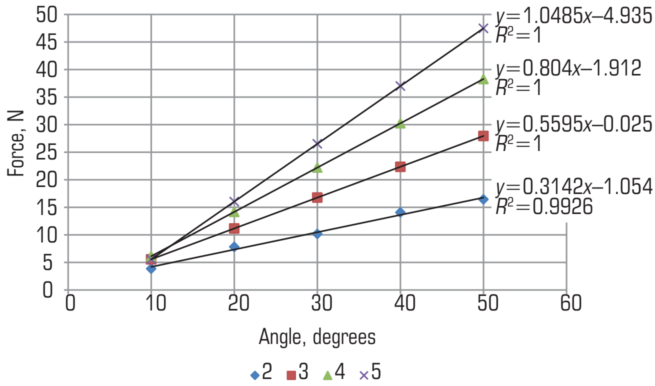


Fig. 2.23 Graphs of the dependence of the piercing force of the melon rindon the angle of spike sharpening (calculated data)

Table 2.8 Comparative assessment of the melon rind piercing force, obtained experimentally (y) and calculated (y_c)

Experiment number	y	y_c	Δy
1	6.25	5.75	0.5
2	9.72	10.15	0.43
3	15.65	14.89	0.76
4	33.78	34.27	0.49
5	16.44	16.77	0.33
6	21.67	22.22	0.55
7	10.58	10.18	0.4
8	25.12	25.15	0.03
9	8.25	8.37	0.12

The significance of the obtained coefficients is checked using the Student's test according to the formula (2.27):

$$t_j = \frac{|b_j|}{s_{b_j}}. \tag{2.28}$$

The obtained calculated values of the confidence interval turned out to be greater than the tabular value, therefore, none of the coefficients is excluded from the regression equation.

Next, using Fisher's criterion, let's check the adequacy of the obtained regression equation by the formula (2.24):

$$F = \frac{s_{res}^2}{s_{rec}^2},\qquad (2.29)$$

where the residual variance is calculated by the formula:

$$S_{res}^2 = \sum_1^N \left(y_i - yr_i\right)^2 / N - L,\qquad (2.30)$$

where L – the number of significant coefficients in the regression equation.

Since the calculated value of the Fisher criterion turned out to be less than the table value, it can be concluded that the obtained regression equation adequately describes the experiment.

2.6.4 F-D-DIAGRAM

For engineering calculations, it is sometimes more convenient to use diagrams; for this purpose, let's carry out additional experiments with a large number of values of the defining parameters. We displayed the results obtained in the form of a diagram «piercing force – spike diameter» (*F*–*d*).

The average results obtained for the puncture strength test of the melon rind are shown in **Table 2.9**.

Table 2.9 The piercing force of the melon peel at different diameters and the tool sharpening angle

Tool sharpening angle, deg.	Tool diameter, m					
	1	2	3	4	5	6
15	3.36/3.29	5.23/5.64	7.84/7.99	10.46/10.34	12.36/12.69	15.21/15.04
30	4.40/4.34	10.58/10.36	16.44/16.38	21.67/22.4	28.21/28.42	34.65/34.44
45	5.29/5.39	15.65/15.08	25.12/24.77	33.78/34.46	43.98/44.15	54.06/53.84

These results are in good agreement with the values obtained by calculation using the regression equation (indicated in the table through a fraction).

The deviation of the calculated data from the experimental data in the investigated range does not exceed 3 percent, therefore, to select the geometric parameters of the piercing tool, an *F*–*d*-diagram was created, shown in **Fig 2.24**.

The diagram shows lines showing the dependence of the piercing force on the tool diameter at different sharpening angles. The lines are drawn according to the regression equation.

The diagram allows to determine the geometric parameters of the piercing tool (spike) depending on the maximum piercing force due to design considerations, or vice versa, the magnitude of this force depending on the diameter and sharpening angle.

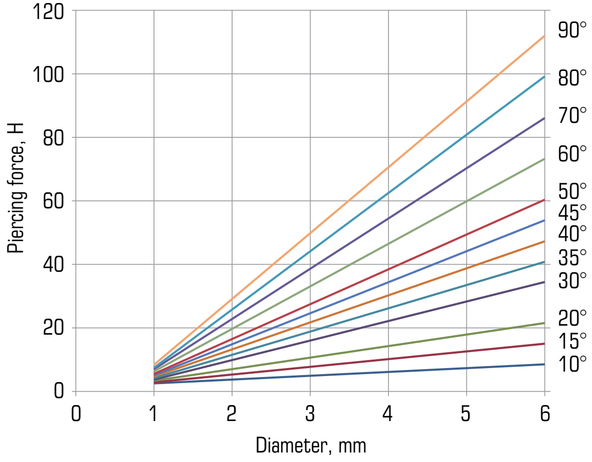


Fig. 2.24 *F–d*-diagram of the dependence of the piercing force of the rind of the Guliabi melon on the diameter and tool sharpening angle

The diagram is used in the structural, strength and force analysis of the model of the plant for peeling and cutting into pieces of melon pulp. In the future, it will be used in the educational process in course and diploma design, as well as in engineering calculations [27].

2.7 MECHANIZATION OF PROCESSING WATERMELON FRUITS

The device works as follows. The device for the destruction of watermelon fruits into juice, pulp and seeds is made in the form of a structure consisting of a chamber, a working body, an electric motor, a descent and ascent mechanism. The prepared watermelon fruit is placed in the working chamber 6, with the help of the handle 8 and the lowering and lifting mechanism 7, the working body is lowered until the drill 5 touches the upper part of the watermelon, then we turn on the electric motor 1, when rotating the drill is introduced into the cavity of the watermelon, while the pulp of the watermelon is crushed and simultaneously separated from the rind of the watermelon. At the bottom there are sieves with a casing, differing in the size of the holes, preventing the passage of seeds through them (**Fig. 2.25–2.27**).

The cuticle is spent on the release of pectin, the peeled watermelon rind for the production of candied fruits, the pulp for further processing into various products, the seeds are separated, washed, dried and packaged.

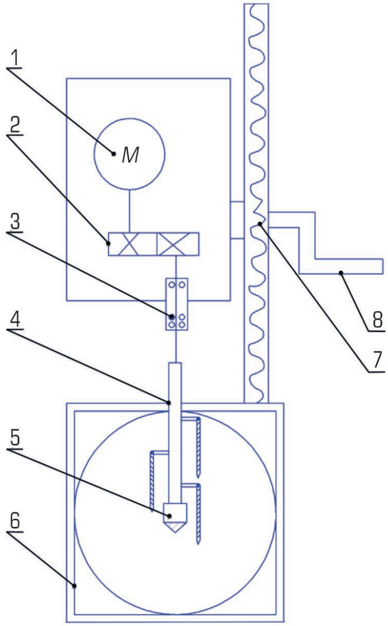


Fig. 2.25 Device diagram: 1 – electric motor; 2 – gear transmission; 3 – bearing; 4 – shaft; 5 – drill; 6 – case; 7 – lifting and lowering mechanism; 8 – handle

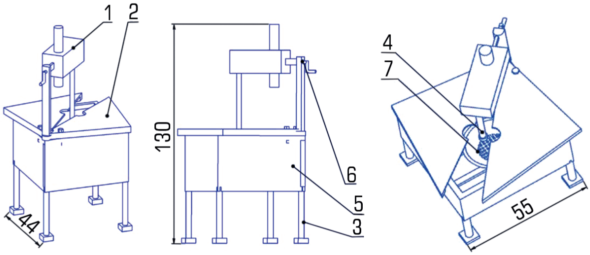


Fig. 2.26 General view: 1 – geared motor; 2 – cover; 3 – legs; 4 – shaft; 5 – case; 6 – lifting and lowering mechanism with a handle; 7 – lodgment

Fig. 2.27 Installation photo

The selected working body was designed and modified on the basis of studying the experimental base of a number of researchers on this topic and taking into account their experiments (the design of cutting bodies). The summary information on the calculations is summarized in **Table 2.10**.

Table 2.10 Calculation results

Indicator		Value
ρ, kg/m^3	Density	1,210
μ, Pa/s	Dynamic viscosity index	2.34×10^{-3}
v, Pa/s	Kinematic coefficient of viscosity	2.6×10^{-6}
N, W	Total power on the stirrer shaft	722
N, W	Starting power, taking into account overcoming the forces of inertia	794.2
M_{cr}, N/m	Torque for the selection of the stirrer electric drive	46.7
P_{1res}, N	Total cutting force including frictional forces	29.4
N_1, W	Cutting power of the pulp from the rind	230.8
N_2, W	Pulp cutting power	94.2
n, s^{-1}	Optimum speed	25
Re_M	Modified Reynolds criterion (for mixing)	129,274
N_3, W	Working power on the stirrer shaft	397
J_p	Cutting intensity criterion	0.4×10^{-3}
σ, N/mm	Crumple stress	0.17
R_D	Criterion for the intensity of the action of the shear deformation force	0.11×10^{-4}
V, kg/s	Device performance	8.4

2.8 DEVELOPMENT OF A LINE FOR PROCESSING WATERMELON

The watermelon processing line consists of several units. A schematic of the recycling process is shown in **Fig. 2.28**.

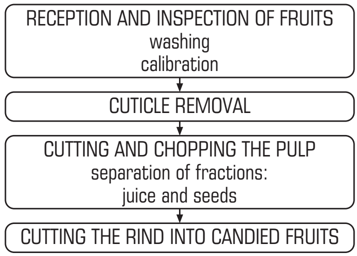


Fig. 2.28 Diagram of the watermelon processing process

At the moment, the technology of removing the outer cover from the fruits of melons is carried out with the use of manual labor, and the existing constructive and technological solutions of machines for peeling fruits from the rind do not provide efficient and high-quality work during the processing of melons: high completeness of peeling and small losses of edible pulp. In addition, in all known peeling machines, the quality of the technological process depends on the shape index of the fruit. In the proposed machines for removing the rind from the fruits of melons, an abrasive tool is most often used as a working body, which makes it possible to obtain a relatively good quality of peeling, but at the same time very high pulp losses (up to 50 %). This method is known as «deep peeling» of the fruit and is referred to as abrasive by the way it is treated. Such machines are distinguished by the obligatory use of spraying devices as an auxiliary working body and by the presence of abrasive fragments in the pulp, which is unacceptable according to technological requirements. There are also known machines equipped with cutting working bodies: slotted knife or packs of cutters. But due to the complexity of the cutting process, peeling from the rind in this way is complicated by a wide variety of shapes and sizes of fruits, which leads to a low completeness of peeling and high losses of edible pulp.

To solve this problem, we have designed a machine with a floating head of a slotted knife, which provides cuticle removal without huge losses of the epidermis and parenchyma.

The pulp is cut by a rotating working body and then fed to the selection of seeds. The seed extraction process is the most difficult process in this scheme. The seeds are found in the pulp of the watermelon in the middle lane. The known technologies provide for mechanical separation and washing out with water, for watermelons this technology is not effective, because, together with the seed yield, there is a possibility of increased juice losses. Pre-crushing of the fruit, used in enterprises, is also not profitable for the processing of watermelon fruits. This leads to the loss of the watermelon rind and loss of pulp. The complex processing of watermelon fruits provides for crushing the pulp without violating the integrity of the rind, because the peel of the watermelon will be processed into candied fruits, the seeds will be released after grinding and centrifuging all the pulp of the watermelon. In order to meet the requirements for semi-finished products from the pulp of melons when processing it into candied fruits, a working body is needed that allows to get pieces of the correct shape without cracks.

The line for processing watermelons (**Fig. 2.29**) consists of a belt conveyor (for transporting raw materials to the sink), a bubbler-type washer, a conveyor for feeding raw materials for peeling the outer peel, a layer of less than a millimeter is cut off. Further, the berry, peeled from the outside, goes to the cutting of the pole (upper), and to the conveyor for peeling the pulp, then the lower pole of the watermelon is cut off and the pulp is merged with the seeds, which enters the pulping machine, where the pulp is freed from the seeds.

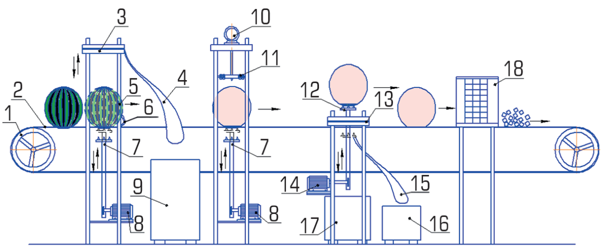


Fig. 2.29 Proposed watermelon processing line

The rind is fed for cutting into candied fruit and further technological operations.

The pulp, cleared of seeds, is homogenized to obtain stable suspended particles and to exclude or slow down the sedimentation process.

Line description. With the help of the drive drum 1, the conveyor belt 2 is set in motion. The conveyor belt is made of thick rubber with a thickness of at least 2 cm. It has round holes for installing watermelons in them. When the conveyor belt moves, it first stops at the first section, where the watermelon is washed under a stream of cold water, then under a stream of boiling water and under a strong pressure of cold water. This removes the cuticle from the watermelon in this area.

Further, the watermelon falls under the section where the upper pole is separated with the help of the guillotine knife 3, which goes down and up along the traverses 5. The cut off pole is rolled along the chute 4 into the container 9. Then the watermelon moves to the next section. In this section, the pulp of the watermelon is crushed using a shaft with chains 11, driven by an electric motor 10. At the same time, the rod 7 rises (the drive is carried out by an electric motor 8, on which a round plate with spikes is fixed, which is introduced into the lower part of the watermelon, while fixing it. After all the pulp of the watermelon has been crushed, the stock 7 begins to rotate around its axis. After the watermelon has been peeled, the rod 7 goes down and the watermelon continues to move to the section for separating the lower pole. At the section of the separation of the lower pole, the watermelon is fixed with a rod 13 and with the help of a guillotine knife 12 the lower pole of the watermelon is separated, which then rolls along the chute 15 into the container 16. When cutting off the lower part, the watermelon juice with pulp and seeds flows into the receiving container 17. Next, the watermelon falls under the last section, where it is divided into 6 parts from top to bottom. Slices of watermelon rind fall on a rotating plate and in the direction of movement of the plate with the help of a guide line up, then cut into cubes using a grating knife cutting unit 18.

The line allows to get semi-finished products for the production of candied fruits from the watermelon rind, the production of watermelon juice or other products of long-term storage from the watermelon, the seeds are used to squeeze medicinal or salad watermelon oil with hepatoprotective properties.

2.8.1 SEPARATION OF THE UPPER POLE WITH A GUILLOTINE KNIFE

For the initial stage of processing the fruits of watermelon, in accordance with the rheological studies of the rind of the watermelon (**Table 2.11**), it was revealed that in the region of the stalk, more effort is required to introduce the working body. To avoid costs, it was decided to cut the disc in the region of the stalk, for this, calculations were made to separate the upper pole of the watermelon (stalk) using a guillotine knife.

Table 2.11 Results of measurements of strength characteristics of watermelons

Name	Peduncle	Receptacle	Equator
Rind breaking force, N	475.74–499.3	431.4–439.3	411.9–434.6
Rind puncture force, N	127.1–130.3	104.5–108.7	111.8–114.7
Rind hardness, kg/mm	1.2	0.8	0.9
Effort of destruction of pulp, N	168.7–183.1	164.8–170.3	98.7–103.6

Engineering calculations. Calculation of the mechanism for separating the upper pole. **Fig. 2.30** shows a mechanism for separating the upper pole, which consists of 1 – pulley, 2 – tape, 3 – mechanism for cutting the upper pole, 4 – chute along which the cut disc of the peduncle is collected in a container 9, 7 – lodgment, prevents the watermelon from spinning and move when forces are applied, 8 – electric motor.

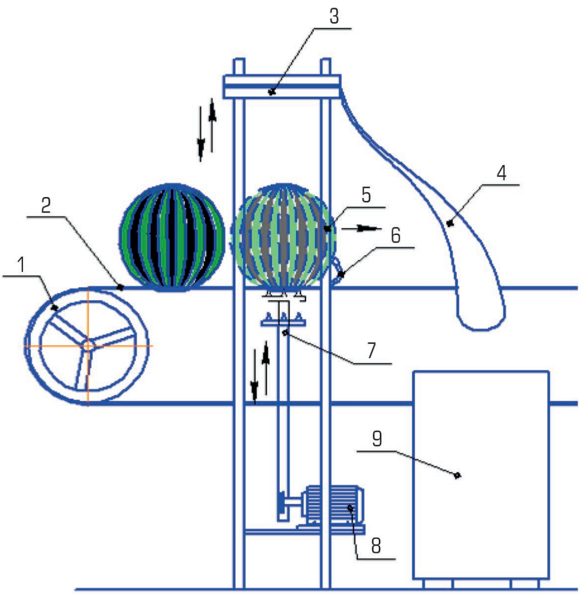


Fig. 2.30 Mechanism for separating the upper pole

1. Average cut area of the upper pole («top» of the watermelon) F_p:

$$F_p = \frac{\pi \cdot d^2}{4} = \frac{3.14 \cdot 0.150^2}{4} = 1.77 \cdot 10^{-2} \text{m}^2.$$

2. Based on the data in **Table 2.11**, let's select the value of the cutting force with a flat knife of the rind $P_\ell = 39.77$ N/cm. Then the total cutting force for the upper pole of the watermelon is determined:

$$P_{cut} = P_\ell \cdot \ell = 39.77 \cdot 10^2 \cdot 15 \cdot 10^{-2} = 596.55 \text{ N},$$

where $\ell = 150$ mm is the cut length. Cutting height 15 mm. Let's accept $P_{cut} = 600$ N.

In the course of the study, 2 options for the movement of the knife were put forward, after analyzing the calculations, it was decided to stop the choice on the rotational movement of the knife. The diagram is shown in **Fig. 2.31**.

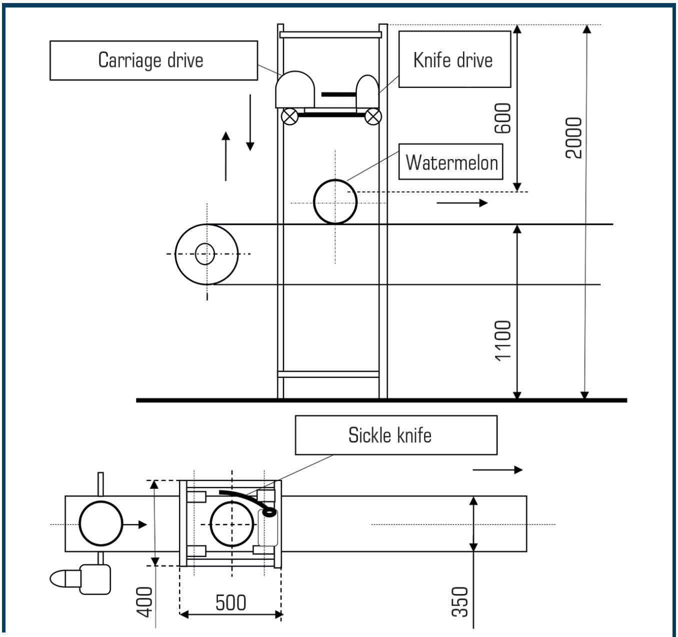


Fig. 2.31 Feed platform for the knife mechanism

2.8.2 CALCULATION OF THE FEED PLATFORM FOR THE KNIFE MECHANISM WITH THE ROTATING MOVEMENT OF THE KNIFE

For the vertical movement of the carriage – platform along the guides, let's use a rack and pinion gear **Fig. 2.32**:

1. Gear wheel (4 pcs.), moving up and down along the guide rail.

2. Fixed toothed rack (4 pcs.) (fragment) along the vertical posts. The vertical stroke length of the platform (carriage) is taken according to the dimensions of the structure ℓ_x=600 mm (±20 mm). For technological reasons, the platform feed speed is taken v=15 cm/s=0.15 m/s.

Then the forward movement time τ_1:

$$\tau_1 = \frac{\ell_x}{\upsilon} = \frac{0.6}{0.15} = 4 \text{ s.}$$

3. Full stroke time (cycle time) $\tau_0=2\tau_1+\tau_{res}+\Delta\tau=8+2+2=12$ s.

4. The total weight of the platform according to enlarged calculations is G=110 N. Each support-gear wheel, which moves upward along the guide toothed rack (4 pcs.), has a load of G_i=27.5 N.

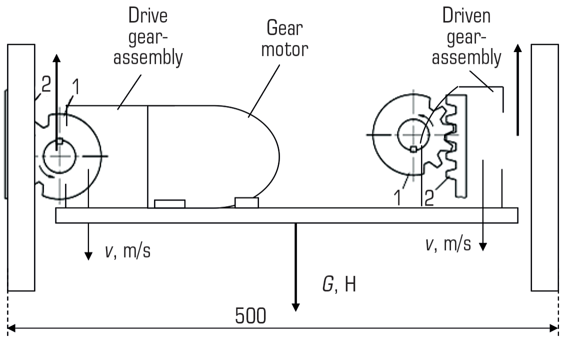


Fig. 2.32 Fragment of the platform for lowering and raising the knife mechanism

5. Determine the rolling friction force (T) in the guide planes of the rack. In each support a gear:

$T_i = f_k \cdot G_i = 0.3 \cdot 27.5 = 8.25$ N,

where $f_k = 0.14$ is the average coefficient of friction (steel on steel), taking into account the lubricant.

Throughout the platform:

$T = 4 \cdot T_i = 8.8 = 33$ N.

6. The total force of the vertical load will be:

$G_0 = G + T = 152$ N.

7. The required power for vertical lifting of the platform in the guides, taking into account overcoming the inertial forces and the efficiency of the gear pair:

$$N = K_i \cdot \frac{G_0 \cdot v}{\eta} = 1.8 \cdot \frac{152 \cdot 0.15}{0.7} = 58.6 \text{ W}.$$

8. Along the length of the threaded part of the rack, we take the diameter of the pitch circle of the gear $D_P = 56$ mm. In this case, the recommended module, taking into account the speed of the translational movement, will be $m = 4$ mm. Then the number of teeth of the gear is:

$$z = \frac{D_P}{m} = \frac{56}{4} = 14.$$

9. The speed of the peripheral gear wheel is expressed as v in m/s:

$v = n_s \cdot \pi \cdot m \cdot z.$

10. Gear rotation frequency n_s in s^{-1}:

$$n_s = \frac{v}{\pi \cdot m \cdot z} = \frac{0.15}{3.14 \cdot 4 \cdot 10^{-3} \cdot 14} = 0.853\ s^{-1}.$$

11. Normal rail pitch:

$p_n = \pi \cdot m = 3.14 \cdot 4 = 12.56$ mm.

