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DEVELOPMENT OF A HIGHLY EFFICIENT PLANT FOR SEPARATING THE PEEL FROM THE PULP OF MELONS

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The object of study is the development of an installation for separating the peel of melon crops (watermelon, pumpkin) for their further processing. The peel of melons contains important compounds such as minerals, polyunsaturated fatty acids, tocopherols, polyphenols, carotenoids and phytosterols. The peel of watermelon and pumpkin make up a fairly significant proportion of the fruit, varying in watermelon from 15 % to 40 %, pumpkin 5–20 %, of the total mass of various commercial varieties, which are usually discarded as by-products after commercial processing. Thus, the peel remains a massive by-product, the most important among agri-food waste, due to the content of natural antioxidants and various other nutrients in them. However, the industrial use of watermelon and pumpkin peel is complicated by the lack of an effective technique for separating melon crops from the peel. Therefore, research on the development of an installation for separating the peel of melons (watermelon, pumpkin) is relevant.

The developed installations for separating the pulp from the peel of melons have a number of disadvantages, Therefore, it seems relevant to develop an installation for separating the peel of melons.

The developed installation has a number of advantages in comparison with analogues. For example, low knife wear is ensured due to the fact that when cutting the fruit, the cutting force is distributed along the entire length of the knife. The simplicity of the design and reduced loads on the cutting tool, as well as the effective design of the knife in the form of a hemisphere ensures maximum removal of pulp from the peel

Keywords: peel and pulp of watermelon and pumpkin, a device for separating the peel

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1. Introduction

In recent years, much attention has been paid to the problem of food waste. The European Union has defined food waste as "food products (including inedible parts) lost from the food supply chain. Estimates provided by FAO (2016) indicate that the global volume of food waste is about 1.6 billion tons per year.

Reducing food losses and food waste has a triple advantage – for the climate, for food security and for the sustainability of our food systems. Nowadays, when food shortages, malnutrition and hunger are growing all over the world, this task of using food waste as "food products" should become a priority [1].

The peel of watermelon and pumpkin make up a fairly significant proportion of the fruit, varying in watermelon from 15 % to 40 %, pumpkin 5–20 %, of the total mass of various commercial varieties [1], which are usually discarded as by-products after commercial processing [2]. Thus, the peel remains a massive by-product, the most important among agri-food waste, due to the content of natural antioxidants and various other nutrients in them [3]. The increase in agri-food waste is primarily observed in farms and the food industry producing vegetable juices [4].

However, the industrial use of watermelon and pumpkin peel is complicated by the lack of an effective technique for separating melon crops from the peel. The developed installations for separating the pulp from the peel of melons have a number of disadvantages. The disadvantages include: incomplete separation of the pulp, i.e. part of the pulp together with the peel goes to waste; rapid wear of cutting tools (knives); the duration of the process of separating the peel from the pulp, etc. therefore, the efficiency of the process of separating the peel from the pulp with the possibility of further use of the separated peel for food production remains unresolved.

Therefore, research on the development of an installation for separating the peel of melons (watermelon, pumpkin) is relevant.

2. Literature review and problem statement

Currently, the world consumes approximately 27 million tons of pumpkin, of which China 5.5 million tons, and Europe, more than 4 million tons.

Despite the fact that some parts of the fruit can be eaten, the pulp is valued more, and by-products are often discarded or used insufficiently [5]. Fruit and vegetable processing operations produce significant waste by-products, which make up from 25% to 30% of the entire commodity group. Waste consists mainly of seeds, peel and cake containing good sources of potentially valuable biologically active compounds.

The lack of highly efficient equipment for high-quality separation of the pulp from the peel is a deterrent to the creation of a technological chain of waste-free processing of melons. [6]. As a result, more than 5 million tons of "food products" are not processed annually, but are thrown away, including up to 1 million tons in Europe when only pumpkins are consumed. However, these parts of fruit may contain important value-added compounds such as minerals, polyunsaturated fatty acids [7], tocopherols [8], polyphenols [9], carotenoids and phytosterols [10]. Consequently, the issue of creating new technological equipment providing deep processing of melons due to the qualitative separation of the pulp from the whole peel remains unresolved.

It has been established that pumpkin peels have a high content of common phenolic compounds and a strong antioxidant potential, evaluated using various chemical analyses [11]. In addition, pumpkin peels were used in bakery products to increase their antioxidant capacity [12] and the total concentration of phenols [13]. Given the chemical composition of these by-products and their important antioxidant and antimicrobial properties, they can find useful applications in the development of natural food preservatives [14]. However, when separating the pulp from the peel, the peel is cut into small parts of different thicknesses, as a result of which it becomes unsuitable for further processing.