2.8.3 STIRRING DEVICE CALCULATION

The working body is lowered into the pulp and begins to rotate. In this case, the pulp is separated from the walls of the rind, and the pulp is chopped for draining and filtration. The seeds are washed and dried, the pulp is filtered for further processing. The full power of the mixer cycle includes the following components:

1) power for separating the pulp from the walls of the rind and mixing;
2) power for pulp crushing and mixing;
3) power for mixing the pulp.

1. The cutting force when separating the pulp from the rind walls, according to experimental data, is $P_{ires} = 21$ N. The total cutting force, taking into account the friction forces along the entire perimeter of the trajectory, will be:

$P_{1res} = K_f \cdot P_{ires} = 1.4 \cdot 21 = 29.4$ N.

2. The optimal value of the number of revolutions of the blades, established by experiment, is $n = 1500$ rpm $= 25\ s^{-1}$. Then angular cutting speed is:

$\acute{\omega} = \pi \cdot n/30 = 17\ s^{-1}.$

3. Circumferential cutting speed:

$v = \acute{\omega} \cdot r = 17 \cdot 0.05 = 7.85$ m/s.

4. Power of cutting the pulp from the rind N_1:

$N_1 = P_{res} \cdot v = 29.4 \cdot 7.85 = 230.8$ W.

5. The cutting force when separating the pulp from the rind walls, according to experimental data, $P_{2res}=12$ N.

6. Power of cutting pulp N_2:

$$N_2=P_{2res}\cdot v=12\cdot 7.85=94.2 \text{ W}.$$

7. The power spent on mixing the pulp N_3 is calculated from the Euler criterion equation:

$$Eu_m=\frac{N_3}{\rho\times\mu\times d^5},$$

where Eu_m – Euler's criterion (power criterion); N_3 – power on the stirrer shaft during the working period of stirring (W); ρ – average density of the liquid system (kg/m^3); μ – average dynamic coefficient of viscosity (Pa/s); d – diameter of the stirrer blades (m).

8. According to the technological conditions of the process, the diameter of the stirrer blades is $d=100$ mm. In our case, we have an oval cross-section of the working area of the mixer (the inner cavity of the watermelon), for which $D=250$–300 mm. The average internal diameter is $D=280$ mm.

9. According to our research, the optimal speed was $n=1{,}500$ min$^{-1}=25$ s^{-1}. The density of the liquid-like system (pulp) at an average temperature of 20 °C $\rho=1{,}210$ kg/m^3. Kinematic coefficient of viscosity $\nu=2.6\cdot 10^{-6}$ Pa/s. Dynamic viscosity coefficient $\mu=2.34\cdot 10^{-3}$ Pa/s.

10. Calculate the modified Reynolds criterion (for mixing):

$$\mathrm{Re}_m=\frac{\rho\times n\times d^2}{\eta}=\frac{1{,}210\times 25\times 0.1^2}{2.34\times 10^{-3}}=129{,}274.$$

11. According to the graph of the dependence of the form $Eu_m=f(\mathrm{Re}_m)$, let's find for curve No. 14 (propeller mixer modified Euler's criterion $Eu_m=2.1$.

12. Calculate the working power on the mixer shaft (N in W) for mixing the watermelon pulp:

$$N=Eu_m\cdot\rho\cdot n^3\cdot d^5,$$

$$N_3=2.1\cdot 1{,}210\cdot 25^3\cdot 0.1^5=397 \text{ W}.$$

13. Determine the total power on the shaft of the mixing and cutting device (mixer drive) N in W. Working power:

$$N_p=N_1+N_2+N_3=230.8+94.2+397=722 \text{ W}.$$

Starting power taking into account overcoming inertial forces:

$$N=1.1\text{ N}=794{,}2 \text{ W}.$$

14. The torque for the selection of the stirrer electric drive is determined:

$$M_t = \frac{N}{\omega} = \frac{794}{17} = 46.7 N \cdot m.$$

According to the SPARKS catalog, let's select a small-sized MNHL geared motor with the following adjustable parameters:

– power 100–800 W;
– torque 11–89 Nm;
– rotation speed of the output shaft 0–1,800 rpm.

2.8.4 CALCULATION OF THE FILTER APPARATUS

Fruit juices and pulps are filtered only at constant and low pressure up to 0.07–0.09 MPa (0.7–0.9 atm). The sludge contained in the juice, consisting of organic particles, is easily compressed under increased pressure, which causes clogging of the filter, which impedes the further carrying out of the process.

The filtration rate increases to a large extent as the amount of sediment decreases. To speed up the process, the clarified juice is decanted from the sediment and centrifuged, and then filtered.

The filtration process requires a differential pressure on both sides of the filter baffle. With an increase in pressure, the porosity of the baffle, as well as the rate of the process, first increase, and then, due to the compression of the precipitate and blockage of the pores of the filter, decrease.

For filtering fruit juices and pulp, mainly filter presses are used (**Fig. 2.33**).

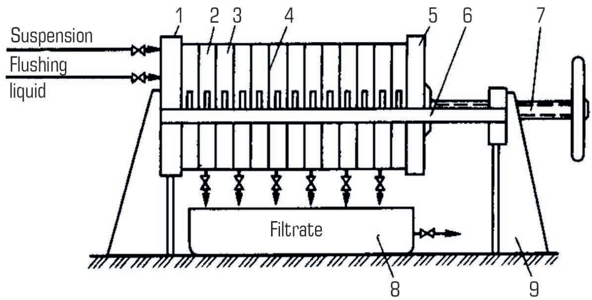


Fig. 2.33 Scheme of a frame filter press: 1 – left support plate; 2 – filtering frame; 3 – frame plate; 4 – rubber seals; 5 – right support plate; 6 – fastening rod; 7 – clamping screw; 8 – reservoir for the clarified filtrate; 9 – fastening edges

As a filtering baffle, filter paper of grades T and W or large-pore plates made of pressed asbestos of grade F are used. Filter paper or plates clamped between the plates of the filter press simultaneously serve as a baffle and filter material.

The juice supplied by the pump enters the channels formed by the flanges of one row, then goes to the grooves of the plates, passes through the filtering partition and falls on the grooves of the adjacent plates, from where it is discharged through the flanges of the plates on the opposite side of the filter:

1. The watermelon pulp passes through a sieve and is cleared of seeds. Then the slurry is poured into a 500 liter tank.

Let's accept, on the basis of experimental data, the mass hourly productivity for watermelon pulp $M=500$ kg/h. It has been established that the optimal filtration rate of juices and juice pulps is provided at an overpressure in the range of 0.07...0.09 MPa. Let's take the excess filtering pressure $\Delta p=0.085$ MPa. Let's select the filtration mode at constant pressure, as the most optimal and recommended for the given raw material.

2. The speed of the filtration process is determined by the Znamensky equation:

$$u_f = \frac{\Delta p}{\sigma \cdot \mu \cdot s},$$

where u_f – average speed of the filtration process, m/s; Δp – excess pressure on the filter, Pa; σ – structural resistance of the sediment layer, (average value for fruit and vegetable pulps according to experimental data) in m^{-2}; μ – dynamic coefficient of viscosity of the wet sludge layer, Pa s; s – thickness of the sediment layer, permissible according to the technological conditions, m; $\mu=2.34 \cdot 10^{-3}$ Pa/s; $\rho=1{,}210$ kg/m^3; $s=20$ mm; $\sigma=1.78 \cdot 10^{12}$ m^{-2}.

$$u_f = \frac{\Delta p}{\sigma \cdot \mu \cdot s} = \frac{0.085 \cdot 10^6}{1.78 \cdot 10^{12} \cdot 2.34 \cdot 10^{-3} \cdot 20 \cdot 10^{-3}} = 0.001\,\text{m/s}.$$

3. Determine the volumetric flow rate of the filtered pulp:

$$V_s = \frac{M}{3{,}600\rho} = \frac{500}{3{,}600 \cdot 1{,}210} = 1.15 \cdot 10^{-4}\ \text{m}^3/\text{s}.$$

4. Determine the area of the filtration process, F:

$$F = \frac{V_s}{u_f} = \frac{1.15 \cdot 10^{-4}}{0.001} = 0.115\ \text{m}^2,$$

where F – filtration area, m^2.

5. Select a small filter press F14-V, Italy from the catalog of technological equipment.

The productivity of the incoming filtrate – 100–500 l/h.

The number of plates – 10–15.

Plate dimensions: 120·150 mm.

6. Determine the required number of plates in the filter press:

$$n = \frac{F}{\eta \cdot f} = \frac{0.115}{0.6 \cdot 0.018} = 10.6,$$

where $f = 0.018$ m^2 – the working area of one plate; η – efficiency of the frame, taking into account sedimentation.

Let's accept the number of plates 11 pcs.

7. Watermelon pulp (suspension) is pumped through the filter by a centrifugal pump. The pump power is determined by N:

$$N = \frac{\Delta p \cdot V_s}{\eta},$$

where Δp is the excess pressure created by the pump, Pa; V_s – volumetric second flow rate of the liquid mass, m^3/s; η – average operating efficiency of the pump, $\eta = 0.82–0.86$.

8. The excess pressure created by the pump for fruit and vegetable pulps is taken as $\Delta p = 0.085$ MPa.

9. Determine the head created by the pump H:

$$H = \frac{\Delta p}{\rho \cdot g} = \frac{0.085 \cdot 10^6}{1{,}210 \cdot 9.81} = 7.16 \text{ m}.$$

10. Pump power:

$$N = K \cdot \frac{\Delta p \cdot V_s}{\eta} = 3.5 \frac{0.085 \cdot 10^6 \cdot 1.15 \cdot 10^{-4}}{0.86} = 42.8 \text{ W},$$

where K – power factor taking into account additional resistances.

Food centrifugal pumps are not self-priming pumps used for pumping liquids such as milk, vegetable oil, beer, wine, spirits, alcohol, juices, concentrates, etc. For these applications, pumps of the G2-OPA, G2-OPB, G2-OPD, ONC и ONC1 brands have proven themselves well. These types of pumps are typically installed at the bottom of the vessel and connected to the bottom drain (under-fill installation). If for pumping food liquids, a pump is needed to take liquid through the upper neck (for example, a tank or cistern), then self-priming food pumps are used.

The self-priming food pump allows to pick up liquid even if the container is below ground level. A self-priming food pump can be installed on a trolley for free movement around the workshop, for example, and taking/pumping liquid from baths, vats or reactors and supplying it to further processes.

From the catalog we select a centrifugal pump for pumping food liquids (with low and medium viscosity) ONC 1.2/10K 0.22/2:

– supply 0.5–2.5 m^3/h;

– head 14–12;

– electric motor power 220 W.

CONCLUSIONS TO SECTION 2

Based on the analysis of the state of mechanization of the primary processing of pumpkin crops, the results of research in this branch of agricultural production and exploratory experiments, the following conclusions can be drawn:

1. Melons are of great food, medical and agrotechnical importance in agriculture.

2. Currently, undeservedly little attention is paid to the production and processing of melons. The current situation in the production of melons requires an integrated approach to solving problems in all branches of melon growing on the basis of the accumulated scientific potential.

3. The issue of a closed technological process involves the development of mechanization means for processing the fruits of melons for seeds, for technical and food purposes.

4. The studies carried out earlier were aimed at substantiating the conditions of the working processes of seed extractors with separating devices of shock impact during the processing of watermelons, but did not touch upon the peculiarities of the extraction of seeds from pumpkins.

5. The qualitative indicators of the existing samples of allocators for the processing of melons do not meet the agrotechnical requirements: the loss of full-value seeds is 8–23 %, the productivity of the aggregates is low, not exceeding 8...13 t/h, and the degree of injury to seeds is high.

6. The reason for the shortcomings of the existing schemes is the low efficiency of the working processes of the allocators, based on the use of impact destruction and crushing methods when crushing fruits and separating seeds from pulp.

7. When processing fruits for food purposes, it is necessary to preserve the pulp as much as possible. To do this, it is most advisable to cut the fruit with pre-peeled rind into halves and isolate the seeds from them. For watermelons, it is effective to cleanse the inside of the cavity of the watermelon in order to reduce the loss of juice.

9. Considering the biological and physical and mechanical properties of pumpkin fruits, of all the existing methods for removing the outer cover from vegetable and melon products, the most suitable method is mechanical peeling; for watermelon fruits, the use of a slotted knife with a calibration of 1 mm will make it possible to use the cuticle for the production of pectin, peeled peel for the production of candied fruits.

10. Prototypes of experimental devices have a number of significant disadvantages:

1) the most important of them is the inability to copy the surface of pumpkin fruits, which leads to an increase in the loss of edible pulp;

2) with the simultaneous peeling of watermelon fruits from the cuticle and from the rind in the cramped conditions of the cavity, if the speeds of the working bodies are incorrectly selected, the loss of juice and rind is not excluded. The speeds are selected for each variety and degree of ripening, which is a serious drawback;

3) when processing melon fruits, the mechanization of peeling from seeds is not taken into account.

3 THEORETICAL AND EXPERIMENTAL RESEARCH OF THE MELONS PROCESSING

ABSTRACT

This chapter describes the design of a machine for removing rind from the fruits of melons, presents the results of theoretical and experimental studies to determine the optimal design and kinematic parameters of its main units.

KEYWORDS

Fruit, rind, peeling, brush drum, kinematics.

3.1 ANALYTICAL STUDY OF THE PROCESS OF REMOVING RIND WITH A BRUSH APPARATUS

Based on the analysis of theoretical materials presented in the works of V. Abezin, A. Tsepliaev, L. Chaban, V. Boromensky, P. Ovcharov and other scientists who studied the issue of removing rind from the fruits of melons and the creation of machines for this technological process, as well as analysis of serially produced and original devices and machines for removing rind from fruits of vegetable and melon products, a new promising scheme of a machine for removing rind from pumpkin fruits was developed [63–69].

A machine for removing rind from melons, mainly pumpkins (**Fig. 3.1**), contains a frame 1, a hopper connected by a tray 2 to a frame 1, a drive drum 3 with brushes 4, top brushes 5, a conveyor 6 of peeled fruits and a conveyor of separated rind 7. The machine is equipped with a drive drum 3 located on the sides with brushes 4, a rubberized roller 8 and a separator 9 in the form of a truncated conical drum. The axes of rotation of the drive drum 3, the rubberized roll 8 and the upper generatrix 10 of the surface of the truncated conical drum of the separator 9 are parallel.

On the surface of the truncated conical drum with equal angular pitch, rods 11 reinforced with elastic material are placed. The truncated conical drum of the separator 9 is equipped with a fruit pusher 18, which is made of an unequal corner.

Upper brushes 5 in the form of a pair of counter-rotating rollers with elastic elements 12 are placed above the lower drive drum 3, rubberized roller 8 and separator 9 and are connected by a synchronizing transmission. The axes of rotation of the brushes 5 are located perpendicular to the axes of rotation of the drum 3 and the roll 8 and have the possibility of horizontal displacement due to the paired grooves 14 and 15 and vertical displacement due to the grooves 16 and 17.

Cinematically connected rubberized roll 8, separator 9 and drive drum 3 with brushes 4 are equipped with an individual electric drive in the form of a gear motor and have the ability to continuously change the angular speeds of the drive shafts. The conveyor 6 of peeled fruits is connected to the frame 1 of the machine by the tray 12. The conveyor of the separated rind 7 is installed in the frame 1 under the drive drum 3, the roller 8 and the separator 9 and is equipped with shields 13. The tray 2 is installed above the additional brush 5. The additional brush 5 is in the form of counter-rotating rollers are equipped with the possibility of horizontal displacement due to the grooves 14 and 15 made in pairs and vertical displacement due to the grooves 16 and 17. The truncated conical drum of the separator 9 is equipped with a fruit 19 pusher 18. The pusher 18 is made of an unequal corner.

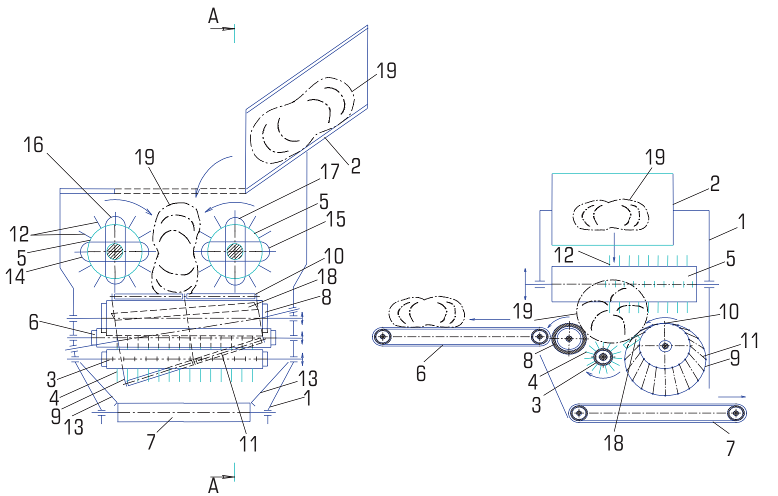


Fig. 3.1 General view of the machine for removing rind from pumpkin fruits: 1 – frame; 2 – feeding tray; 3 – drive drum; 4 – brush; 5 – conveyor of peeled fruits; 6 – conveyor of peeled fruits; 7 – conveyor of the separated rind; 8 – rubberized roll; 9 – separator; 10 – upper generatrix of the separator surface; 11 – rod; 12 – tray; 13 – shield; 14, 15 – horizontal displacement grooves; 16, 17 – vertical displacement grooves; 18 – pusher; 19 – fruit

The machine works as follows. Pre-sorted for the average size pumpkin fruits 19 from the hopper along the tray 2 enter the space between the counter-rotating upper brushes 5 and rests on a rubberized roller 8, a separator 9 and a drive drum 3 with a brush 4. With reinforced rods 11, the fruit 19 periodically rises from the drive drum 3 into direction of the additional brush 5 and descends to the brushes 4 of the drive drum 3.

Due to the significant difference in the peripheral speeds of the rods 11 of the separator 9, the fruit is given a rotational movement around the axis of symmetry. Counter rotating brushes 5 with elastic elements 12 remove the rind from the fruit from the end surfaces, and the brushes 4 of the drive drum 3 from the outer surface of the fruit. The peeled fruit from the surface of the rubberized roller 8 is directed by the pusher 18 of the separator 9 to the conveyor 6. The separated rind by the flaps 13 is directed to the surface of the conveyor 7 and is removed from the cavity of the frame 1. Thus, the rind is removed from the surface of the fruit 19.

For the high-quality operation of the brush drums, ensuring complete removal of the rind from the surface of the pumpkin and minimal removal of the pulp, it is necessary that the fruit rotate reliably without slipping on the support-drive drums. In principle, there are several possible solutions to this problem.

In the first of the options, it is assumed that this condition will depend on the roughness and frictional properties of the surface material of the support-drive drums and the fruit. Therefore, it is necessary that the surface of the drums is made of a material with a coefficient of friction which will be sufficient for the occurrence of friction forces in the contact zone between the fruit and the supporting drums, which are necessary for the rotation of the fruit. In this case, the own weight of the fruit should be sufficient so that it does not rise relative to the supporting surfaces during the action of the brush elements on it.

In the second version, the condition of high-quality rotation of the fruit can be ensured by making the surface of the support-drive drums needle-like, that is, the rotation of the fruit will be carried out due to the forced introduction of the needles into the surface of the fruit.

Comparing these two options, it is necessary to note some of the advantages and disadvantages of each of them.

In the first case, a simpler design is assumed in terms of manufacturing and economic investments, but since the fruit rotates during the peeling process, not only the rind, but also the subrind pulp comes into contact with the support-drive drums. Therefore, in the contact zone «drum-surface of the fruit»there is a change in the values of the friction forces that arise there. Fluctuations in these values are explained by the fact that the roughness and moisture content of the rind and subrind pulp are different. At the same time, three mutually perpendicular brush drums act on the fruit from three sides, which have an abrasive effect on the fruit. Depending on the direction of rotation of the brush drums relative to the surface of the fruit (forward or backward), they will either help or counteract the rotation of the fruit. Based on the above, it can be assumed that the working process of the machine will be periodically disrupted due to slipping of the fruit relative to the supporting surfaces.

Using in the second case the needle surface of the support-drive drums, the disadvantages associated with a change in the frictional properties of the surface to be cleaned are eliminated. Since the rotation of the fruit will be forced. This will also solve the problem of the effect of brushing elements that are in contact with the surface of the fruit at any given time. That is, the effect of vertical movement of the fruit will be practically eliminated due to the fact that the needles with their ends describing a circle will penetrate into the fruit at a certain angle and resist its movement.

For the reliable introduction of the needles into the surface of the fruit, it is necessary to determine the pitch of the needles and their geometric parameters. In addition, the penetration of the needles will be influenced by rind shavings that form during the peeling process and adhere to the surface of the support-drive drums.

Since the work of the brushes occurs relative to the movement of the fruit around its own axis, the ends of the elastic brushing elements (and their other points) in relation to the surface of the fruit have a complex movement.

The process of brushes is characterized by the position of the axis of rotation in space and the direction of rotation in relation to the forward movement of the pumpkin fruit. If, during operation, the brush element begins to cut off chips from the surface of the fruit (**Fig. 3.2, *a***), then the rotation of the brush is called direct. If the brush element cuts off the chips, moving from the bottom of the furrow to the surface of the fruit, then the brush rotation is called reverse (**Fig. 3.2, *b***).

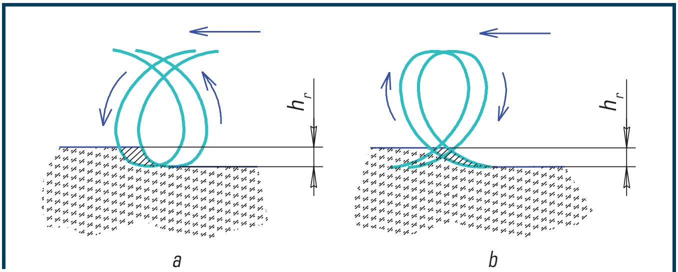


Fig. 3.2 Scheme of rind shavings formation:
a – forward rotation; *b* – reverse rotation

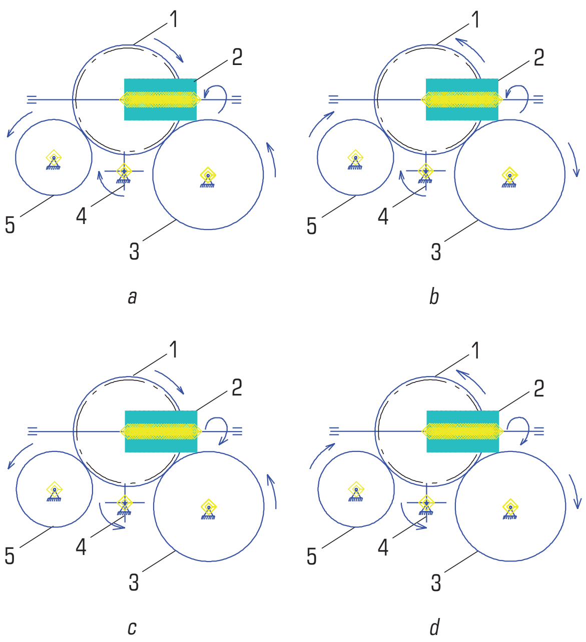
When cutting off the shavings from top to bottom, its cross-section decreases from maximum to zero. In this case, the force created by the pile is applied to the rind. First, the energy of the brush element is used to crush, and then to shear the rind. Reverse rotation will increase the chip section from zero to maximum and cut from bottom to top. The force of the pile will be applied to the subrindal pulp, and the energy of the brush element will only be used to shear the rind.

In the design of the developed machine, several options for changing the forward rotation to reverse rotation and vice versa are possible. **Fig. 3.3, *a*** shows a diagram of the reverse rotation of the brush drums, with the fruit rotating clockwise 1, the brush drum of the lower tier 4 counterclockwise, and the brush drums of the upper tier 2, so that they try to press the fruit against the support drums 3 and 5.

Fig. 3.3, *d* also shows the reverse rotation of the brush drums relative to the surface of the fruit, but in this case the fruit rotates counterclockwise, the brush drum of the lower tier is clockwise, and the brush drums of the upper tier, so that they try to raise the fruit, tearing it away from the supporting drive drums.

Comparing the two possible modes of operation of the machine in forward rotation, the following advantages can be noted. In the first case, the brush drums of the upper tier acting on the fruit tend to press the fruit to the supporting surfaces, which contributes to an increase in the force of the coupling weight between the fruit and the support-drive drums. Due to this, the fruit is pricked in the best way on the needles located on the surface of the support-drive drums. The disadvantage of this option is that the entire removed rind will fall on the surface of the tapered drive drum and clog the space between the needles. In the second case (**Fig. 3.3, *d***), the fruit will rise above the supporting surfaces, which can lead to the formation of gaps in the unpeeled rind, but the surface of the cone-shaped drum 3 will be practically unclogged. Choosing from these two possible options for the operation of the machine, with reverse rotation, the first option looks the most preferable, since the clogging of the surface of the cone-shaped drum has less effect on the technological process of removing the rind.

In **Fig. 3.3, *b***, a diagram of the direct rotation of the brush drums is shown, with the fruit 1 rotating counterclockwise, the brush drum of the lower tier 4 clockwise, and the brush drums of the upper tier 2, so that they try to press the fruit against the support-drive drums 3 and 5.



1 – fruit; 2 – brush drums of the upper tier; 3 – cone-shaped rotary drum;
4 – brush drum of the lower tier; 5 – cylindrical drum

Fig. 3.3 Schemes of the direction of rotation of the brush drums and the fruit: *a*, *d* – reverse rotation of the brush drums; *b*, *c* – direct rotation of the brush drums

Fig. 3.3, *c* also shows the direct rotation of the brush drums relative to the fruit surface, but in this case the fruit rotates clockwise, the brush drum of the lower tier is counterclockwise, and the brush drums of the upper tier, so that they try to raise the fruit, tearing it away from the supporting drive drums.

Drawing an analogy between forward and reverse rotation, it can be seen that the variant of the machine shown in **Fig. 3.3, *c*** has the same advantages in forward rotation as the option in **Fig. 3.3, *d*** for reverse rotation.

3.2 DETERMINATION OF THE BASIC KINEMATIC PARAMETERS OF CYLINDRICAL BRUSH DRUMS

The basis for the search for optimal conditions for the course of the working process of the brush peeling apparatus is the technical conditions for the processing of fruits: the need to obtain a completeness of peeling of at least 95 % and the loss of edible pulp not more than 5 %.

In order to obtain the most rigorous analytical results that simplify the task in the course of research, the following basic assumptions were made:

1. The fruit is fed into the space between the brush drums at the moment when their movement is steady ($\omega_b = \text{const}$).
2. The process of removing the rind from the surface of pumpkin fruits occurs at a constant peripheral speed of the fruit ($v_f = \text{const}$).
3. The brush elements of the drums are considered as low-stiffness rods.
4. Brush elements have constant stiffness, deformation and stresses arising in them do not go beyond the elastic limit of the material of the brush elements.
5. The intrinsic weight of the brush elements is so low that it does not cause noticeable deformation.
6. The fastening of the brush elements on the brush shaft is rigid, the reduction in the length of the brush element S_b per revolution (due to wear) is small.
7. The tensile deformation of the brush element compared to the bending deformation is so small that its influence on the operation and movement of the brush element can be neglected.
8. Rind and pulp are absolutely elastic bodies, the compression of which within elastic deformations obeys Hooke's law.
9. The fruits are in the shape of a torus.

The introduced assumptions apply to all possible cases of operation of brushing devices in practice.

During the brush operation, its pile has two different phases of its movement, differing in the presence or absence of contact with the surface to be cleaned. Upon contact with this surface, a significant deformation of the elastic brush element occurs, since the value ΔS_b is always greater than zero and in some cases is commensurate with the free length of the rod S_b.

The forces arising in this case and the indicated deformation are so significant that they have a decisive influence on the subsequent movement of the brush element even in the absence of its contact with the surface to be cleaned. In this regard, when solving the problem, there is no essential need to consider the stage of the onset of rotational motion, which is secondary to practice, and assess its influence on the steady motion. Taking into account the above, it is possible to give the following qualitative picture of the movement of the pile in each of the phases of the steady movement of the brush.

During the movement of the pile, in the absence of contact with the surface to be cleaned, elastic vibrations take place at significant amplitudes (in any case, in the period of time immediately following the exit of the brush pile rod from contact with the pumpkin surface to be cleaned) and with simultaneous rotation of the brush elements around the translationally moving axis pumpkin fruit. The amplitude of such vibrations will be the more significant, the greater the deformation of the brush element in another phase of movement and its rigidity. During the movement of the pile, in the presence of contact with the peeled surface, there are small elastic vibrations of the pile with its simultaneous bending due to the rotation of the brush and the translational movement of the axis of the pumpkin fruit with sliding of the ends of the pile along the surface of the formed trace. The mode of this movement depends on the initial conditions, which are determined by the previous phase of the pile movement, as well as the general parameters of the steady movement of the brush. Let's consider the phase of the pile movement, which is of the greatest interest for practice, when it comes into contact with the surface to be cleaned.

When the brush drum interacts with the rind of the fruit, four characteristic positions of the individual brush elements can be distinguished (**Fig. 3.4**). At the beginning of the contact of the next element with the surface of the fruit rind (position 1), under the action of a tensile centrifugal force, it occupies a radial position at an angle β_1 to the vertical axis. Due to the torque supplied to the brush drum, the end of the pile is embedded in the surface of the rind.

As the brush rotates further with angular speed ω_b, the rod bends and the potential energy of elastic deformation (position 2) accumulates in it, while the pile, deforming the rind, cleaves it, forming shavings. At the final moment of contact with the rind, the brush element is in a bent state (position 3), then sharply unbends, discarding the rind shavings and again taking up a radial position (position 4).

Due to the fact that in its free movement the pile does not remain rectilinear and is deformed, and also has an oscillatory motion, the positions of the extreme point of the pile from 1 to 3 sections of the trajectory are distorted due to a change in the radius of the brush drum, described with some approximation by the equations below.

For a complete analysis of the operation of the brush drums, it is necessary to take into account the basic kinematic parameters that determine the quality of the machine for removing the rind from pumpkin fruits, which include the trajectories, speeds and accelerations of the brush elements.

Since the operation of the brushes occurs relative to the movement of the fruit around its own axis, the ends of the elastic brushing elements (and their other points) in relation to the surface of the fruit have a complex movement.

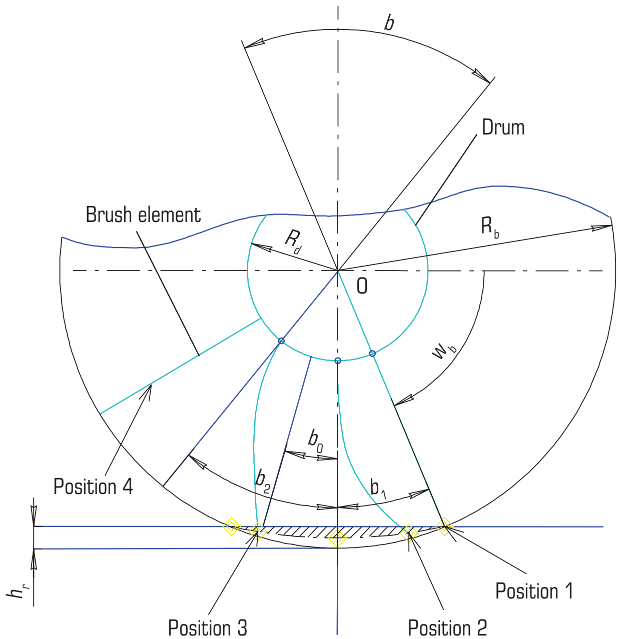


Fig. 3.4 Interaction of the brush element with the surface of the rind of the pumpkin fruit

Consider the direct movement of the brush element. Let's assume that the pile of a brush drum with a radius R_b in the process of operation rotates uniformly around a horizontal axis with an angular speed ω_b (**Fig. 3.5**) and at the same time participates in translational motion relative to a horizontal surface with a speed v_b. In this regard, the trajectory of motion will be a cycloid shape, which depends on the ratio of the peripheral and translational speeds, that is, the indicator of the kinematic mode:

$$\lambda = \frac{u_b}{v_b} = \frac{\omega_b \cdot R_b}{\omega_f \cdot R_f}, \tag{3.1}$$

where ω_b – angular speed of the brush element s^{-1}; R_b – radius of the brush drum, m; ω_f – angular speed of the fruit, s^{-1}; R_f – radius of the fruit, m.

Let's compose the equations of the trajectory of motion for point A of the end of the brush element. To do this, consider the movement of the brush element $C_0A_0=R_b$ relative to the horizontal surface.

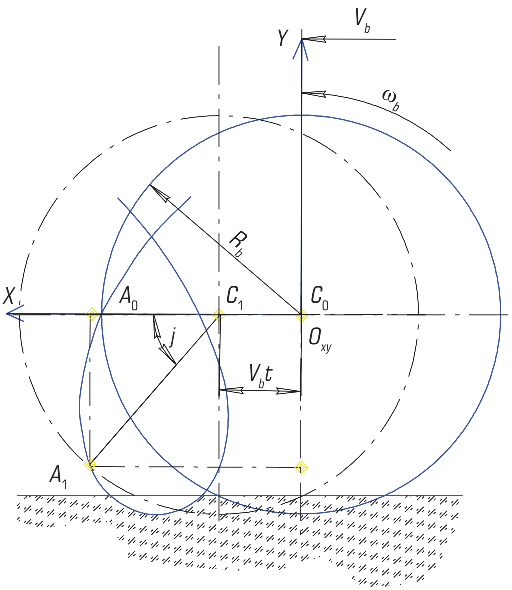


Fig. 3.5 Trajectory of movement of pile points with direct rotation of the brush drum

In this case, we introduce the following notation:

– O_{xy} – origin of the rectangular coordinate system;

– O_x – horizontal coordinate axis, coinciding with the horizontal surface, and directed towards the movement of the brush drum;

– O_y – vertical coordinate axis passing through the center of the brush drum;

– C_0A_0 – initial horizontal position of the brush element.

Let the brush move forward at a speed v_b over a distance $C_0C_1 = v_bt$ during time t. During the same time, the C_0A_0 brush element will move to the C_1A_1, position, having turned through an angle $\phi = \omega_bt$. Then the coordinates of point A_1 in the adopted coordinate system will be $x = C_0C_1 + C_1A_1\cos\omega t$. Considering that $C_1A_1 = R_b$, $C_0C_1 = v_bt$ let's obtain the equations of the trajectory described by the point A:

$$x = v_bt + R_b\cos\omega_bt;\ \ y = -R_b\sin\omega_bt. \tag{3.2}$$

Since, in practice, there is a case when the fruit with a radius R_f uniformly rotates at a speed ω_f relative to its own axis towards the brush drum, and a pivotally mounted brush drum with a radius R_b, motionlessly fixed on the machine frame, rotates uniformly at an angular speed ω_b (**Fig. 3.6**), then the equations of the trajectory of motion will be described by the following equations:

$$x = \omega_f R_f t + R_b \cos\omega_b t;\ \ y = -R_b \sin\omega_b t. \quad (3.3)$$

Whence it can be seen that the trajectory of movement of the point of the elastic brush element will be a cycloid (**Fig. 3.6**).

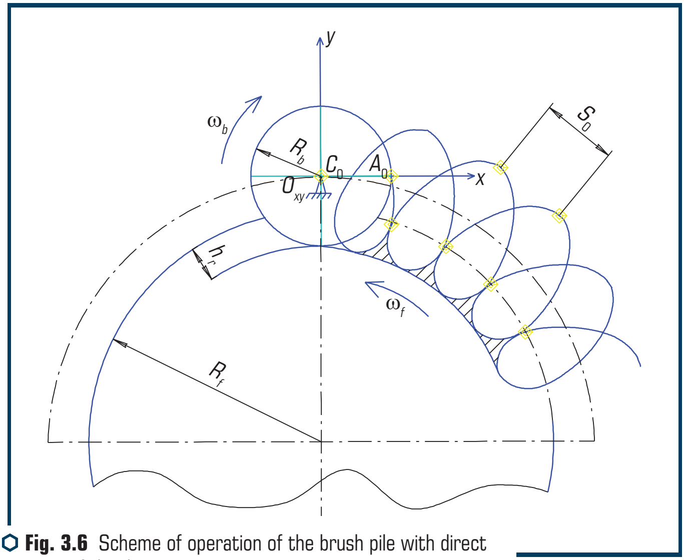


Fig. 3.6 Scheme of operation of the brush pile with direct rotation of the drum

The absolute speed of the considered point of the brush element will be equal to:

$$v = \sqrt{\left(\frac{d(x)}{d(t)}\right)^2 + \left(\frac{d(y)}{d(t)}\right)^2} =$$

$$= \sqrt{\left(\frac{d(\omega_f \times R_f \times t + R_b \times \cos\omega_b \times t)}{d(t)}\right)^2 + \left(\frac{d(-R_b \times \sin\omega_b \times t)}{d(t)}\right)^2} =$$

$$= \omega_f \times Rf\sqrt{1 + \left(\frac{\omega_{fe} R_b}{\omega_f \times R_f}\right)^2 - 2\left(\frac{\omega_b \times Rb}{\omega_b \times R_f}\right) \times \sin\omega_b \times t} =$$

$$= v_b\sqrt{1 + \lambda^2 - 2 \times \lambda \times \sin\omega_b \times t}. \quad (3.4)$$

Next, let's consider the reverse rotation of the brush drum. To do this, let's compose the equations of the trajectories of motion of the ends of the brush elements during reverse rotation. In this case, the notation introduced in the case of forward rotation will also be retained for the reverse rotation. We only change the direction of rotation of the brush element (**Fig. 3.7**).

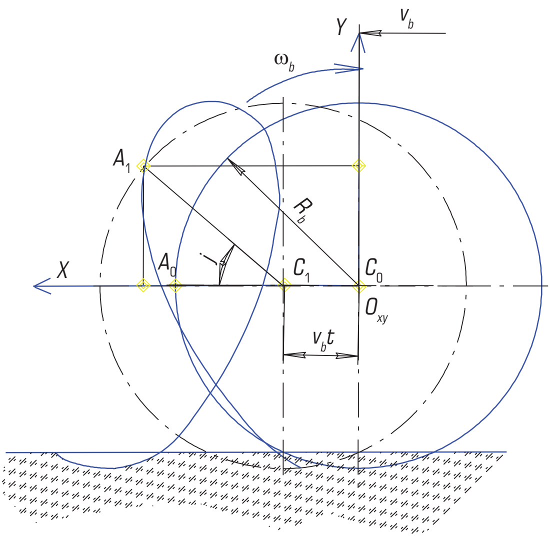


Fig. 3.7 Trajectory of movement of pile points with reverse rotation of the brush drum

Let's assume that the pile of a brush drum with a radius R_b in the process of operation rotates uniformly around a horizontal axis at an angular speed ω_b and at the same time participates in translational motion relative to a horizontal surface at a speed v_b. In this regard, the trajectory of movement will be an inverted cycloid, the construction of which can be seen from **Fig. 3.8**.

Let the brush move forward at a speed v_b over a distance $C_0C_1 = v_b t$. At the same time, the brush element C_0A_0 will move into position C_1A_1, having turned through an angle $\phi = \omega_b t$. Then the coordinates of the point A_1 in the adopted coordinate system will be $x = C_0C_1 + C_1A_1 \cos\omega t$, $y = C_1A_1 \sin\omega t$.

Considering that $C_1A_1 = R_b$, $C_0C_1 = v_b t$, let's obtain the equations of the trajectory described by the point A:

$$x = v_b t + R_b \cos\omega_b t; \;\; y = R_b \sin\omega_b t, \tag{3.5}$$

where v_b – peripheral speed of the fruit, m/s; t – time of fruit rotation, s; R_b – radius of the brush drum, m; ω_b – angular speed of the brush element.

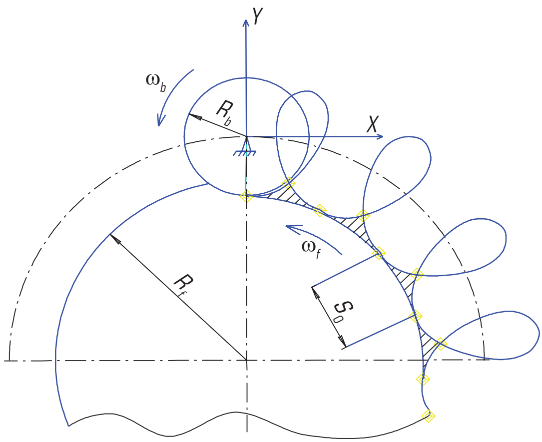


Fig. 3.8 Scheme of operation of the brush pile with reverse rotation of the drum

Replacing the peripheral speed of the fruit v_b with the product $\omega_f \cdot R_f$, the equations of the trajectory of motion will look like this:

$$x = \omega_f R_f t + R_b \cos \omega_b t; \;\; y = R_b \sin \omega_b t. \tag{3.6}$$

The absolute speed of the point A will be equal to:

$$v = \sqrt{\left(\frac{d(x)}{d(t)}\right)^2 + \left(\frac{d(y)}{d(t)}\right)^2} =$$

$$= \sqrt{\left(\frac{d(\omega_f \times R_f \times t + R_b \times \cos\omega_b \times t)}{d(t)}\right)^2 + \left(\frac{d(R_b \times \sin\omega_b \times t)}{d(t)}\right)^2} =$$

$$= \omega_f \times R_f \sqrt{1 + \left(\frac{\omega_b \times R_b}{\omega_f \times R_f}\right)^2 - 2\left(\frac{\omega_b \times R_b}{\omega_f \times R_f}\right) \times \sin\omega_b \times t} =$$

$$= v_b \sqrt{1 + \lambda^2 - 2 \times \lambda \times \sin\omega_b \times t}. \tag{3.7}$$

Comparing the absolute speeds for the two rotations, it is easy to see that the expressions obtained are similar.

In this case, the path traveled by the fruit in one revolution of the brush drum (**Fig. 3.6, 3.8**) is equal to:

$$s_0 = \frac{v_f 2\pi}{\omega_b} = \frac{\omega_f R_f 2\pi}{\omega_b} = \frac{2\pi R_b}{\lambda}. \tag{3.8}$$

The pile pitch or feed per brush element will be determined as the distance between the same points of two cycloids described by the same points of the adjacent brush elements. Since in the process of work the rind layer is removed in a few strokes of the brush elements, the total number of brush elements will be determined:

$$z_{bt} = z_b n, \tag{3.9}$$

where z_b – theoretical number of brush elements, pcs; n – the number of blows required to remove a layer of rind of a given thickness, pcs.

Since when the trajectories of adjacent brush elements located on the same radius overlap, the energy consumption for the operation of the brushes increases, and the removal of the trajectory of one brush from the trajectory of another leads to gaps in the work, then to solve this problem it is necessary to find the number of brushes z_b at which the trajectories of adjacent brushes touch each other, given λ.

To do this, let's use the equation (F. Kanarev) to determine the number of knives of the rotation rotor, provided that their trajectories touch each other:

$$z_b = \frac{\pi}{\left(\lambda \sin\arccos\frac{1}{\lambda} - \arccos\frac{1}{\lambda}\right)}. \tag{3.10}$$

The results of solving this equation on a PC are presented in **Table 3.1**.

Table 3.1 Required number of brush elements z_b (pieces) at different values

z_b	1	2	3	4	5	6	7	8	9	10	11	12
λ	4.6	2.97	2.4	2.11	1.93	1.8	1.72	1.65	1.6	1.55	1.51	1.48

Analyzing the solutions of this equation, it can be seen that with a decrease in the value of the kinematic parameter λ, that is, the ratio of the peripheral speed of the brush drum to the translational speed of the fruit, the number of brush elements increases.

The size of the fruit rind chips by the brushing elements will depend on the feed s. Knowing the number of brush elements z_{bt} and the movement of the fruit during one revolution of the brush drum s_0, let's find the value of the step (feed per brush element) s:

$$s = \left(\frac{2\pi}{z_{bt}\lambda}\right)R_b. \tag{3.11}$$

The pitch of the brush drum pile is directly proportional to the radius of the brush drum R_b and is inversely proportional to the number of brush elements z_{bt} and the speed ratio λ.

The radius of the brush drum depends on the thickness of the rind h_r, as well as the surface relief of the pumpkin fruit. The radius of the brush drum will be determined by:

$$R_b = R_d + S_b, \tag{3.12}$$

where R_d – drum radius, mm; S_b – length of the brush element, mm.

The length of the brush element S_b should be such that the brush element does not slide over the rind with its lateral side.

The drum radius R_d is selected from the condition that the trajectory of movement of one element will not depend on the trajectory of movement of the adjacent one, i.e. none of the brush elements located on one radius affects the operation of the other.

Depending on the fraction of the calibrated fruits and their sizes, it is necessary to adjust the distance between the axes of the brush drums l_d and the size of the working part of the brush drum l_{wp}.

Since the fruit has the shape of a torus (it can be assumed that the surfaces in the part of the peduncle and the receptacle are flat), the distance between the axes of the brush drums (**Fig. 3.9**) is determined by:

$$l_d = (R_b + R_b + h_f) - 2h_r = (2R_b + h_f) - 2h_r, \tag{3.13}$$

$$L_d = (D_b + h_f) - 2h_r,$$

where D_b – diameter of the brush drum, mm; h_f – fruit height, mm; h_r – rind thickness of the fruit or the maximum depth of immersion of the pile in the fruit of the pumpkin, mm.

The size of the working part l_{wp} of the brush drums structurally depends on the technological scheme of the machine proposed in this work. Since it is assumed that the rind will be removed from the surface of the fruit in one revolution of the cone-shaped drive drum, the l_{wp}^{l} of lower brush drum will be equal to the length of its generatrix of the cylindrical rotary drum. The length of the working part of the upper brush drums l_{wp}^{u} will depend on the radius of the fruit R_f, and in the first approximation will be determined by the expression $R_f^{\min} \le l_{wp}^{u} \ge R_f^{\max}$. The pile (**Fig. 3.9**) should ensure high-quality removal of the rind with a thickness h_r along the entire length of the contact patch of the brush element with the surface of the fruit.

The depth of immersion of the pile of the lower brush drum will be determined by the relative position of the support-drive drums in the vertical plane.

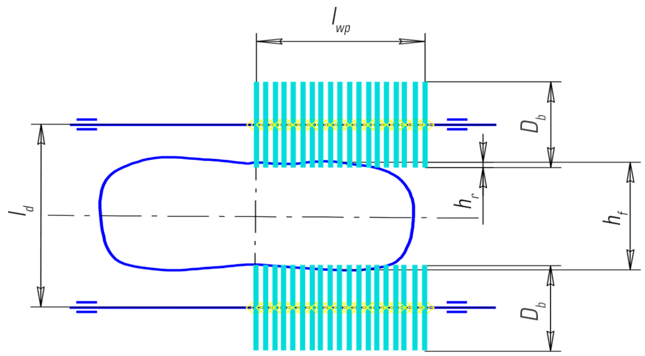


Fig. 3.9 Layout of the fruit in the space between the brushes

The distance between the brushing elements T should ensure uniform peeling of the fruit surface along the entire length of the working part of the brush drum without the formation of blemishes. At the same time, excessive overlapping of adjacent brush elements can, firstly, lead to an increase in energy consumption for peeling a unit of fruit surface area, and secondly, to create favorable conditions for the brush elements, producing a trace of a certain depth, to move into an adjacent one formed by an adjacent brush element, which will certainly lead to the formation of a blemish. Therefore, it is more expedient to take the distance between the pile equal to the width of the brush element, i.e. $T = b_e$.

When determining the cross-sectional shape of the brush element, it is necessary to take into account the conditions under which it moves. Since the surface of the fruit is complex, when copying it, there is a possibility of twisting deformation, which in turn can lead to a displacement towards the brush element and the formation of a blemish.

The greatest resistance to torsional deformation will be provided by rectangular brush elements, the axial moment of inertia of which is greater than that of other simple sections.

The section of the chips cut by one brush element at a certain moment will be determined by the expression:

$$F = b \times S^s, \tag{3.14}$$

where b – width of capture of one brush element or the distance between adjacent brush elements along the shaft of the brush drum; S^s – the thickness of the shavings in the investigated position of the pile, which with a sufficient degree of accuracy can be determined from the triangle ABC (**Fig. 3.10**).

$$S^s = S \times \sin\alpha, \tag{3.15}$$

where S – feed to one brush element of the brush drum.

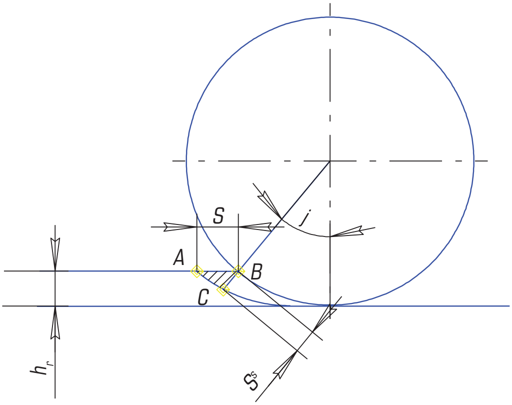


Fig. 3.10 Scheme for determining the cross section of the shaving

Hence, the cross section of the shavings will be equal to:

$$F = b \times S \times \sin(\phi). \quad (3.16)$$

Since several brush elements are simultaneously involved in the work, which are at different angles, the total section of the shavings removed by the brush drum:

$$F_s = b \times S \times i \sum_{1}^{i} \sin(\phi), \quad (3.17)$$

where ϕ_c – angle of contact of the brush element with the surface of the fruit, rad; i – the number of simultaneously operating brush elements.

On average, the number of simultaneously operating brush elements per cycle is:

$$i = \frac{\beta_1 \times z_{bt}}{720}, \quad (3.18)$$

where z_{bt} – total number of brush elements, pcs.

The angle of contact of the brush element with the fruit surface will be determined (**Fig. 3.4**):

$$\beta_1 = \arccos\left(1 - \frac{h_r}{R_b}\right), \quad (3.19)$$

where h_r – rind thickness (the maximum depth of penetration of the pile into the fruit), m.

Comparing the two rotations forward and backward, it is possible to see that for the first case β_1 it will be the angle of the beginning of contact with the surface of the fruit, and for the second – the angle at which the pile will be straightened and the cut chips will be thrown away.

When the brush drum is operating with a horizontal axis of rotation, the surface of the peeled fruit is ridged, which is undesirable from the point of view of loss of edible pulp. When designing the brush drum, it is necessary to choose such parameters that would provide a minimum height of the ridges, aiming for a smoother cleaned surface (**Fig. 3.11**).

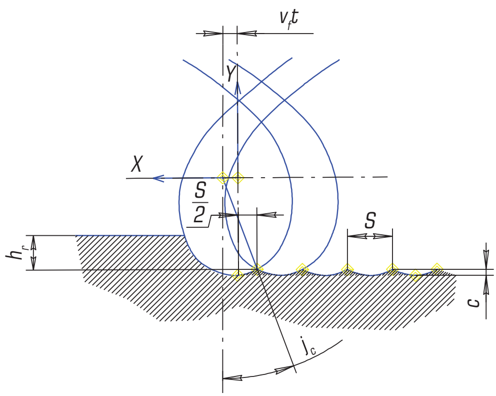


Fig. 3.11 Determination of the total cross-section of the chips removed by the brush drum

From equation (3.6) the trajectory of movement for direct rotation, the coordinate of the ridge apex:

$$y_c = -R_b \times \sin\phi_c, \tag{3.20}$$

where ϕ_c – angle of inclination of the brush element at which the ridge is formed, rad.

The second coordinate of the ridge vertex $x = S/2$. Substituting this value into equation (3.20) and taking into account that $\omega_b \times t = \phi_c$ and $t = \phi_c/\omega_b$, let's obtain:

$$\frac{S}{2} = R_b \times \cos\phi_c + V_f \times \frac{\phi_c}{\omega_b} = R_b \times \cos\phi_c + R_f \times \omega_f \times \frac{\phi_c}{\omega_b}.$$

For small angles, it can be accepted with a small error $\cos\phi_c \approx \phi_c$. Wherein:

$$\frac{S}{2} = R_b \times \phi_c + \frac{V_f \times \phi_c}{\omega_b} = \phi_c \times \left(R_b + \frac{V_f}{\omega_b}\right),$$

where

$$\phi_c = \frac{S}{2\left(R_b + \dfrac{V_b}{\omega_b}\right)}. \tag{3.21}$$

Substituting the angular speed into this formula $\omega_b = V_{ang}/R_b$, let's write:

$$\phi_c = \frac{S}{2R_b\left(1 + \dfrac{V_b}{V_{ang}}\right)}. \tag{3.22}$$

Then the height of the ridges will be equal to:

$$c = \pm R_b \times \sin\frac{S}{2R_b\left(1 + \dfrac{V_b}{V_{ang}}\right)}. \tag{3.23}$$

Taking into account equations (3.1) and (3.11), let's write:

$$c = \pm R_b \times \sin\frac{\dfrac{2\pi R_b}{\lambda \times z_{bt}}}{2R_b\left(1 + \dfrac{1}{\lambda}\right)}. \tag{3.24}$$

Simplifying the expression, let's obtain:

$$c = \pm R_b \times \sin\frac{\pi}{z_{bt}\left(\lambda + 1\right)}. \tag{3.25}$$

The plus sign is taken with reverse rotation, minus with the forward rotation of the brush drum.

3.3 DETERMINATION OF THE PERMISSIBLE ABSOLUTE SPEED OF COLLISION OF THE FRUIT RIND WITH THE BRUSH ELEMENT

In the process of active influence of the working bodies, the fruit rind is destroyed and separated from the pulp. The interaction of the working bodies is of a fleeting, dynamic nature and can be considered as a shock phenomenon.

When the brush element strikes the fruit rind, its shell is deformed. In the event that the impact speed is higher than the speed of propagation of elastic deformations in the rind, the stresses in the shell and deformations reach the limiting values at which the rind will collapse.

If we consider the fruits of pumpkin crops as elastic bodies, then we can assume that the particles begin to vibrate under the impact of impact. Therefore, to determine the permissible speeds of collision of elastic elements with the rind, one can use the formula of V. Goriachkin [70], obtained on the basis of the equations of coupled vibrational motion:

$$v_e = \frac{G_b}{\sqrt{E_m \rho}}, \tag{3.26}$$

where G_b – breaking stress of the material, N/m^2; E_m – modulus of elasticity of the material, N/m^2; ρ – density, kg/m^3.

The density is equal to $\rho = m/V$, and the modulus of elasticity $E_m = G_p / \varepsilon$, where m – mass of a piece of rind, kg; V – volume of a piece of rind, m^3; ε – relative deformation of the material.

In this case, the breaking stress of the rind is equal to:

$$G_b = G_{cr} + G_{sh}, \tag{3.27}$$

where G_{cr} – destructive stresses of the fruit rind during crushing, N/m^2; G_{sh} – destructive stresses of the fruit rind during shear, N/m^2.

In case of reverse rotation:

$$G_b = G_{sh}. \tag{3.28}$$

Thus, proceeding from the fact that the permissible impact speed is directly proportional to the destructive stresses of the material (rind, pulp), is inversely proportional to the square root of the elastic modulus and density of the rind, pulp and does not depend on the parameters of the elements of the working bodies, it follows that the absolute speed of the fruit pumpkin and brush elements must satisfy the condition:

$$v_a \geq v_e = \frac{G_b}{\sqrt{E_m \rho}}. \tag{3.29}$$

3.4 DETERMINATION OF THE FORCE PARAMETERS OF THE RIND REMOVAL WORKFLOW

Let's consider the process of operation of a cylindrical brush, the axis of which is installed parallel to the axis of rotation of the pumpkin fruit (**Fig. 3.12**). With the steady movement of the pumpkin fruit, the circumferential speed of the rotational movement of the fruit $u_f = \text{const}$, as well as the angular speed of the relative rotational movement of the brush $\omega_b = \text{const}$.

In addition, the dead weight of the brush element, which is cantilevered in the brush core, acts differently at different times. So, before the brush element meets the fruit surface (in the area of angle β_1), the rod's own weight force coincides with the direction of its movement and bends it so that it accelerates its meeting with the fruit surface. In the area of angles β_0 and β_2, this force of the brush element counteracts the movement and, under its action, the exit of the brush element from contact with the surface of the fruit is delayed.

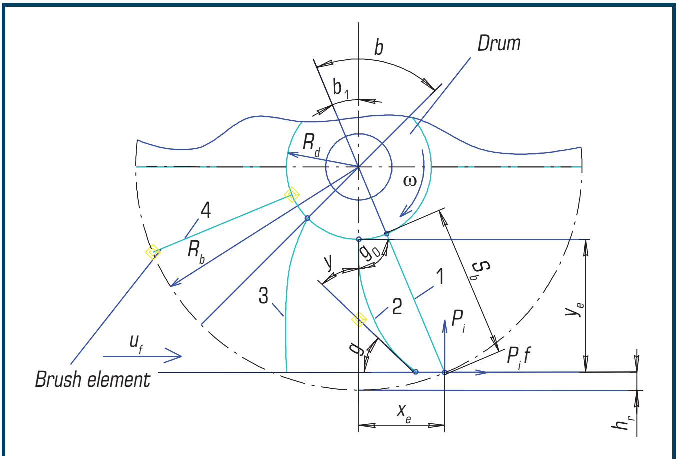


Fig. 3.12 Diagram of the forces acting on the brush element

The forces listed above are applied to different points of the brush element and their magnitude, and in some cases, their direction during the action change. In addition, these forces act at different times and, in most cases, change according to a nonlinear law. Thus, it is possible to conclude that the movement of the pile rods of the brushing devices occurs as a result of the interaction of a number of forces acting at different times and changing according to nonlinear laws, even when the steady and portable movement of the brush is uniform.

To determine the power and energy parameters of the working process of a cylindrical brush drum, consider the bending of the rod in a quasi-vertical position, when the tangent to the rod at the origin of coordinates of point *O*, which coincides with the point where the pile is embedded in the drum, is directed vertically along the *y*-axis and the initial angle at the point of embedding $\gamma_0 = \pi/2$ (position 2). It is possible to make a reasonable assumption that this position of the pile rod corresponds to the maximum vertical reaction P_i of its interaction with the surface of the fruit rind. In addition to the force P_i, the external horizontal friction force of the pile on the surface of the fruit F_i acts on the end of the rod:

$$F_i = P_i \cdot f_h, \tag{3.30}$$

where f_h – coefficient of friction of the pile on the surface of the fruit, for high-carbon steel $f_h = 0.25–0.27$, for synthetic pile $f_h = 0.22–0.24$. Since the own weight of the pile is small enough, let's neglect inertial forces and its own gravity. Bending moment $(N \cdot m)$, in an arbitrary cross-section of the pile with coordinates (*x* and *y*):

$$M_i = P_i \times (x_e - x) + P_i \times f_h \times (y_e - y), \tag{3.31}$$

where x_e – distance between the end and the vertical axis y; y_e – the distance between the drum rim and the horizontal surface of the road, $y_e = S_b - h_r$ (S_b – the free length of the pile rod, $S_b = R_b - R_d$, R_d – drum radius of the cylindrical brush; h_r – pile deformation).

Differential equation describing the shape of a bent elastic pile rod:

$$\frac{d(\gamma)}{d(S)} = \frac{M_i}{E \times J}, \tag{3.32}$$

where γ – current angle between the tangent to the rod and the horizontal; M_i – unit bending moment $N \cdot m$; E – modulus of elasticity of the pile, for steel wire $E = 2.1 \times 10^5$ MPa, for synthetic pile $E = (7.1 \div 8) \times 10^3$ MPa; J – moment of inertia of the cross-section of the pile rod relative to the axis perpendicular to the plane of rotation for a round pile $J = 0.25 \times \pi \times r_h^4$; r_h – the radius of the cross-section of the rod.

Then

$$\frac{d(\gamma)}{d(S_b)} = \frac{P_i}{E \times J}\left(x_e - x + f_h \times (y_e - y)\right). \tag{3.33}$$

Using the expression $\psi = \pi/2 - \gamma$; $\psi_e = \pi/2 - \gamma_e$; $dy = dS_b \times \sin(\gamma) = dS_b \times \cos(\psi)$, let's obtain:

$$dS_b = \frac{d\psi}{\sqrt{\cos(\psi) - f_h \times \sin(\psi) - \cos(\psi_e) + f_h \times \sin(\psi_e)}} \times \sqrt{\frac{E \times J}{2P_i}}, \tag{3.34}$$

$$dy = \frac{\cos(\psi) \times d\psi}{\sqrt{\cos(\psi) - f_h \times \sin(\psi) - \cos(\psi_e) + f_h \times \sin(\psi_e)}} \times \sqrt{\frac{E \times J}{2P_i}}, \tag{3.35}$$

where γ_e, ψ_e – angles of inclination to the horizontal and vertical, respectively, of the tangent to the end of the pile rod. As a result of integration for the average value of the friction coefficient, let's obtain in general, the form:

$$P_i = \frac{0.691 E \cdot J \cdot S_b^6}{y_e^8}. \tag{3.36}$$

Limiting angle of rotation of the end section of the brush element:

$$\psi_e = \arcsin\left[0.21 \cdot \left(\frac{S_b}{y_e}\right)^{10}\right], \tag{3.37}$$

whence the restriction follows $\sin(\psi_e) \le 1$; $y_e \ge 0.85 S_b$.

When the deformation of the brush element $h_e = S_b - y_e$ is greater than the maximum allowable, i.e. when $h_e \succ 0{,}15 \cdot S_b$, the brush element either begins to slide along the surface of the rind with its lateral side, reducing the free length S_b, ensuring the above inequality, or, in special cases, another, more complex law of bending deformation of the brush element comes into force.

When integrating within the angle of rotation β of the brush element from the beginning to the end of contact with the fruit rind during the contact time $t = \beta/\omega_b$, there is the average value of the vertical reaction $P_{av} = P_i \times K_\beta$, where K_β – integral coefficient, which can be taken as $K_\beta \approx 0.6$. To determine the total value of the vertical brush reaction P as a whole, it is necessary to determine the number of brush elements that are constantly present with the fruit rind during contact:

$$i_e = i_c \frac{\beta}{2\pi} = \frac{i_c}{2\pi} 2.6 \arccos \frac{y_e + R_d}{R_b}, \tag{3.38}$$

since for cylindrical brushes with radial bristles $\beta \approx 2.6\beta_1$.

The total number of brushing elements of a cylindrical brush i_c is determined from the condition of overlapping traces of brushing elements on the surface of the fruit rind both in width and in the radial plane of rotation:

$$i_c = \frac{\pi \times B_s \times K_a \times V_s}{2.6 \arccos\left(\dfrac{y_e + Rd}{R_b}\right) \times r_h \times \omega_b \times R_b}, \tag{3.39}$$

where B_s – width of the contact strip, m; K_a – coefficient of uneven arrangement of brush elements on the generating surface of the brush drum $K_a = 2 \div 2.5$; V_s – circumferential speed of rotation of the fruit. Taking into account expressions (3.37 and 3.39), the total vertical reaction is equal to:

$$P = 0.17 E \times J \frac{S_b^6}{y_e^8} i_c \times \arccos\left(\frac{y_e + Rd}{R}\right). \tag{3.40}$$

To determine the moment of elastic deformation of the brush elements of a cylindrical brush, we use the previously obtained expression for dS and transform it to the form:

$$-\frac{d(\gamma)}{d(S_b)} = \sqrt{\frac{2 \times P_i}{E \times J}} \sqrt{\sin(\gamma) - f_h \times \cos(\gamma) - \cos(\psi_e) + f_h \times \sin\psi_e}.$$

Then the reactive moment of resistance of the brush element to bending deformation at the place of embedding in the drum at $\gamma = \gamma_0 = \pi/2$, will be:

$$M_i = \sqrt{2P_i \times E \times J\left(1 + f_h \times \sin(\psi_e) - \cos(\psi_e)\right)}. \tag{3.41}$$

For a cylindrical brush as a whole, after substitution of the value P_i, let's obtain:

$$M = 0.583E \times J \frac{S_b^{\,3}}{y_e^4} \sqrt{\left(1 + f_h \times K - \sqrt{1 - K^2}\right) \times i_c \times \arccos\left(\frac{y_e + Rd}{R}\right)}, \tag{3.42}$$

where $K = \sin(\psi_e) = 0.21(S_b/y_e)^{10}$.

3.5 OPTIMIZATION OF DESIGN AND KINEMATIC PARAMETERS OF THE MACHINE FOR REMOVING RIND FROM PUMPKIN FRUITS

The research of the machine for removing the rind from pumpkin fruits was carried out by the method of experiment planning, which allows determining the optimal values of the parameters that affect the quality of the device.

When carrying out experiments to substantiate the parameters of the machine for removing rind from pumpkin fruits, the experimental setup shown in **Fig. 3.13** was used. The design of the experimental setup provides for the possibility of adjusting the following parameters:

– frequency of rotation of the brush drums (by changing the pulleys on the drum shafts);

– rotation frequency of the cone-shaped rotary drum (manually operated from the operator's seat);

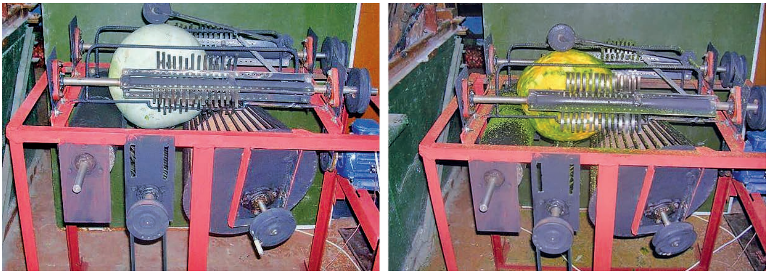
– direction of movement of the brushes in relation to the fruit or the direction of fruit rotation in relation to the brush drums, forward or reverse;

– magnitude of the overlap of the treatment zones of the peeling apparatus (mutual displacement of the brush drum racks along the guide grooves, in the vertical plane and along the grooves of the strips, in the horizontal plane);

– rigidity (by replacing pre-made sets of brush elements with different widths) and the shape of the cutting edge of the elastic brush element.

The principle of operation of the experimental setup is as follows. At the same time, with the help of the automatic switch, the electric motors of the drive of the brush drums are simultaneously turned on. With a steady movement of the brushes, the fruit is fed into the space between the brush drums from above (**Fig. 3.13, *a***). At this moment, from the operator's seat, manually begin to rotate the cone-shaped drum, which transfers the rotational motion to the fruit. At the same time, a layer of rind is removed from the surface of the pumpkin fruit (**Fig. 3.13, *b***). After one revolution of the cone-shaped drum, the fruit is peeled. After that, the electric motors of the brush drive are turned off by the switch of the machine.

To control the process of removing rind from pumpkin fruits and adjusting it, it is necessary to know the optimal values of the parameters that affect the quality of the peeling machine. This quality is assessed by the percentage of peeling and the percentage of the amount of loss of edible pulp, at the most optimal working parameters.



a *b*

Fig. 3.13 Technological process of removing the rind from pumpkin fruits during a multifactorial experiment: *a* – the initial state of the fruit; *b* – type of fruit after peeling

The completeness of peeling was assessed visually and was determined as a percentage from the expression:

$$C = \frac{S_{us}}{S_t} \times 100\ \%, \tag{3.43}$$

where S_{us} – area of the unpeeled surface of the pumpkin fruit cm^2; S_t – total surface area of the pumpkin fruit cm^2. The loss of edible pulp was determined as a percentage by the following expression:

$$M = \frac{M_{pf}}{M_{uf}} \times 100\ \%, \tag{3.44}$$

where M_{pf} – mass of the peeled fruit, M_{uf} – mass of the unpeeled fruit.

Analysis of literature data, results of exploratory experiments, theoretical studies of the process of removing rind from pumpkin fruits, high-speed filming made it possible to identify three main controllable factors that affect the quality of peeling: the stiffness of the brush element X_1, the angular speed of the brush drum X_2 and the kinematic parameter equal to the ratio of the circumferential speed of the brush drum to the circumferential speed of the fruit X_3 and intervals of their variation (**Table 3.2**).

Table 3.2 Levels and intervals of variation by factors

Factors	Designation	Units	Factor levels		
			Top level	Main level	Lower level
			+1	0	–1
Stiffness of the brush element, X_1	N	N/m^2	0.81	0.61	0.41
Brush drum angular speed, X_2	ω_b	s^{-1}	160	130	100
The ratio of the peripheral speeds of the brush drum (kinematic parameter), X_3	λ	–	20	15	10

The optimization criteria in the course of the experiment, by which the process was evaluated, were the peeling completeness – Y_1 and, as an additional, the loss of edible pulp – Y_2.

To solve the problem of regression analysis, the matrix of the Rechtshafner plan for a three-factor experiment was used.

Regression coefficients were calculated on the basis of experimental data using the proposed program on a PC.

The significance of these coefficients was assessed by the Student's test. All coefficients were found to be significant.

As a result of calculations, regression equations were obtained in coded form for pumpkin fruits of the varieties Volzhskaya gray 92 and Krupnoplodnaya 1:

a) by the completeness of peeling from the rind:

$$y = 95.44 + 2.75x_1 + 1.75x_2 + 1.0x_3 + 0.625x_1x_2 + 0.375x_1x_3 + \\ +0.875x_2x_3 - 2.187x_1^2 - 1.687x_2^2 - 1.437x_3^2, \quad (3.45)$$

$$y = 94.87 + 3.0x_1 + 1.624x_2 + 0.875x_3 + 0.375x_1x_2 + 0.38x_1x_3 + \\ +1.0x_2x_3 - 2.37x_1^2 - 1.5x_2^2 - 1.25x_3^2; \quad (3.46)$$

b) for the loss of edible pulp:

$$y = 1.76 + 0.77x_1 + 1.07x_2 + 1.1x_3 + 0.22x_1x_2 + 0.35x_1x_3 + 0.55x_2x_3 + \\ +1.96x_1^2 + 1.16x_2^2 + 1.54x_3^2, \quad (3.47)$$

$$y = 1.84 + 0.85x_1 + 1.1x_2 + 1.15x_3 + 0.275x_1x_2 + 0.375x_1x_3 + 0.525x_2x_3 + \\ +1.91x_1^2 + 1.16x_2^2 + 1.5x_3^2. \quad (3.48)$$

The adequacy of the obtained mathematical models was checked by Fisher's criterion. It was found that in all cases of fruit peeling studies $F_r \prec F_{tab}$ (here $F_{tab} = 2.6$ is the tabular value of the Fisher criterion at a significance level of 5 %). Thus, the mathematical model is adequate to the experimental results.

To determine the optimal values of the factors, it is necessary to differentiate the obtained regression equations for each variable and equate the partial derivatives to zero, solve the resulting systems of equations.

After solving the systems of equations, we obtained the values of the factors that optimize the value of the optimization criterion presented in **Table 3.3**.

To analyze the results obtained and study the response surface, a canonical transformation of second-order mathematical models was carried out.

Table 3.3 Optimal values of factors

Factor	Completeness of fruit peeling		Loss of edible pulp	
	Volzhskaya gray 92	Krupnoplod-naya 1	Volzhskaya gray 92	Krupnoplod-naya 1
x_1 – rigidity of the brush element, N/m^2	$\frac{0.81}{0.77}$	$\frac{0.77}{0.76}$	$\frac{-0.15}{0.58}$	$\frac{-0.165}{0.577}$
x_2 – angular speed of the brush drum, s^{-1}	$\frac{0.85}{155.5}$	$\frac{0.91}{157.3}$	$\frac{-0.38}{118.6}$	$\frac{-0.39}{118.3}$
x_3 – kinematic parameter, λ	$\frac{0.71}{18.55}$	$\frac{0.83}{19.15}$	$\frac{-0.27}{13.65}$	$\frac{-0.29}{13.55}$

Note: the values in the numerator are encoded, the denominator is encoded

As a result of this transformation, the regression equations (3.45–3.48) presented in canonical form are:

a) by the completeness of the fruit peeling:

$$Y-97.8=-2.337X_1^2-1.96X_2^2-1.01X_3^2, \tag{3.49}$$

$$Y-97=-2.42X_1^2-1.88X_2^2-0.81X_3^2; \tag{3.50}$$

b) for the loss of edible pulp:

$$Y-1.37=2.07X_1^2+1.01X_2^2+1.57X_3^2, \tag{3.51}$$

$$Y-1.41=2.04X_1^2+1.02X_2^2+1.51X_3^2. \tag{3.52}$$

Since all the coefficients of the square terms have the same signs, the response surfaces described by equations (3.49–3.52) represent a family of ellipses with the coordinates of the centers of the surfaces in the optimal values of the factors.

For the first main criterion according to technical conditions, the completeness of peeling should be at least 95 % of the surface, for the second additional criterion, the loss of edible pulp should be no more than 5 %. We will be guided by these two restrictions when choosing the limits of the factor variation intervals.

Solving the compromise problem, we needed to ensure the maximum possible percentage of peeling and a satisfactory value of the loss of edible pulp.

For the completeness of peeling Y_{comp}=95–96 % and for the loss of edible pulp Y_{loss}=3–5 % of Volzhskaya gray 92 pumpkin fruits, we obtained that the stiffness of the brush elements should be in the range of H=0.6–0.8 N/m^2 , the angular speed of the brush drum is Ω=15–16 s^{-1}, and the kinematic parameter is Λ=15–18. For cultivar Krupnoplodnaya 1, the optimal values of the factors with the same values of the optimization criteria are $H = 0.6–0.8$ N/m^2, $\Omega = 150–160$ s^{-1}, $\Lambda = 15–19$.

Thus, using two-dimensional sections, we determined the optimal values of the factors that most affect the process of removing the rind from pumpkin fruits, as well as indicated their maximum and minimum values that ensure the completeness of peeling permissible according to technical conditions [71].

3.6 OBTAINING MATHEMATICAL MODELS FOR INDIVIDUAL PROCESSES OF PROCESSING WATERMELON FRUITS

3.6.1 SEPARATION OF THE PULP FROM THE RIND WALLS

There is a sliding cut of the pulp from the inner walls of the rind. Elementary energy (work) dA (J), expressed:

$$dA = dA_1 + dA_2 + dA_3, \tag{3.53}$$

where dA_1 – elementary work spent on volumetric plastic deformation, J; dA_2 – elementary work spent on the formation of a new surface element (at the limit of molecular forces or surface energy), J; dA_3 – elementary energy spent on compensation of losses associated with the process of friction and the release of heat, respectively, J [6].

The terms dA_1, dA_3 are negligible in comparison with the value of dA_2.

Let's take into account only the value of dA_2 for cutting with sharp edges of the blades:

$$dA_2 = H_F \times 2dF, \tag{3.54}$$

where H_F – constant for a given material, characterizing its surface-active properties, or otherwise specific work (energy) spent on the formation of a unit area of the cut material, J/m^2; dF – elementary surface increment during cutting deformation, m^2.

Total energy (work) consumed for cutting:

$$A_2 = 2H_F \int dF, \tag{3.55}$$

where dF – elementary surface area of the cut, m^2; F – internal area of the cut surface, m^2; $2H_F$ – the newly formed surface is equal to the double cross-sectional area of the section, m^2.

With a constant cut area with a known configuration, the work will be expressed:

$$A = 2H_F F. \tag{3.56}$$

The speed of the cutting process, as the most important kinetic factor, is expressed:

$$v_c = \frac{dT}{F_c \times d\tau}, \tag{3.57}$$

where dT – elementary cutting force when separating the pulp from the inner surface of the watermelon; v_c – speed of the cutting process; F_c – cutting area. Let's represent the mathematical model of the pulp cutting process in the form of a system of equations:

$$\begin{cases} \nu_c = \dfrac{dT}{F \times d\tau}; \\ A = 2H_F \int dF, \end{cases} \tag{3.58}$$

or

$$\begin{cases} dT = \nu_c \times F d\tau; \\ dA = H_F \times 2dF. \end{cases} \tag{3.59}$$

3.6.2 GRINDING THE PULP INSIDE THE CAVITY

The fragile structure of the watermelon pulp is destroyed. Failure occurs as a result of compression deformations (mainly) and cutting. Arguing in a similar way (3.53), let's obtain:

$$dA = dA_1 + dA_2 + dA_3. \tag{3.60}$$

Let's neglect only the quantity dA_3:

$$dA = dA_1 + dA_2. \tag{3.61}$$

Let's express the elementary work dA_1 spent on volumetric deformation:

$$dA_1 = \frac{\sigma^{2 \times dV}}{2E}, \tag{3.62}$$

where σ – fracture stress at the pressure of the blades, Pa; dV – elementary volume increment during deformation, m^3; E – modulus of elasticity of the second kind, which characterizes the strength properties of a given material (product pulp), Pa.

Total energy (work) spent on volumetric deformation:

$$A_1 = \frac{\sigma^2}{2E} \int dV. \tag{3.66}$$

Total energy (work) consumed for cutting:

$$A_2 = 2H_F \int dF. \quad (3.67)$$

The speed of the process is determined by the cumulative effect of crushing and cutting deformations:

$$v_p = \frac{dR}{Fd\tau}, \quad (3.68)$$

where $dR = dR_1 + dR_2$ – elementary crushing and cutting force; F – processing area.

Let's represent the mathematical model of the pulp destruction process in the form of a system of equations:

$$\begin{cases} v_c = \dfrac{dR}{F \cdot d\tau}; \\ A_1 = \dfrac{\sigma^2}{2E} \int dV; \\ A_2 = 2H_F \int dF, \end{cases} \quad (3.69)$$

or

$$\begin{cases} v_c = \dfrac{dR}{F \cdot d\tau}; \\ dA_1 = \dfrac{\sigma^2 dV}{2E}; \\ dA_2 = 2H_F \cdot dF. \end{cases} \quad (3.70)$$

3.6.3 STIRRING THE PULP INSIDE THE CAVITY

The process of mixing a liquid is characterized by a complex distribution of speeds in its volume, which depends on the shape, dimensions of the tank and mixer, as well as on the rotation speed of the mixer blades.

According to Stokes' theorem, in a closed loop (with mixing), the circulation of the vector $\vec{a}$ will be expressed (**Fig. 3.14**):

$$G_A = \oint \vec{a} \cdot \overrightarrow{\delta r}. \quad (3.71)$$

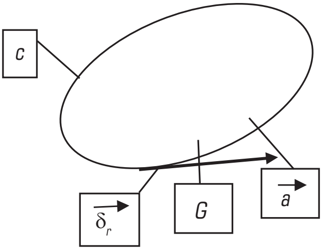


Fig. 3.14 Circulation of vector A: *c* – closed loop; *a* – circulation vector (peripheral speed); G_c – circulation of the vector *a* along the closed contour *c* (in the particular case around the circle with stirring); δr – elementary movement (elementary path)

In this case, the work (A_c) of the force of motion along a closed loop will be expressed:

$$A_c = \oint \vec{R} \cdot \overrightarrow{\delta r}, \tag{3.72}$$

where R – force that overcomes the resistance of the fluid layers, N.
For a unit of time, work in a closed loop represents the power spent on stirring in a transient mode:

$$N = \oint_c \frac{dA}{\tau}. \tag{3.73}$$

According to the first Helmholtz theorem, the angular speed vector is determined:

$$\vec{\omega} = \frac{1}{2} rot\vec{V}, \tag{3.74}$$

where $rotV$ – rotational speed rotor, which characterizes the intensity of the circumferential movement and is equal to twice the angular speed:

$$rot\vec{V} = \vec{\Omega}, \tag{3.75}$$

$$\Omega = rot\vec{V} = 2\vec{\omega}. \tag{3.76}$$

The rotor is the spatial derivative of the speed, or otherwise the rotor is a vorticity equal to twice the angular speed. If the circulation $G_c > 0$, then this means that there is vorticity in the liquid. Thus, there is a mixing of individual layers of liquid and the whole as a whole.

When mixing the liquid, the kinetic energy E in J is reported:

$$dE = \frac{\rho \cdot (\omega_0 \cdot x)^2}{2} \cdot h \cdot \omega_0 \cdot xdx, \quad (3.77)$$

where dE – elementary kinetic energy imparted to the stirrer blades; ρ is the density of the liquid system, kg/m^3; ω_0 – constant angular speed of rotation of the mixer, s^{-1}; x – distance from the axis of rotation (rotor axis), m; h – blade height, m; dx – elementary length of the blade, m.

$$E = \frac{\rho \cdot \omega_0^3 \cdot h}{2} \int_{r_1}^{r_2} x^3 \cdot dx = \frac{\rho \cdot \omega_0^3 \cdot h}{8} \cdot \left(r_1^4 - r_2^4\right), \quad (3.78)$$

where r_1 – radius of the inner edge of the blades, m; r_2 – radius of the outer edge of the blades, m.

The elementary force (dP) of friction acting on the blade will be expressed according to Newton's law:

$$dP = \frac{\xi \cdot \rho \cdot (\omega \cdot r_0)^2}{8} dF. \quad (3.79)$$

The total force (P) of friction N (hydrodynamic resistance) is determined:

$$P = \frac{\xi \cdot F \cdot \rho \cdot (\omega \cdot r_0)^2}{8}, \quad (3.80)$$

where F – area of the blade, m^2; ξ – drag coefficient of the blade, which depends on its shape and the mode of motion of the fluid; r_0 – radius of the blades, m; ω – working angular speed of rotation of the mixer, s^{-1}. Frictional force moment M_f:

$$M_f = \frac{\xi \cdot F \cdot \rho \cdot \omega^2 \cdot r_0^2}{8}. \quad (3.81)$$

Torque in operating mode M_t:

$$M_t = \frac{h \cdot \rho \cdot \omega^2 \cdot \left(r_2^4 - r_1^4\right)}{8}, \quad (3.82)$$

where μ – dynamic coefficient of viscosity of the liquid system, Pa/s.

Working power (N in W) on the mixer shaft is determined:

$$N = M_t \cdot \omega, \quad (3.83)$$

$$N = \frac{h \cdot \rho \cdot \omega^3 \cdot \left(r_2^4 - r_1^4\right)}{8}. \quad (3.84)$$

At a frequency of rotation of the stirrer blades n in rev/s, the angular speed:

$$\Omega = 2\pi n \text{ and } r = d/2, \tag{3.85}$$

where d – diameter of the stirrer blades. Let's get the working power equation:

$$N = K_N \cdot \rho \cdot n^3 \cdot d^5, \tag{3.86}$$

where K_N – power factor (power criterion).

Let's represent the mathematical model of the mixing process in the form of the following system of equations:

$$\begin{cases} A_c = \oint \vec{R} \cdot \overrightarrow{\delta r}; \\ N = \oint \frac{dA}{\tau}; \\ E = \frac{\rho \cdot \omega_0 \cdot h}{8} \cdot \left(r_1^4 - r_2^4\right); \\ P = \frac{\varepsilon \cdot F \cdot \rho\left(\omega \cdot r_0\right)^2}{8}; \\ N = K_N \rho n^3 d^5. \end{cases} \tag{3.87}$$

3.6.4 DERIVATION OF CRITERION EQUATIONS FOR INDIVIDUAL PROCESSES

Derivation of the criterion equation for the process of cutting the pulp

The power of the process of cutting the pulp with the blades inside the watermelon is a functional dependence of the type:

$$N = f(T, \rho, n, \ell), \tag{3.88}$$

where T – force required to cut the pulp, N; ρ – density of the raw material at the flesh-inner subrind border, kg/m^3; n – frequency of rotation of the cutting blades of the mixer, s^{-1}; ℓ – cutting path length, m.

According to the second similarity theorem, the functional dependence is expressed as a power-law equation (exponential equation):

$$N = AT^x \rho^y n^z \ell^q, \tag{3.89}$$

where A – coefficient depending on the intensity of the cutting process; x, y, z, q – power exponents, depending on the intensity of movement of the feed of the cut material.

To determine the number of similarity criteria that will be obtained in the course of transformations, according to the π-theorem, it will be determined:

$$\Omega=\Psi-\Lambda, \tag{3.90}$$

where Ω – the number of similarity criteria; Ψ – the number of unknowns in the equation; Λ – the number of primary units of measurement for mechanical processes.

$\Psi=5$; $\Lambda=3$ (kg, m, s).

Then

$\Omega=5-3=2.$

Let's apply the method of analyzing the dimensions of the quantities included in the power equation:

$$[N]=\mathrm{W}=\frac{\mathrm{J}}{\mathrm{s}}=\frac{\mathrm{N\cdot m}}{\mathrm{s}}=\frac{\mathrm{kg\cdot m}}{\mathrm{s^2}}\cdot\frac{\mathrm{m}}{\mathrm{s}}=\mathrm{kg\cdot m^2\cdot s^{-3}},$$

$$[T]=\mathrm{N}=\frac{\mathrm{kg\cdot m}}{\mathrm{s^2}}=\mathrm{kg\cdot m\cdot s^{-2}},$$

$$[\rho]=\mathrm{kg\cdot m^{-3}},$$

$$[n]=\frac{1}{\mathrm{s}}=\mathrm{s^{-1}},$$

$$[\ell]=\mathrm{m}.$$

Let's transform the obtained formulas in the form of units of measurement, substitute them into equation (3.2), replacing the alphabetic characters:

$$\mathrm{kg\cdot m^2\cdot s^{-3}}=A\cdot(\mathrm{kg\cdot m\cdot s^{-2}})^x\cdot(\mathrm{kg\cdot m^{-3}})^y\cdot(\mathrm{s^{-1}})^z\cdot(\mathrm{m})^q.$$

When performing some actions on the resulting transformation, it is possible to:

$$\mathrm{kg\cdot m^2\cdot s^{-3}}=A\cdot(\mathrm{kg})^{x+y}\cdot(\mathrm{m})^{x-3y+q}\cdot(\mathrm{s})^{-2x-z}.$$

Let's equate power exponents for the same reasons:

$$\text{kg}\,|\,1 = x + y \Rightarrow y = 1 - x;$$

$$\text{m}\,|\,2 = x - 3y + q \Rightarrow q = 5 - 2x;$$

$$\text{s}\,|\,-3 = -2x - z \Rightarrow z = 3 - 2x.$$

Let's substitute the power expressions (3.89) into the resulting equation:

$$N = A \cdot T^{x} \cdot \rho^{1-x} \cdot n^{3-2x} \cdot \ell^{5-2x}. \quad (3.91)$$

Let's make our transformations in a clearer form and obtain:

$$N = A \cdot \left(\frac{T}{\rho \cdot n^{2} \cdot \ell^{2}} \right)^{x} \cdot \rho \cdot n^{3} \cdot \ell^{5}. \quad (3.92)$$

There is:

$$\frac{N}{\rho \cdot \ell^{3} \cdot n^{5}} = A \cdot \left(\frac{T}{\rho \cdot n^{2} \cdot \ell^{2}} \right)^{x}. \quad (3.93)$$

In the analysis, let's obtain the dimension of the denominator $\rho \cdot n^{3}\ \ell^{5}$:

$$\left[\rho n^{3} \ell^{5} \right] = \frac{\text{kg} \cdot \text{s}^{-3} \cdot \text{m}^{5}}{\text{m}^{3}} = \text{kg} \cdot \text{m}^{2} \cdot \text{s}^{-3},$$

$$\left[N \right] = W = \frac{\text{J}}{\text{s}} = \frac{\text{N} \cdot \text{m}}{\text{s}} = \frac{\text{kg} \cdot \text{m}}{\text{s}^{2}} \cdot \frac{\text{m}}{\text{s}} = \text{kg} \cdot \text{m}^{2} \cdot \text{s}^{-3},$$

whence the dimensions:

$$\left[\rho n^{3} \ell^{5} \right] = \left[N \right].$$

Therefore, the dimension of the fraction on the right is:

$$\left[\frac{N}{\rho \cdot n^{3} \cdot \ell^{5}} \right] = 1.$$

Thus, a similarity criterion was obtained, which characterizes the ratio of the active cutting power to the power of cutting resistance forces:

$$\frac{N}{\rho \cdot \ell^3 \cdot n^5} = K_p. \quad (3.94)$$

On the right side, let's analyze the dimension of the fraction:

$$\left(\frac{N}{\rho n^2 l^2}\right) = 1.$$

A similarity criterion is obtained that characterizes the ratio of the active shear force to the resistance force:

$$\frac{T}{\rho \cdot n^2 \cdot \ell^2} = J_c, \quad (3.95)$$

J_c – criterion of cutting intensity.

Thus, the criterion equation will take the form:

$$K_p = A \cdot J^x. \quad (3.96)$$

The values of A and x are determined experimentally.

Derivation of the criterion equation for the destruction of watermelon pulp

There is a deformation of crushing (squeezing) the pulp of the watermelon. A certain deformation work is spent, which represents the power of the process per unit of time.

Let's express the functionally required cardinality N:

$$N = f(\sigma, F, \rho, n), \quad (3.97)$$

where σ – normal shear stress, $\sigma = \sigma_{cr}$ (N/m^2=Pa); F – area of destruction of the pulp, m^2; ρ – density of the pulp raw material, kg/m^3; n – rotation frequency of the stirrer cutting blades, s^{-1}.

According to the second similarity theorem, the functional dependence is expressed as a power-law equation (exponential equation):

$$N = B \cdot \sigma^x \cdot F^y \cdot \rho^z\, n^q, \quad (3.98)$$

where B – numerical coefficient depending on the intensity of deformation; x, y, z, q – power exponents depending on the intensity of movement (feed) of the cut material.

According to the π-theorem, the number of similarity criteria (Ω) that will be obtained during the transformation of equation (3.90) is determined:

$$\Omega = \Psi - \Lambda, \quad (3.99)$$

where Ω – the number of similarity criteria; Ψ – the number of unknowns in the equation; Λ – the number of primary units of measurement for mechanical processes:

$\Psi=5$; $\Lambda=3$ (kg, m, s).

Then

$\Omega=5-3=2$.

Let's apply the method of analyzing the dimensions of the quantities included in the equation of power consumption when crushing the pulp:

$$[N]=\mathrm{W}=\frac{\mathrm{J}}{\mathrm{s}}=\frac{\mathrm{N}\cdot\mathrm{m}}{\mathrm{s}}=\frac{\mathrm{kg}\cdot\mathrm{m}}{\mathrm{s}^2}\cdot\frac{\mathrm{m}}{\mathrm{s}}=\mathrm{kg}\cdot\mathrm{m}^2\cdot\mathrm{s}^{-3},$$

$$[\sigma]=\frac{\mathrm{N}}{\mathrm{m}^2}=\frac{\mathrm{kg}\cdot\mathrm{m}}{\mathrm{s}^2\cdot\mathrm{m}^2}=\mathrm{kg}\cdot\mathrm{m}^{-1}\cdot\mathrm{s}^{-2},$$

$$[F]=\mathrm{m}^2,$$

$$[\rho]=\mathrm{kg}\cdot\mathrm{m}^{-3},$$

$$[n]=\frac{1}{\mathrm{s}}=\mathrm{s}^{-1}.$$

The resulting transformations in the form of dimensions are substituted into equation, replacing the physical parameters with alphabetic characters:

$$\mathrm{kg}\cdot\mathrm{m}^2\cdot\mathrm{s}^{-3}=\mathrm{B}\cdot(\mathrm{kg}\cdot\mathrm{m}^{-1}\cdot\mathrm{s}^{-2})^x\cdot(\mathrm{m}^2)^y\cdot(\mathrm{kg}\cdot\mathrm{m}^{-3})^z\cdot(\mathrm{s}^{-1})^q.$$

Let's perform transformations on the right side:

$$\mathrm{kg}\cdot\mathrm{m}^2\cdot\mathrm{s}^{-3}=\mathrm{B}\cdot(\mathrm{kg})^{x+z}\cdot(\mathrm{m})^{-x+2y-3z}\cdot(\mathrm{s})^{-2x-q}.$$

Let's group the parameters of the equation according to the principle of one base by dimension:

kg$=x+z$, x – for the base, $z=1-x$;

$\mathrm{m}^2=-x+2y-3z$, $5-2x=2y$, $y=2.5-x$;

$\mathrm{s}^{-3}=-2x-q$, $q=3-2x$.

Then

$$N = B \cdot \sigma^{x} \cdot F^{2.5-x} \rho^{1-x} \cdot n^{3-2x}, \tag{3.100}$$

$$N = B \cdot \sigma^{x} \cdot \frac{F^{2.5}}{F^{x}} \cdot \frac{\rho}{\rho^{x}} \cdot \frac{n^{3}}{n^{2x}},$$

$$N = B \cdot \left(\frac{\sigma}{F \cdot \rho \cdot n^{2}} \right)^{x} \cdot \rho \cdot F^{2.5} \cdot n^{3}.$$

Let's group and get the criterion equation for crushing deformation (destruction of watermelon pulp):

$$\frac{N}{\rho \cdot F^{2.5} \cdot n^{3}} = B \cdot \left(\frac{\sigma}{F \cdot \rho \cdot n^{2}} \right)^{x}. \tag{3.101}$$

Let's group and get the criterion equation for crushing deformation (destruction of watermelon pulp):

$$\left[\frac{N}{\rho \cdot F^{2.5} \cdot n^{3}} \right] = \frac{\text{kg} \cdot \text{m}^{2} \cdot \text{s}^{-3}}{\frac{\text{kg}}{\text{m}^{3}} \cdot \text{m}^{5} \cdot \text{s}^{-3}} = 1.$$

A criterion of mechanical similarity is obtained, which characterizes the ratio of the active power of crushing (destruction) to the power of resistance forces:

$$D_{F} = \frac{N}{\rho \cdot F^{2.5} \cdot n^{3}}, \tag{3.102}$$

D_F – criterion for the strength of the shear deformation.

On the right side, let's also have a dimensionless complex criterion of mechanical similarity:

$$\left(\frac{\sigma}{F \cdot \rho \cdot n^{2}} \right) = \left[\frac{\text{kg} \cdot \text{m}}{\text{s}^{2} \cdot \text{m}^{2} \cdot \text{m}^{2} \cdot \text{kg} \cdot \text{m}^{-3} \cdot \text{s}^{-2}} \right] = 1,$$

$$R_{D} = \frac{\sigma}{\rho \cdot F \cdot n^{2}}, \tag{3.103}$$

R_D – criterion of the intensity of the action of the shear deformation force. After substitution of criteria expressions, let's obtain a criterion equation of the form:

$$D_{F} = B \cdot R_{D}^{\ x}. \tag{3.104}$$

Can be presented in the form:

$$D_F = B \cdot \left(\frac{\sigma}{\rho \cdot F \cdot n^2} \right)^x \tag{3.105}$$

or

$$\frac{N}{\rho \cdot F^{2.5} \cdot n^3} = B \cdot R_D{}^x. \tag{3.106}$$

Criterial equation of the pulp mixing process

This equation is well known and is used to calculate the working power of the mixing process:

$$N = K_N \cdot \rho \cdot n^3 \cdot d^5, \tag{3.107}$$

where N – operating power spent on the mixing process, W; K_N – power criterion or otherwise modified Euler criterion for mixers; ρ – the density of the liquid system, kg/m^3; d – diameter of the stirrer blades, m; n – rotation frequency of the stirrer blades, s^{-1}.

The criterion equation is presented in several forms:

$$\frac{N}{\rho \cdot n^3 \cdot d^5} = C \cdot \mathrm{Re}_m^k,$$

where

$$\frac{N}{\rho \cdot n^3 \cdot d^5} = Eu_m,$$

$$N = Eu_m \cdot \rho \cdot n^3 \cdot d^5. \tag{3.108}$$

The mixing quality is affected by the correctly selected and calculated angular speed ω (s^{-1}). It is related to the so-called relative mixing rate [6].

Derivation of the criterion equation for the relative speed of mixing the pulp

After starting the motor, the stirrer stabilizes rather quickly and the stirring mode becomes a steady state. Let's determine the torque on the shaft and blades of the mixer:

$$M_t = \frac{\rho \cdot h \cdot \omega_1^2}{8\mu} \cdot \left(r_2^4 - r_1^4 \right), \tag{3.109}$$

where M_t – torque on the mixer shaft, N/m; ρ – average density of the liquid system, kg/m^3; ω_1 – steady-state angular speed, s^{-1}; μ – dynamic coefficient of fluid viscosity, Pa/s; r_1 and r_2 – respectively, the inner and outer radii of the stirrer blades, m.

In this case, let's determine the moment of the friction force of the blades relative to the liquid and the walls of the mixer vessel (the inner cavity of the watermelon):

$$M_F = \frac{\xi \cdot F \cdot \rho \cdot \omega^2 \cdot r_0^3}{8} = \frac{\xi \cdot F \cdot \rho \cdot (\omega_0 - \omega_1)^2 \cdot r_0^3}{8}, \tag{3.110}$$

where M_F – frictional force moment, N/m; F – the area of the friction force, m^2; ξ – coefficient of hydraulic resistance; ω – initial angular speed, s^{-1}; ω_0 – maximum operating angular speed acquired by the blades immediately after starting, s^{-1}; $\omega_1 = \omega_0 - \omega$.

All torque energy is converted into energy to overcome frictional forces. Thus:

$$M_t = M_f;$$

$$M_t = \frac{\rho \cdot h \cdot \omega_1^2}{8\mu} \cdot \left(r_2^4 - r_1^4\right) = \frac{\xi \cdot F \cdot \rho \cdot (\omega_0 - \omega_1)^2 \cdot r_0^3}{8}. \tag{3.111}$$

Let's transform and obtain the criterion equation:

$$\left(\frac{\omega_0 - \omega_1}{\omega_1}\right)^2 = \frac{h}{\xi \cdot F} \cdot \frac{r_2^4 - r_1^4}{r_0^3}. \tag{3.112}$$

The left side of the equation is a dimensionless complex – the square of the similarity criterion for angular speeds with stirring. This is the criterion for the relative speed (*Sd*):

$$Sd = \frac{\omega_0 - \omega_1}{\omega_1}, \tag{3.113}$$

$$Sd^2 = \left(\frac{\omega_0 - \omega_1}{\omega_1}\right)^2. \tag{3.114}$$

The criterion equation for the relative angular speed with stirring were received:

$$Sd^2 = \frac{h}{\xi \cdot F} \cdot \frac{r_2^4 - r_1^4}{r_0^3}. \tag{3.115}$$

The criterion of the relative speed (*Sd*) is decisive for ensuring good mixing:

$$F = 2\pi r_0 \cdot H, \tag{3.116}$$

H – height of the mixer tank (average vertical height of the inner cavity of the watermelon).

When mixing, two processes take place simultaneously: the macro process is mixing of individual parts and components of the liquid system and the micro process is some separation of the mixed components.

It was found that optimal mixing at high angular speeds is characteristic of propeller and turbine mixers. Let's denote dimensionless complexes – simplices as follows:

$$\frac{r_2^4 - r_1^4}{r_0^4} = G_r \frac{h}{H} = G_M \frac{1}{2\pi\xi} = \phi(\mathrm{Re}).$$

Then there is the criterion equation for the relative speed in the form:

$$Sd^2 = \frac{1}{2\pi\xi} \cdot G_M \cdot G_r. \tag{3.117}$$

For a screw mixer, the use of the following criterion equation for calculating the optimal value of the Reynolds number for mixing has been experimentally confirmed:

$$\mathrm{Re}_s = 0.105 \cdot Ga^{0.6} \cdot S_\rho^{\ 0.8} \cdot G_r^{\ 0.4} \cdot G_d^{\ 1.9}, \tag{3.118}$$

Ga – Galilean criterion:

$$Ga = \frac{d_s^{\ 3} \cdot g}{\upsilon^2}. \tag{3.119}$$

Physical simplex of particle and medium densities:

$$S_\rho = \frac{\rho_p}{\rho_m}. \tag{3.120}$$

Geometric simplex of particle sizes and stirrer:

$$G_p = \frac{d_p}{d_s}. \tag{3.121}$$

Geometric simplex of the stirrer:

$$G_d = \frac{D}{d_m}. \tag{3.122}$$

The value of the minimum energy consumption corresponding to the optimal operating mode for propeller mixers was determined experimentally and is: $(n\tau)_{\min} = 85–120$, τ – the optimal mixing time.

It should be noted that it is possible to cut the fruits arbitrarily: when cutting, the pieces calmly move to the sides of the knife, without changing the shape.

There is a concept of constrained cutting: when cutting, the pieces do not move anywhere, then their deformation occurs during the cutting process. This requires additional force on the knife. In our experiment, the pulp was chopped as in cramped conditions, and the pulp was mixed inside the fruit.

Rotation speed is definitely important for quality and productive work. But the speed of rotation has a primary effect on the working body, because in the process of work, two main forces act on it:

– centrifugal, which tries to keep it in a radial position. It depends on the speed of rotation of the working mechanism;

– force of resistance of the medium, leading to bending of the working body. The bending depends on the resistance of the medium and the strength of the working body [72].

The correct selection of these parameters made it possible to gently chop the pulp, leaving the inner part of the watermelon rind intact.

In the course of research, the following device design with improved working bodies is proposed (shown in **Fig. 3.15**).

The device for peeling watermelon fruits from the rind and extracting a homogeneous mass of pulp contains (**Fig. 3.15**) fastener 1, tap 2, cradle 3, with a watermelon 4 located on it, drill 5, pipe 6, frame 7, gear pulley 8, chain 9, hollow pipe 10.

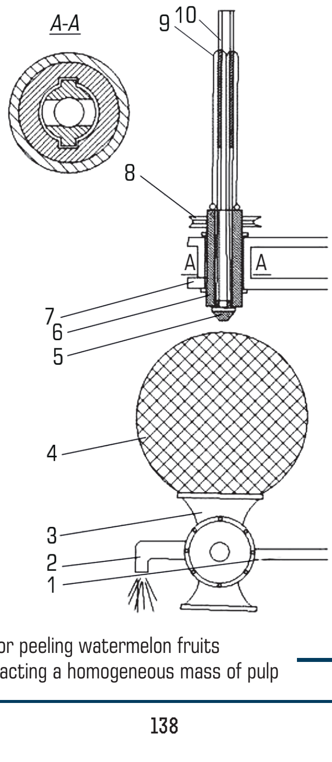


Fig. 3.15 Device for peeling watermelon fruits from the rind and extracting a homogeneous mass of pulp

The device works as follows.

The device for breaking fruits into juice, pulp and seeds is made in the form of a working body, consisting of a hollow pipe 10 with a chain 9 and a drill 5, which makes a reciprocating motion, in which it rotates downward and cuts into the receptacle of a watermelon, drills a hole in it and penetrating deep into the watermelon, it crushes the pulp and simultaneously separates it from the rind.

At the bottom there is a lodgment 3 which rotates and on which a watermelon 4 is put on. At the bottom of the lodgment there is a tap 2, from which juice comes out, the pulp of the seeds remains on the filter and when the lodgment is rotated, they fall into the seed tank (not shown). When the working body starts spinning, the chain 9 begins to unfold, takes the shape of a watermelon, the chain feed stops. During this time, the pulp inside is all crushed, then the organ continues to move downward, rotating around its axis and exits through the lower disc. Juice, pulp and seeds are poured onto a filter with a diameter of 4 mm. At the bottom there are sieves with a casing, differing in the size of the holes, preventing the passage of seeds through them.

The cuticle is spent on the release of pectin, the peeled watermelon rind for the production of candied fruits, the pulp for further processing into various products, the seeds are separated, washed, dried and packaged [75].

Also, during the study, the design was changed and is shown in **Fig. 2.28**. The installation works in the following way, the upper disc is first removed from the watermelon prepared for processing. The fruit is placed in a working chamber. At the beginning of work, it is necessary to connect the equipment to the network, prepare the fruit (load into the chamber), lower the working body with handle 8 until it stops in the fruit, close the chamber and press the «start» button on the dashboard. The working body begins to rotate, peeling the cuticle at the same time and crushing the pulp in the cavity of the watermelon. The moment the working body reaches the bottom of the watermelon, it will drill the bottom. Through a hole drilled with a drill, with a diameter of 5 cm, juice and watermelon seeds will flow out, which will fall on the sieves, different fractions will remain on the sieves, the seeds will remain on the last sieve, the juice is collected in a container under the device, different pulp fractions will be collected on the sieves. These fractions can be used for the production of cooking, etc., the juice is sent for boiling and obtaining watermelon syrup or molasses. The seeds are washed, dried and sent for storage, the rind is cut into even squares and sent for further processing into candied fruits.

Assembly and testing were carried out in accordance with the rules of the technological process. The commission found that the presented prototype meets the requirements of 1-SKD and the terms of reference [54].

Studies have been carried out on the selection of speeds and the number of outboard impellers. The data obtained during the experiments are shown in **Table 3.4**. The length of the rods was selected taking into account the diameter of the watermelons. The table shows the analysis of watermelons with a diameter of 30 cm and 13 cm long impeller.

To determine the level, location and number of suspended impellers, a diagram of the watermelon cavity for different diameters is also drawn up in **Fig. 3.16**.

Table 3.4 Selection of the number of hanging impellers and grinding efficiency

Number of hanging impellers	300 rpm	750 rpm	1,500 rpm	2,900 rpm
2 opposite each other	10	25	30	30
3 in a spiral	35	50	75	75
4 in a spiral	40	55	85	Loss of rind
6 in a spiral	50	60	75	Loss of rind
8 in a spiral	55	Loss of rind	–	–

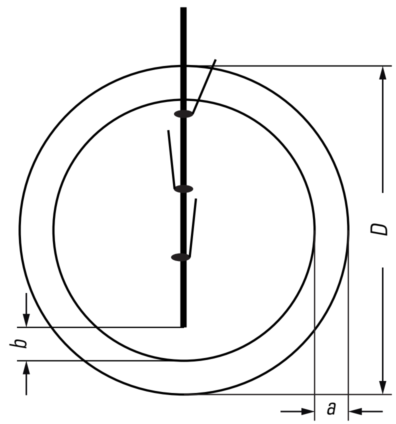


Fig. 3.16 Layout of suspended impellers:
a – rind thickness (8–15 mm); *D* – outer diameter or height of the watermelon; *b* – gap between the tip (drill) and the watermelon rind

As shown in **Fig. 3.16**, the location of the impellers is also an important aspect, the impellers are selected according to the following principle, the lower impeller must end above the drill, in order not to damage the rind, there should be a gap at the base between the lower impeller and the rind, the impellers should not touch each other when moving:

$$l = D - b - 2a, \tag{3.123}$$

where l – impeller length, mm; D – watermelon diameter, mm; b – gap, mm; a – rind thickness, mm.

So, the length of the impeller was experimentally determined for different diameters of the watermelon. The data are summarized in **Table 3.5**.

Table 3.5 Selection of impeller lengths depending on the watermelon diameter

Watermelon diameter, mm	Impeller length, mm
200–250	7
250–300	10
300–350	13

CONCLUSIONS TO SECTION 3

1. The reliability of the technological process is determined by the given location of the fruit on the surface of the support-drive drums, and ensuring the constancy of the torque supplied to the fruit due to the surface roughness of the drums.

2. The quality of fruit peeling depends on the kinematic modes of operation of the brush drums: the angular speeds of the drums and the fruit, the ratio between them, the fruit supply to one brush element, the direction of rotation of the fruit, the radii of the drums and the fruit, the number of brush elements on the drum surface.

3. The loss of edible pulp for this process is a limiting criterion that limits the variation of parameter values within a wide range.

4. The loss of edible pulp is largely dependent on the correct choice of the stiffness of the brush elements, the angular speeds of the brush drums and the fruit, as well as the direction of rotation of the fruit.

5. The power to drive a cylindrical brush drum has three components: power to overcome the frictional resistance of the brush elements against the fruit rind, power to separate the rind and throw it away, power to overcome aerodynamic resistance to brush rotation.

6. The obtained dependencies allow, with sufficient accuracy for practical calculations, to determine the kinematic and geometric parameters of the working bodies, rational from the point of view of the maximum abrasive effect of brushes, reducing the loss of edible pulp and ensuring the effectiveness of the proposed technological process of the machine for removing rind from pumpkin fruits.

7. The mass productivity of the peeling apparatus is determined by the geometric and operating parameters of its working bodies and the physical and mechanical properties of the fruit.

The design of device for the primary processing of watermelons has been developed, which allows to simultaneously obtain a rind, pulp, juice, seeds. The processing process takes place in the cavity of the watermelon, the rind should not collapse, because goes to the production of candied fruits from the rind of watermelon, a mass of homogeneous pulp passes through the sieves and seeds and large pieces of pulp remain on the sieve.

Calculated dependencies for determining the length of the impellers and their number are given and determined.

Methods for calculating the power on the shaft of the device are also presented.

This section proposes a new engineering solution that offers a complete replacement of manual labor in the process of peeling the watermelon from the rind and separating the pulp. The waste of raw materials has been reduced to a minimum, the time for obtaining the peel, pulp, juice and separation of watermelon seeds has been reduced. The machine provides ample opportunities to increase productivity and automate the entire line.

Therefore, the proposed device is recommended for the processing of watermelons for food. This experimental device has undergone extensive laboratory tests at an enterprise in the Almaty region, with the help of the developed device, 462 kg of watermelon juice were obtained. Recommended for small enterprises.

4 TECHNOLOGIES OF PROCESSING MELONS FRUITS

ABSTRACT

This chapter describes the technology and development of sweet and smart products, sugar-free candies made from natural and inexpensive products from melons, mainly watermelons and melons. The works aimed at expanding the range of products from melons are presented. At the beginning, the equipment for processing fruits was described, this chapter describes the technology for processing melons using the equipment described above.

KEYWORDS

Fruit jelly, juices, technology, watermelons, melons.

4.1 WATERMELON MARMALADE

Watermelon juice and pulp is an effective diuretic and choleretic agent. The pulp contains fructose, which is well absorbed by diabetics, nitrogen substances, fiber, iron minerals, vitamins B1, B2, C and PP. Watermelon is very rich in carotenoids, which have antioxidant effects, so they neutralize the harmful effects of free radicals. Carotenoids improve the functioning of the immune and reproductive systems [74].

Children are the most important consumer of sweets. Today, special attention is paid to organic products for baby food. Among the physiological features of early childhood – the immaturity of the gastrointestinal tract (GIT), characterized by high permeability of the intestinal wall, enzyme deficiency, as well as the immaturity of the immune system, lack of antioxidant protection. Children are particularly sensitive to unfavorable environmental factors during the period of active growth. Studies of the role of genetic polymorphism of the paraoxonase gene in children have shown that the paraoxonase enzyme is involved in protection against organophosphorus compounds and oxidative stress, and also inactivates pesticides in the body. Lower levels of the enzyme persist in children until at least seven years of age. This explains the ability of pesticides to influence the development of atopic dermatitis, the endocrine, immune, reproductive systems and cognitive impairments in young children [75].

According to the World Health Organization (WHO), about 60 % of deaths in the world are caused by noncommunicable diseases. In 2005, an estimated 17.5 million people died from cardiovascular disease (CVD), accounting for 30 % of all deaths in the world, of which 80 % were from low- and middle-income countries. By 2020, studies show that CVD mortality is expected to increase by 120 % for women and 137 % for men. These results highlight the need to explore options for minimizing or eradicating CVD and other noncommunicable diseases in developing countries such as Nigeria [76].

The number of overweight people worldwide has more than doubled since 1980, according to the World Health Organization. In 2015, this value reached 38 %. In Eastern Europe, the average overweight is 58 %. Among the countries in the region, the highest rates are found in Turkey (65 %), Greece (61 %) and Serbia (61 %) [77].

People, in order to lose weight, limit themselves in sugar and fats in their diets.

Allergic reactions are another of the most important nutritional problems for children and many adults. Most often, it is not the food itself that causes the allergy, but food additives – dyes, flavors, emulsifiers or preservatives. Significant changes in demographic indicators observed in recent decades (an increase in the world's population, including the elderly and sick people, the growth of the urban population, social stratification of society) required the improvement of technologies in the food industry [78].

Jelly marmalade, like most confectionery (CI), is characterized by a high content of easily digestible carbohydrates, excessive consumption of which can contribute to the accumulation of excess body weight and obesity – the leading risk factors for diseases such as atherosclerosis, coronary heart disease, hypertension, diabetes mellitus [60].

Due to the presence of agar and pectin in the jelly marmalade recipe, the carbohydrate composition consists of simple sugars (sucrose, glucose, maltose), oligosaccharides (molasses dextrins).

It is known that digestible carbohydrates entering the body under the action of enzymes are broken down to glucose and absorbed into the blood, after which they are oxidized for energy, and the excess is converted into glycogen [61].

The glycemic index, as well as the rate of degradation and stability of carbohydrates, depends on the structure of sugar substitutes, the conformations of individual monomeric units and the nature of the bond between them.

The watermelon fruit was sorted, sized and washed. They were then cut into cubes and mixed in a coffee grinder with 20 ml or 200 ml of water separately. They were then filtered into a closed container and stored in a refrigerator at +4 °C until use. The juices were mixed in different ratios: watermelon juice and rowan juice (90:10, 80:20, 70:30, 60:40 and 50:50).

Fruit jellies serve as an adequate balanced diet and contain antioxidants such as vitamins C and A, which play an important role in the prevention of cancer, cardiovascular problems and improvement of vision. It has been reported that watermelon has nutritional properties and is rich in antioxidant properties that can scavenge free radicals, thereby improving the body's antioxidant status. Thus, it is considered advisable to make marmalade from these perishables but healthy products in order to make them available throughout the year, as well as add to various foods.

The proposed method consists in cooling the fruit of the watermelon to a temperature of +4 °C, then washing and calibration. Sorted by size and weight, the fruits of the watermelon are peeled from the rind, the pulp is cut into cubes, passed through a press and the juice is separated from the seeds. Rowan fruits are peeled, washed, and juiced. Watermelon juice and prepared rowan juice in various ratios were heated to 95 °C and held for 15 minutes. The recipe for marmalade provides for the preparation of sugar-treacle or sugar-syrup-invert syrup, boiling it down to a mass fraction of dry matter 85–87 %, cooling the resulting syrup to a temperature of 55–65 °C, followed by the introduction of swollen gelatin, lemon juice pre-soaked in a juice mixture. acid, mixed, the resulting mass is cooled to a temperature of 40–50 °C, after which it is cast and allowed to stand to obtain the final product – jelly marmalade, which is made from the starting components taken at the following ratio, wt. % (**Table 4.1**).

Table 4.1 Marmalade recipe

Ingredient name	Percentage
Sugar-treacle or sugar-treacle-invert syrup	50–60
Gelatin	10–15
Juice mixture (watermelon + mountain ash) 90/10	40–25
Other	1

The obtained samples of marmalade showed a mass fraction of protein 0.40–0.80 %, fat 0.20–0.40 %, ash content 1.20–1.70 %, crude fiber 0.10–0.30 %, carbohydrates 62.10–67.16 %, β-carotene 610–1350 μg/100 g and ascorbic acid 9.60–15.40 mg/100 g. The total amount of carotenoids in the marmalade recipe (1,347±0.30 – 720±0.18) μg/100 g was higher than that of the control sample (610±0.30) μg/100 g, which means that the jujube contains a significant amount of carotenoids.

Carotenoids in large quantities can fight diseases such as age-related muscle degenerative diseases, hypercholesterolemia, cardiovascular diseases, hypertension, and cancer in humans [63, 79].

In addition, the carotenoid value indicates that marmalade is a potential source of vitamin A, given that the recommended daily intake is 750 μg/100 g per 65 kg adult. The carotenoid content of cooked marmalade was lower than some commonly consumed foods, such as corn (200 μg/100 g), plantain (800 μg/100 g), cabbage (2,000 μg/100 g), and carrots (12,000 μg/100 g). Carotenes are usually converted to retinol (vitamin A) in the small intestine, and its color also makes food more attractive to the eyes, as reported by Müller [37]. The high carotenoid levels in jujube may be the result of the red (lycopene) pigment in watermelon.

The result of the organoleptic evaluation showed that the prototype of the marmalade compares very well with the imported strawberry marmalade in terms of color, taste, and taste. The 90/10 sample was rated higher than the 50/50 sample. This observation is consistent with the chemical analysis, in which a sample with a juice ratio of 90/10 showed better nutritional value and a longer shelf life. The variation in the ratio of watermelon and mountain ash juices is shown in **Fig. 4.1**, in the context of the assessed sensory characteristics.

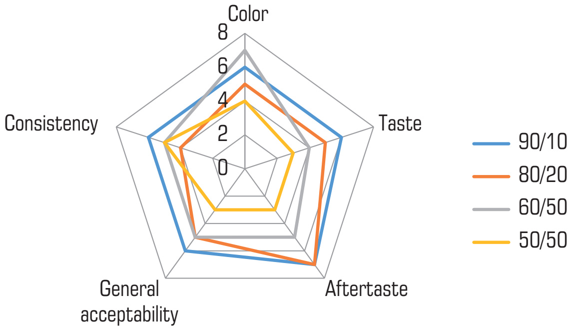


Fig. 4.1 Organoleptic analysis of watermelon pulp marmalade

The result of analyzes for microbial contamination showed that the total number of aerobic bacteria 2.0×10^1 CFU/g for the sample of the prototype jujube was lower than 4.1×10^1 CFU/g of the imported commercial brand. Likewise, the amount of yeast and mold 1.0×10^1 CFU/g, respectively, for the test fruit jelly was lower than 2.1×10^1 CFU/g for the control. The results showed that no coliforms were detected in all samples. This indicates that all samples are safe for human consumption, moreover, the total number of microorganisms does not exceed the tolerance limits of $>10^5$ recommended by the International Commission on Microbiological Characterization of Foods, ICMSF [80].

4.2 DEVELOPMENT OF MELON JELLY MARMALADE

Melon varieties during their biological ripeness have a different pulp structure:

1) spreading, extremely juicy, melting in the mouth;
2) dense, viscous;
3) crispy, watermelon-like;
4) potato, crumbly.

In Kazakhstan, melons of local breeding have a dense, viscous flesh. The type of pulp that spreads and melts in the mouth is due to its high juiciness and cell maceration. The crispy watermelon-like flesh of melons has a highly porous structure and a more developed coarse conductive system. The pulp has many intercellular spaces with a large number of air bubbles, which also create elasticity, which is why these melons «crunch» when eaten fresh.

There are three systems of feeding vessels in the fruits of melons:

1) passing through the center of the fruit;
2) along its periphery;
3) in the middle of the cow pulp. They are joined by the ends of the branching [81].

According to the Committee on Statistics of the Ministry of Economy of the Republic of Kazakhstan [82], in terms of the cultivated areas of melons, the main part is the Turkestan region – 61.8 thousand hectares.

Currently, there is a problem of processing the fruits of melons of early ripeness, in view of their poor keeping quality. This aspect is poorly studied in world practice.

In modern market conditions, the issue of production of new functional food products of high quality is one of the most urgent. It provides for the innovative development of agriculture, an accelerated transition to the use of high-performance, resource-saving technologies.

Problems of production of high-quality raw materials, their maximum preservation during storage and processing remain relevant. One of the defining factors for improving the integrated system for the production of fruits and berries is a scientifically grounded approach to raw materials as an object of storage and processing, the quality of which is determined by the genotype of the variety, environmental, soil-climatic, and technological factors [83].

Confectionery (CI) is an integral and favorite component of the diet of all categories of the population due to its pleasant sweet taste and attractive aroma. Consumption of CI in developed countries reaches 18...20 kg per person per year.

At the same time, the consumer today has become much more demanding and seeks to get pleasure without harm to health. When making a purchase, it weighs its expediency, focuses not only on the price, but also carefully analyzes information about the composition of each purchased product, which indicates an increase in the culture of consuming sweets.

Fruit and fruit-jelly marmalade is characterized by the highest nutritional value and the lowest energy value, the provision of the necessary structure of which is achieved due to the pectin-containing fruit and berry raw materials included in their composition, with a weak jelly-forming ability of which a gelling agent is added [84].

For an accelerated quantitative and qualitative assessment of the degree of microbial contamination of finished products, the determination was carried out on an automated express system, the «BakTrak» device. This method makes it possible not only to determine the number of microorganisms in a sample, but also to determine the level of their activity, which is decisive in the process of food spoilage by microorganisms [85].

Microbiological analysis of samples by a standard method was carried out based on the standards of SanPiN 42-123-4940-88 by standard methods immediately after manufacture and periodically during storage. The total number of mesophilic aerobic and facultative anaerobic microorganisms in 1 g (MAFAM), the titer of bacteria of the group of E. coli, the presence of pathogenic microorganisms, incl. Salmonella in 25 g and pathogenic staphylococcus in 1 g, the number of yeasts and micromycetes in 1 g [86–91].

In the course of the research, part of the sugars included in the formulation was replaced with GFS, which made it possible to save up to 70 % of sugar. All types of raw materials must meet the requirements of regulatory documents. for the agar we use, it is provided for soaking in water in the ratio agar: water – 1:40 for 30...40 minutes. The prepared gelling agent, together with the prescription amount of water, is loaded into an open digester using a weighing batcher, and heated (steam pressure – 0.3 MPa). After complete dissolution of the agar, add the prescription amount of glucose-fructose syrup required for the preparation of jelly marmalade and mix. After completely stirring the mass, add the melon pulp in the form of a homogeneous milled mass. Stirred and boiled in a vacuum cooker. Up to the mass fraction of dry substances 73–75 %. Next, the syrup is filtered, rowan juice is added, brought to a dry matter content of 60 %, and sent to a tempering machine with a temperature of 60 °C. Then the marmalade is poured into molds and allowed to stand at room temperature until it hardens, within 80 minutes, the moisture content in the finished products is 18 %. Then they are sent for drying in a ventilated drying cabinet at a temperature of 40 °C for 20 minutes.

The chemical composition of raw materials, in our case, melon puree, is shown in **Table 4.2**.

Table 4.2 Chemical composition of melon puree

Nutrient	Quantity	Norm**	% of the norm in 100 g	% of the norm in 100 kcal	100 % normal
Calorie content	337 kcal	1,684 kcal	20 %	5.9 %	500 g
Protein	0.04 g	76 g	0.1 %	–	190,000 g
Fats	0.01 g	56 g	–	–	560,000 g

The energy value of jelly-melon marmalade is 337 kcal.

According to the developed technology, jelly-melon marmalade has an increased nutritional value, especially in terms of the content of sodium, potassium, calcium, phosphorus, vitamins C and E, neurovitamins.

Dyes and flavors are excluded from the recipe, since the marmalade acquires color due to the content of juice and melon puree, turning into a jelly mass.

In the proposed method, the carbohydrate-containing raw material, namely sugar, is replaced by stevioside, which makes it possible to use the product for people suffering from diabetes mellitus.

An increase in the dosage of melon juice over 250 kg/t leads to an increase in the content of reducing sugars, the consistency of finished products becomes friable, a decrease in its dosage to less than 214 kg/t leads to a deterioration in its consistency becomes glassy, the nutritional value decreases, and the stickiness increases.

Microbiological indicators of the finished product are summarized in **Table 4.3**.

The amount of yeast and mold 1.0×10^{1} CFU/g, respectively, for the experimental marmalade sample was lower than 2.1×10^{1} CFU/g for the control. The results showed that no coliforms were detected in all samples. This indicates that all samples are safe for human consumption, moreover, the total microorganism count does not exceed the tolerance limits of $>10^{5}$ recommended by the International Commission on Microbiological Characterization of Foods, ICMSF [92].

In terms of organoleptic characteristics, the products must comply with the requirements given in **Table 4.4** [93, 94].

Table 4.3 Microbiological indicators of melon-jelly marmalade

Indicator name	Indicator value
Colibacillus	Absent
Causative agents of botulism	Absent
Coliforms	Absent
Salmonella in 25 cm^3 of product	Absent
Yeast, CFU/g	no more than 50
Mold, CFU/g	no more than 50

Table 4.4 Organoleptic characteristics of jelly marmalade made from pulp and melon juice

Indicator name	Index
Taste, smell, color	Taste and smell characteristic of melon, color from light yellow to dark yellow
Consistency	Jellylike, lingering consistency is allowed for marmalade on agaroid, gelatin, modified starch
Form	For molded – correct, with a clear contour without deformation. Slight beads are allowed, for marmalade by casting, fuzzy edges are allowed

The moisture content of marmalade in accordance with the indicators of regulatory documents does not exceed 20 %, the mass fraction of reducing substances is not more than 20 %. The mold content according to the regulatory documents for jelly marmalade is 100 g/cm^3, in our marmalade does not exceed 50 g/cm^3.

Fruit jelly should be stored at a temperature of +15 °C without exposure to direct sunlight. The shelf life without loss of quality under these conditions is 1.5 months.

4.3 MELON JUICE

In the course of the experimental research carried out, we have developed a technology for the production of juice from melons, with preliminary heat treatment (blanching) of the raw material before extracting the juice from it.

Technological process (**Fig. 4.2**).

Acceptance of raw materials. Raw materials supplied to the plant must be accompanied by a quality certificate and a toxicological certificate with confirmation of the residual content of pesticides and nitrate nitrogen, as well as a conclusion on the permission of its processing.

Sorting and inspection. Melon fruits are graded and inspected, removing unusable specimens and grading into separate lots containing fruits and berries of the same type, ripeness, color and size.

Defective fruits are taken from the total mass – broken, crumpled, unripe, overripe, affected by agricultural pests, as well as foreign impurities.

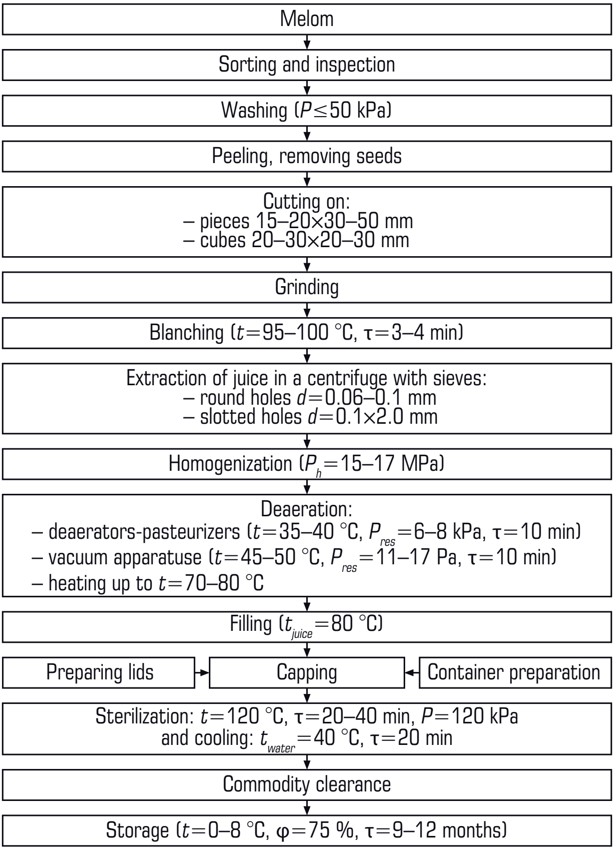


Fig. 4.2 Technological scheme for the production of juice from melon 1

Washing. Melons are washed under the shower at a pressure of no more than 50 kPa in the shower heads and rinsed.

Melons are peeled, seeds and cut into pieces of 15–20 mm (thickness) and 30–50 mm long or into cubes with 20–30 mm edges. The fruits are crushed on KDN-3M crushers and blanched at 95–100 °C for 3–4 minutes.

Getting juice. Prepared melon pulp is sent for juice extraction. To obtain it, disintegrators, rubbing machines or centrifuges are used.

Juice is obtained from melons only on disintegrators or centrifuges with sieves having round holes 0.06–0.1 mm in diameter or slot-like holes 0.1×2.0 mm in size (NVSH-350 centrifuge).

Homogenization. The juice is finely ground in homogenizers of various systems or colloid mills at a pressure of 15–17 MPa.

Deaeration and heating. Juices are deaerated in deaerators – pasteurizers at a temperature of 35–40 °C and a vacuum of 700–715 mm Hg. (residual pressure 6–8 kPa). It is allowed to carry out deaeration in a vacuum apparatus at a temperature of 45–50 °C and a vacuum of 630–680 mm·Hg (residual pressure 11–17 kPa) for no more than 10 minutes. After deaeration, the juice is heated to 70–80 °C.

Filling and capping. Melon juice is poured on automatic fillers into glass and varnished cans and bottles with a capacity of up to 3 liters, bottles with a capacity of up to 1 liter and aluminum tubes with a capacity of 0.2 liters.

The filled container is sealed on a vacuum-sealing or seaming machine with a lacquered sheet lid.

Sterilization and cooling. The sealed products are sterilized in an autoclave or continuously operating pasteurizers at a temperature of 70–120 °C for 20–40 minutes, depending on the type and capacity of the container.

After pasteurization, jars and bottles with juice are cooled with cold water until the temperature of the water in the autoclave drops to 40 °C for 20 minutes.

Storage. Juices are stored in peel, dry, well-ventilated rooms, protected from direct sunlight. Warehouse air temperature should be from 0 to 8 °C, relative humidity not less than 75 %.

The recipes and consumption rates of raw materials and auxiliary components for the production of natural juice from melons are presented in **Table 4.5**.

Table 4.5 Recipe and consumption rates of raw materials and auxiliary components for the production of melon juice

Name of raw material and product	Dry matter content in raw materials, %	Ratios, %
		juice
Melon juice		
Melon	11	100

Comparative analysis of the nutritional and biological value of juice (**Table 4.6**) shows that the water content in the raw material is 88.5 %, and in the juice it is slightly higher than 88.7 %, but the dry matter in the juice is lower. The content of carbohydrates and vitamins B1, B2 is at the same level, the amount of proteins in the product is 0.48 %, which is 0.12 % less than in the raw materials. Vitamin C is reduced by 15 mg/100 g of product as a result of heat treatment. The amount of minerals is at the same level, except for potassium, its content in the product is relatively higher (9 mg/100 g), and the remaining trace elements (Ca, Mg), except for Fe, change insignificantly. The titratable acidity of the product is 0.4 % higher. In general, the nutritional and biological value of melon juice is higher due to dry matter, carbohydrates, and raw proteins [95–98].

Table 4.6 Nutritional and biological value of melon juice

Indicators	Name of raw material and product	
	melon	**Melon juice**
Water, % 88.5	88.5	88.7
Dry substances, % 11.5	11.5	11.3
Carbohydrates, % 9.6	9.6	9.6
Proteins, % 0.6	0.6	0.48
Vitamins, mg/100 g		
B1	0.04	0.03
B2	0.04	0.03
C	27	11.9
β-carotene	6.4	0.32
Minerals, mg/100 g		
Na	32	11
K	118	127
Ca	16	14.2
Mg	13	10.8
Fe	0.49	287
Ash, %	0. 6	0.48
Titratable acidity in terms of malic acid, %	0.1	0.5

The organoleptic characteristics of melon juice (**Table 4.7**) indicate that the juice has a light yellow color, in appearance it is a homogeneous mixture with a slight sediment at the bottom, slight stratification is observed, the taste is characteristic of melon, pleasant, sweet, without extraneous shades, the smell is pleasant characteristic of a melon, without defamatory shades and without foreign aroma, and the consistency is viscous.

Table 4.7 Organoleptic characteristics of melon juice

Product name	Organoleptic indicators			
	appearance	**taste**	**smell, aroma**	**consistency**
Melon juice	Light yellow in color, homogeneous mixture with little sediment at the bottom, slight delamination	Peculiar to melon, pleasant, sweet, without extraneous shades	Pleasant, peculiar to melon, without defamatory shades and without foreign aroma	Viscous

Also, another technology for the production of juice from melons with preliminary freezing and subsequent defrosting of raw materials has been developed (**Tables 4.6, 4.7**). Technological process (**Fig. 4.3**). Raw materials supplied for processing must be accompanied by a quality certificate and a toxicological certificate with confirmation of the residual content of pesticides and nitrate nitrogen, as well as a conclusion on the permission of its processing.

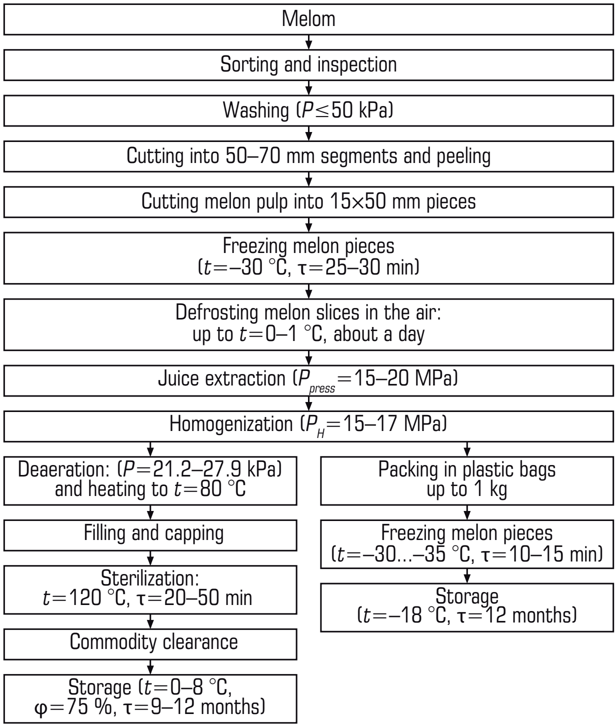


Fig. 4.3 Technological scheme for the production of juice from melon 2

Melons are graded and inspected by removing unusable specimens and grading into separate lots containing fruits of the same type, ripeness, color and size. Defective fruits are selected from the total mass – broken, dented, cracked, rotten, rotten, unripe and others. Melon fruits are washed under pressure in shower heads of no more than 50 kPa and rinsed.

To facilitate further processing, the melon is cut into 50–70 cm segments, freed from seeds and inner film, and the stalk is cut out. The melons are freed from the peel, seeds, and the melon pulp is cut into pieces measuring 15×50 mm.

The melon is rubbed as follows. The melon pulp, separated from the rinds, is rubbed in rubbing machines through sieves with holes 1.5...2 mm in diameter (to remove seeds and coarse parts of fiber). At the same time, soft whips are installed in the wiping machine, the rotation frequency of which should be no more than 320 rpm in order to prevent the seeds from breaking. For finer grinding and obtaining a homogeneous dispersed mass, the pulp is rubbed a second time through sieves with holes of 0.4...0.8 mm in diameter.

To incre ase the yield of juice and preserve the nutritional and biological value in the production of juice from melons, crushing of raw materials is replaced by preliminary freezing followed by defrosting. The pieces of melon were frozen at a temperature of 35 °C until the temperature in the center reached 18 °C.

Frozen melon is defrosting by air until the temperature reaches 0...1 °C.

Melon juice is obtained by separating the gravity juice after defrosting the crushed melon on a drier (up to 50–60 % of the melon mass is removed) and subsequent pressing.

Option I. The finished juice is homogenized at a pressure of 15–17 MPa and deaerated at a residual pressure of 21.2–27.9 kPa, heated to 80–85 °C and sent for filling into glass jars with a capacity of not more than 3 liters.

Filled cans are sealed with prepared lacquered tinplate lids and sterilized at 120 °C for 20–50 minutes.

Option II. After receiving the juice is packed in heat-sealed plastic sacs with a capacity of up to 1 kg, the juice is packed so that 6...8 % of the container capacity remains free. This ensures the integrity of the container during subsequent freezing, when the volume of production increases as a result of the transition of the liquid into a solid state [99–101].

Freezing of juice is carried out at temperatures below –30...35 °C and air speed up to 7 m/s in a GKA-2 freezer or in freezers at temperatures of –30…40 °C and a speed of up to 6 m/s. Freeze to a temperature of –18 °C in the thickness of the product. Upon reaching this temperature, the juice takes the form of monolithic briquettes or rectangular blocks with a tight-fitting film. Quick-frozen juice is stored at a temperature of –18 °C for 12 months.

Thus, the developed technology for the production of juice from melons, with preliminary freezing and subsequent defrosting of the crushed raw materials, allows increasing the yield of juice and preserving the nutritional and biological value of the finished product [102, 103].

Table 4.8 shows the recipe and consumption rates of raw materials for the melon juice production.

Comparative analysis of the nutritional and biological value of juice (**Table 4.9**) shows that the water content in the raw material is 88.5 %, and in the juice is slightly lower than 84.9 %, respectively, the dry matter in the juice is 3.6 % higher. The content of carbohydrates in juice is much higher (6.8 %) compared to raw materials, which is explained by the preliminary freezing of raw materials before extracting the juice. The amount of protein and vitamins B1, B2 is at the same level. Vitamin C is preserved. With regard to minerals, the content of potassium in the product slightly increases on a dry basis, and the remaining trace elements (Ca, Mg), except for Fe, practically do not change. The titratable acidity of the product does not change. In general, the nutritional and biological value of melon juice is higher due to dry matter, carbohydrates and proteins of the main raw materials.

Table 4.8 Recipe and consumption rates of raw materials for the melon juice production

Name of raw material and product	Recipe		Loss and waste		Consumption rates, kg/t
	%	kg	%	kg	
Melon juice					
Melon	100	1,000	22.6	273	1,381

Table 4.9 Nutritional and biological value of melon juices

Indicators	Name of raw material and product	
	melon	melon juice
Water, % 88.5	88.5	84.9
Dry substances, % 11.5	11.5	15.1
Carbohydrates, % 9.6	9.6	16.39
Proteins, % 0.6	0.6	0.42
Vitamins, mg/100 g		
B_1	0.04	0.03
B_2	0.04	0.03
C	27	25
β-каротин	6.4	0.09
Minerals, mg/100 g		
Na	32	14
K	118	128
Ca	16	4
Mg	13	12
Fe	0.49	406
Ash, %	0.6	0.4
Titratable acidity in terms of malic acid, %	0.1	0.1

The organoleptic characteristics of melon juice (**Table 4.10**) indicate that the juice is a homogeneous mixture, colored in the color of the raw material (from pale yellow to intense yellow), the taste of the juice is characteristic of the variety of raw materials, pleasant, sweet, the smell is characteristic of the melon, without defamatory shades and without foreign aroma, and the consistency is delicate.

We have also proposed a technology for producing melon juice, which is shown in **Fig. 4.4**.

According to this technology, the inspection and sorting of melon fruits are carried out in the process of their acceptance on the conveyor, while the spoiled and unripe fruits are separated. Unripe fruits are sent for storage at a temperature of 4 °C, the ripening occurring at the same time contributes to an increase in the amount of separated juice.

Table 4.10 Organoleptic characteristics of melon juice

Product name	Organoleptic indicators			
	appearance	taste	smell, aroma	consistency
Melon juice	Homogeneous mixture, colored in the color of the raw material: from pale yellow to intense yellow	Peculiar to this type of melon, pleasant, sweet	Peculiar to melon, without defamatory shades and foreign smell. Fragrant	Delicate

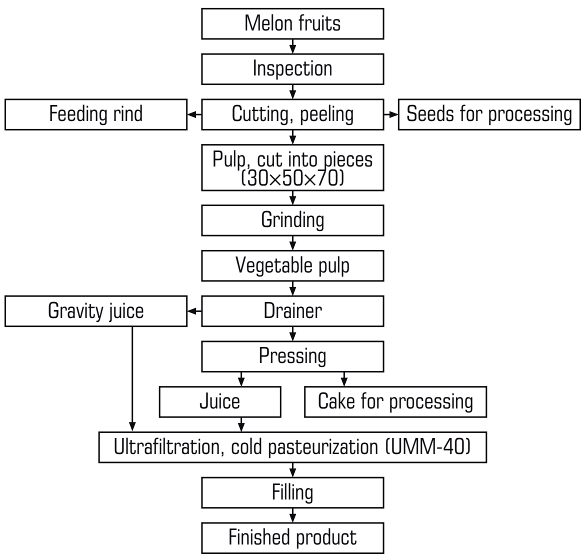


Fig. 4.4 Technological scheme for the production of juice from melon 3

It is proposed to peel melon fruits from peel and seeds according to the technology and on the developed device. This provides for a separate processing of fruits, depending on the size and shape.

The obtained pieces of melon are sent for grinding to the EG-400 shredder, which can process up to 6–10 tons of raw materials per hour, depending on the power of the installed drive and the state of the product. The design of the EG-400 provides uniform crushing of raw materials into pieces of the maximum uniform size with smooth edges, which increases the juice yield during its subsequent squeezing from the crushed mass.

To reduce the amount of pulp obtained after grinding, part of the juice is separated on drainers. In this case, the amount of gravity juice is determined by the permissible content of suspended dry matter in it and can be 40–60 %.

The remaining pulp is fed to a press to separate the remaining juice. Presses of various designs are used to squeeze juice: screw, press filters, vacuum filters, basket filters and others.

Each of the listed types of presses has its own advantages and disadvantages. So, screw filters are distinguished by high productivity, but at the same time, a large amount of solid impurities in the juice is obtained, therefore we proposed to use the SX-280 press filter with a capacity of up to 1,700 liters of juice per hour to obtain juice from melons.

The crushed raw material is loaded into the press compartments of one of the two chambers (open) using a pump. Then the operator switches the press to the compression mode of the filled chamber, where the juice is squeezed out, which is collected in the collector.

This opens the second chamber, which allows the operator to separate the cake from the walls of the sacs and dump the cake into a substituted hopper or onto a cake removal conveyor, turning the extraction chamber 180° using a hydraulic drive. Then the pressing chamber returns to its original position, and the operator fills its compartments with the crushed mass. The unit is ready for the next work cycle.

To separate the impurities remaining after pressing and draining, the juice must be subjected to a clarification process, and before filling, it must be heat treated for sterilization.

These processes require special material-intensive equipment and are time-consuming, and heat treatment, in addition, requires significant energy consumption. In this regard, it is proposed to apply the ultrafiltration process using a membrane modular installation UMM-40 with filters MTU-1/1030, with a capacity of 0.8–4.0 m^3/h. The installation allows to separate suspended matter, bacteria and viruses contained in the juice.

Thus, the authors proposed a technological scheme for obtaining juice from a melon, excluding heat treatment of fruits and juice (**Fig. 2.6**).

According to the scheme, the fruits of melons of various varieties, after inspection and rejection, go for peeling. At the same time, the peel and seeds are sent for further processing to other enterprises in accordance with the intended purpose. On the same installation, the pulp is cut into pieces.

Melon juice recipe is presented in **Table 4.11**.

Comparative analysis of the nutritional and biological value of juice (**Table 4.12**) shows that the dry matter in juice is 2.2 % higher in relation to raw materials, as for the content of carbohydrates, their total content in the juice is much higher (by 6.6 %), for other types of carbohydrates, an increase is also noted, which is explained by the use of cold pasteurization before filling. The protein content in the finished juice is relatively lower. In general, the nutritional and biological value of melon juice is higher due to dry matter, carbohydrates and proteins.

Table 4.11 Juice recipe

Juice and product name	Dry matter content	Ratio, %
		juice
Natural melon juice		
Melon	12.6–13	100

Table 4.12 Nutritional and biological value of melon juice (g/100 g)

Product name	Raw material							Juice						
		carbohydrates							carbohydrates					
	dry matter	general	mono- and disaccharides	Starch pectin	pectin	proteins	Ash	dry matter	general	mono- and disaccharides	Starch pectin	pectin	proteins	Ash
Melon	12.6	9.6	9.0	–	0.2	0.6	0.6	14.8	16.3	13.4	0.2	0.23	0.4	0.4

The organoleptic characteristics of melon juice (**Table 4.13**) indicate that melon juice, depending on the raw materials used, are different, so the juice obtained from the Kolkhoznitsa variety has a banana taste, yellowish-white color, aromatic, from the Ternek variety – with a sweetish taste , transparent cream color, and weak aroma.

The juice obtained from the Garry kyz variety has a sweet taste, transparent lemon color and vanilla aroma. Juice from the Tor Navat Biishek variety has a sweetish taste, white color and delicate aroma. Juice from the Khojeyli biyshek variety has a sweetish taste with a greenish-brown color and a delicate aroma. The taste of juice from the Ak kash biyshek melon variety is very sweet, the color is white, the aroma is sugary-vanilla. When using the Kok Gulyabi melon variety, the juice is obtained with a sweetish taste, greenish color and delicate aroma. From the melon variety Kara Guliabi juice is obtained with a sweetish taste, green color and aromatic. The use of the Kizil Guliabi melon variety makes it possible to obtain juice with a sugary-sweet taste, white, opaque color and aromatic. Juice from the Sara Guliabi melon variety with a sweet taste, creamy color and aromatic.

Table 4.13 Organoleptic characteristics of melon juice

Melon variety	Organoleptic characteristics of melon juice		
	taste	colour	aroma
Kolkhoznitsa	Banana	Yellowish white, dense, opaque	Fragrant
Turnack	Slightly sweet	Transparent, cream	Weakly pronounced
Garry kyz	Strongly sweet	Transparent, lemon	Vanilla
Tor Navat Bishek	Delicate, sweetish	White	Delicate, melon
Khojeyli biyshek	Sweetish	Greenish brown	Delicate, melon
Ak kash biishek	Very sweet	White	Luscious vanilla
Kok Guliabi	Sweetish	Greenish	Delicate, melon
Kara Guliabi	Sweetish	Green	Fragrant
Kizyl Guliabi	Lusciously sweet	White, opaque	Fragrant
Sary Guliabi	Sweet	Cream	Fragrant

4.4 BLENDED JUICES BASED ON MELON AND PUMPKIN

Technological schemes for the production of blended juices are shown in **Fig. 4.5, 4.6**.

Raw materials supplied for processing are accompanied by a quality certificate and a toxicological certificate with confirmation of the residual content of pesticides and nitrate nitrogen, as well as a conclusion on permission for its processing.

Upon receipt of raw materials, its compliance with the requirements of regulatory and technical documentation is determined.

Fruits are subjected to sorting and inspection, at the same time removing unsuitable specimens and sorting into separate lots containing fruits of the same type, degree of ripeness, color, size. Defective fruits were selected from the total mass – broken, crumpled, unripe, overripe, affected by agricultural pests, as well as foreign impurities.

Melons, pumpkins, lemons are washed under the shower at a pressure of no more than 0.5 atm in the shower heads [55]. Then peel, remove the seeds and cut the melon into pieces 15–20 mm thick and 30–50 mm long or into cubes with 20–30 mm edges. Peeling and seed removal, as well as cutting the melon into pieces, was carried out using a device developed at ATU [104].

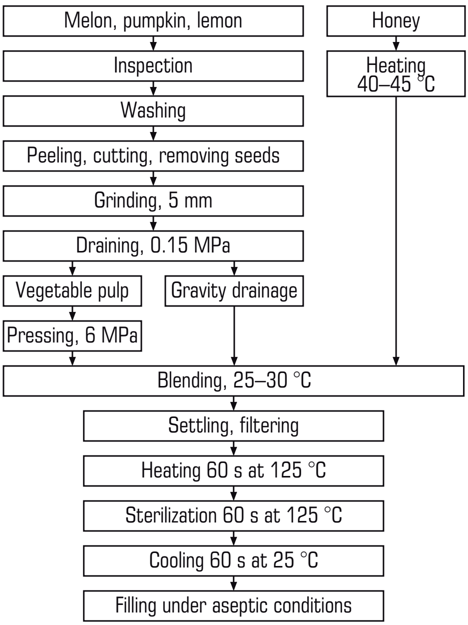


Fig. 4.5 Technological scheme for the production of blended juice «Limtyk»

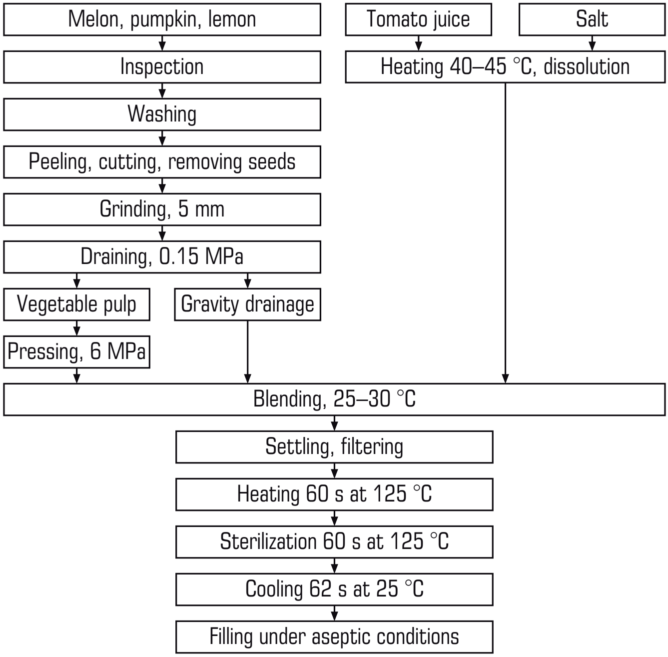


Fig. 4.6 Technological scheme for the production of blended juice «Tomtyk»

The resulting pieces are crushed on an EG-400 unit.

To increase the yield of juice, facilitate and accelerate pressing, the pulp is directed to the drainer at a pressure of 0.15–0.2 MPa, while 52–57 % of the juice is separated (gravity).

The extraction of the juice was carried out by the pressing method. The remaining pulp is pressed on a press filter with a constant increase in pressure up to 6 MPa.

Before adding honey, it was heated to 40–45 °C and dissolved in the finished blend.

To remove large suspended particles (suspensions), the juice is filtered through a sieve with a hole diameter of 0.75 mm.

For blending, we also used ready-made tomato juice.

The necessary components according to the recipe are served for blending (mixing).

Further filling takes place under aseptic conditions.

The juice is poured into sterilized bottles with a capacity of 0.5 liters. The bottles are sealed with sterilized metal caps [52].

Nutritional and biological values of blended juices are presented in **Table 4.14**.

Table 4.14 Nutritional and biological values of functional blended juices (g/100 g)

The name of indicators, units of measurement	Limtyk	Tomtyk
In raw materials		
Dry matter	16	14
Proteins	0.68	0.6
Ash	0.5	0.45
Carbohydrate content, %		
General	16.26	12.67
Mono- and disaccharides	15.89	10.85
Starch	0.26	0.28
Pectin	0.22	0.21
Finished products		
Dry matter	17	16
Proteins	0.7	0.5
Ash	0.6	0.45
Carbohydrate content, %		
General	17.13	12.98
Mono- and disaccharides	16.41	11.7
Starch	0.20	0.28
Pectin	0.18	0.20

An analysis of the results obtained allows to note that the developed blended juices are distinguished by the fact that in terms of the quantitative set of basic nutrients and biological substances they are not inferior to the traditional ones, and in some of them their predominance is observed [105].

For example, juice «Limtyk», which contains juices of lemon, pumpkin, melon and honey, and juice «Tomtyk» – juice of tomato, melon, pumpkin and table salt, differ from traditional apple and tomato by a high dry matter content (16 % and 14 %, respectively, mono- and disaccharides, total carbohydrates and polysaccharides (starch and pectin)).

The difference in quantitative terms, in our opinion, is explained by the introduction of additives – fortifiers (honey and lemon).

New types of juices differ in starch and pectin content, which reaches 0.26 and 0.22 % (respectively) at Limtyk, while Apple traditional juice contains only pectin in an amount of 0.1 %. Therefore, the new juices are more viscous and sweet, well absorbed.

A similar picture is observed in other juices compared to added traditional juices.

The results of studies of the mineral composition, experimental products and control samples are presented in **Table 4.15**.

Table 4.15 Mineral composition of juices

Minerals	Content, mg/100 g			
	Experimental juices		Traditional	
	Limtyk	Tomtyk	Apple	Grape
Sodium	10.7	14.5	2	15
Potassium	0.36	0.45	0.12	0.21
Calcium	14.3	16.3	8	19
Magnesium	2.7	3.9	5	16
Manganese	3.2	3.4	6.3	5.4
Phosphorus	18	17	9.0	20
Iron	0.75	0.62	0.2	0.3
Sulfur	0.2	0.35	0.5	0.3
Zinc	0.93	0.93	0.15	–

In quantitative terms, the content of individual minerals differs both in the experimental samples and in comparison with the control samples [102].

In terms of sodium content, Tomtyk juice is superior to Limtyk juice (14.5 mg/100 g), a similar picture is in the content of potassium and calcium in Limtyk juice – 0.36, 14.3, Tomtyk – 0.45, 16.3 respectively). There is a high iron content compared to traditional juices.

In terms of phosphorus content, our juices are inferior to grape juice – 20 %, but have a big advantage over apple juice 9 %.

Comparative assessment of the mineral composition of control and experimental samples indicates that the mineral composition of new types of juices in quantitative terms prevails over traditional juices: in terms of the content of calcium, phosphorus, iron, potassium, zinc. This is due to the biological characteristics of various types of raw materials.

In addition, mineral substances perform a plastic function in human life processes, participate in metabolism, but their role is especially great in the construction of bone tissue, where elements such as phosphorus and calcium predominate. The healthfulness of drinks lies in the fact that they contain zinc and iron in large quantities, which are necessary for the life of the human body.

The results of studies of the vitamin composition are shown in **Table 4.16**.

Comparison of the data on the content of vitamins (**Table 4.16**) made it possible to draw certain conclusions that the experimental products contain vitamins B (B1; B2), β-carotene, acids, niacin and others.

The folic acid content is much higher than traditional juices. Limtyk juice is 3.06 higher than the content of vitamin C in apple juice, but inferior to grape juice. In terms of vitamin B6 content, the «Limtyk» and «Tomtyk» juices significantly exceed those of apple and grape. The content of vitamin B3 in Tomtyk juice is higher than that of traditional juices and Limtyk.

Table 4.16 Composition of vitamins in juices

Vitamin	Content, mg/100 g			
	Experimental juices		Control juices	
	Limtyk	Tomtyk	Apple	Grape
Vitamin E	0.31	0.34	0.65	0.070
Pyridoxine B6	0.073	0.082	0.07	0.014
Vitamin A	0.79	1.01	0.08	0.065
Ascorbic acid (C)	17.47	14.21	14.41	24.08
Riboflavin B2	0.046	0.045	0.01	0.02
Thiamin B1	0.044	0.042	0.01	0.01
Niacin (vitamin PP)	0.378	0.429	0.238	0.317
Pantothenic acid B3	0.27	0.29	0.17	0.26
Biotin (vitamin H)	0.024	0.29	0.09	0.08
Folic acid B9	9.35	9.83	6.6	4.3

In «Tomtyk» the content of vitamin A prevails in comparison with «Limtyk» and traditional juices. In terms of vitamin B2 content, our juices are much higher than the control apple and grape juices. Vitamin B1 predominates in experimental juices much more than in control ones. The content of vitamin PP in Tomtyk exceeds Limtyk, apple and grape. «Tomtyk» is rich in vitamin H – 0.29, while «Limtyk» – 0.024, apple – 0.09 and grape – 0.08.

In a comparative assessment of the content of vitamins in experimental juices and control samples, it is noted that the experimental products differ in both qualitative and quantitative set of these representatives.

CONCLUSIONS TO SECTION 4

This section examines all varieties of melons sold in the territory of the Republic of Kazakhstan and melons of domestic selection. The works of the employees of the Almaty Technological University on the processing of melons into blended juices, marmalade, pectin, etc. are presented. The results of works on the production of marmalade from the pulp and juice of the fruits of watermelon and melon are presented.

The watermelon and rowan extract marmalade is very nutritious and good for human consumption. In the production of marmalade, the technology should be maintained, the marmalade should be produced in safe, hygienic conditions, the watermelon must be brought to a temperature of +4 °C before processing, and the watermelon juice is stored in sealed containers and kept in a refrigerator at a temperature of 4±4 °C no more than 24 hours. Further research work will be carried out to investigate the preservative effect of natural antioxidants, alone or in combination with each other, on jujube samples.

The analysis of the results of the studies carried out allows to note that the obtained blended juices are distinguished by a richer vitamin composition in qualitative and quantitative terms. Consequently, the raw materials taken for the enrichment make it possible to obtain drinks enriched with vitamins of a given qualitative composition. This is of no small importance, because according to research by scientists, it has been established that vitamins are involved in the regulation of the most important processes in the body only in the form of coenzymes (the vitamins themselves are inactive). Therefore, the processes in which vitamins participate are complex and they involve not one, but two or even several (up to 6) vitamins.

CONCLUSION

As a result of the research, the geometrical parameters of melons of eight domestic varieties, watermelons of 5 varieties, which are most sold in Kazakhstan for the development of a universal installation for separating the rind, have been determined. Information on 2 varieties of pumpkin of the Russian Federation has been provided. Information on 4 varieties of watermelons has been provided. The physical and mechanical characteristics of various parts of melon, watermelon, pumpkin have been determined. The mathematical dependences of the main mechanical characteristics of the pulp and rind of melon, watermelon, pumpkin have been determined. The data obtained were used in the development of technology and installation for separating the rind and crushing the pulp used in the proposed technology.

The chemical composition of the pulp, rind and seeds of the most common varieties of melon has been established. The rind contains pectin in the amount of 1.18...1.67 % of the total mass. The share of protopectin in the total content of pectin substances is in the range of 75.37–96.25 %, which makes it possible to economically process melon rinds into pectin. Melon pulp and seeds contain vitamins and minerals, seeds contain unsaturated fatty acids.

Formulations of blended juices, melon jams, marmalade products made from watermelon pulp have been complied.

The optimal parameters for extracting pectin from the rinds have been determined: the concentration of hydrochloric acid is 0.5 % at a hydromodule of about 5 and a temperature of 80–90 °C, the size of the pieces is +3…–5 mm, and the duration is 60…90 minutes. Pectin was obtained with a degree of esterification of 67...69 %, a jelly-forming ability of more than 170° Tarr-Baker, and a jelly strength of about 460 mm Hg, according to mandatory standardized indicators, meeting the requirements of GOST and sanitary standards. Conditions and terms of storage have been established.

An overview of the technique for processing melons is given: peeling from the rind, extracting pulp, separating seeds for technical and food needs. The results of research and development of mechanisms and devices for processing watermelons, pumpkins and melons are presented. The theoretical foundations of the research and the evidence base are presented. The criterion equations for all processes of processing the fruits of melons are derived.

The technologies developed by the authors for processing melons into food are presented.

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