It was found that the content of total carotenoids and the composition of carotenoids in pumpkin depend mainly on the type and variety, climatic conditions, part of the plant (pulp, peel or seed) [15]. Consequently, the question of the relationship and regularity of the influence of external factors on the chemical composition of melons remains unresolved.

It has been found that watermelon and pumpkin peels, which make up a fairly significant proportion of the fruit, also contain important value-added compounds such as minerals, polyunsaturated fatty acids, tocopherols, polyphenols, carotenoids and phytosterols, are discarded as by-products after commercial processing. A limiting factor in the industrial use of watermelon and pumpkin peel is the low efficiency of existing installations for separating the peel from the pulp of watermelon and pumpkin. The processing of the peel is very important both from an economic point of view and from the point of view of environmental problems and the possibility of creating new food products.

During the primary processing of melons, the problem arises of quickly and easily cutting certain parts of watermelon and pumpkin into spheroidal segments for further processing, while conventional manual methods required a lot of time, were dangerous, and led to the formation of segments of watermelons and pumpkins of various sizes.

It is noted, according to the literature data [6, 16], that the main part of the presented installations is characterized by the complexity of the design and high material consumption, can be used to produce one product, mainly seeds, while the useful part of the fruit is crushed and mixed with the particles of the crust or its juice, therefore it cannot be used for food. Also, in some developed installations, the pulp is not completely removed or the peel is not suitable for its further processing.

The quality of the cleaning process depends on the size of the contact surface of the work surface and the fruit, the pressing force and the type of relative movement of the surface and the watermelon itself. To mechanize some of these processes, a machine for separating the crust is proposed (Fig. 1) [16].

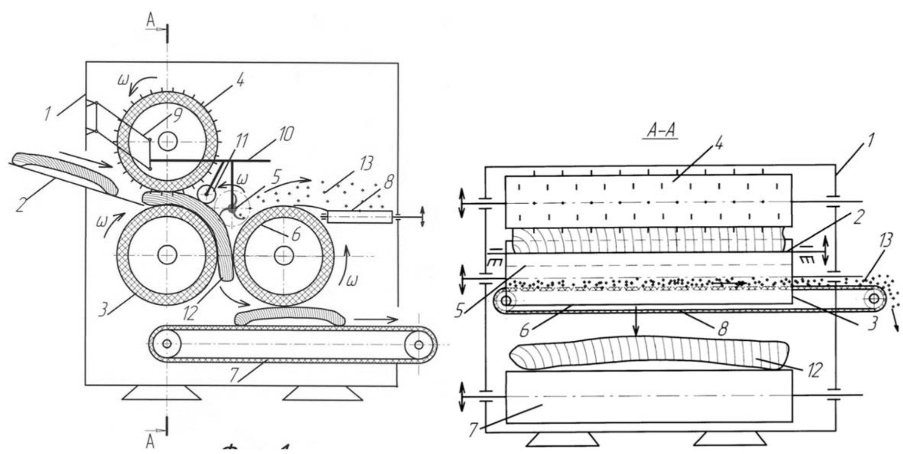

Fig. 1. A machine for cleaning the surface of melon fruits from the peel: 1 — bed; 2 — feeding tray; 3 — support roll; 4 — needle roll; 5 — milling drum; 6 — clamping roll; 7 — pulp conveyor; 8 — peel conveyor; 9 — parallelogram mechanism; 10 — holder; 11 — wheel; 12 — separated pulp; 13 — cut crust [6]

To remove the peel, installations with slit-shaped knives or cutters are used, which, due to the peculiarities of the structure of fruits and peel, are difficult to use for watermelons and other melons, therefore, the authors [17] developed a machine for peeling pumpkins equipped with a brush cleaning device. Disadvantages of the mechanical method, which are most often manifested by damage to the pulp and incomplete cleaning, which is explained by the imperfection of the designs of mechanical means.

A device is known in which to improve the quality of bark removal from the fruits of melons, in particular hard-rooted elongated fruits of pumpkin, melon, watermelon and squash using pressed abrasive disc elements that can change the angle of inclination depending on the change in the shape of the surface of the fruit [18]. The disadvantage is the focus on a specific type of watermelon or pumpkin, frequent change of abrasive, the inability to use on melon fruits, and when cleaning watermelon fruits, the abrasive may slip on the surface.

The authors proposed to clean the watermelon peel by cutting. The watermelon is peeled with a floating-head knife. The design diagram is shown in Fig. 2.

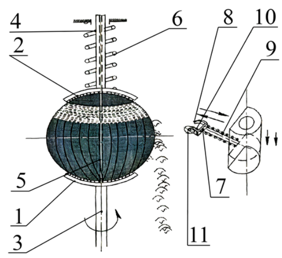

Fig. 2. Device for removing the peel of melon fruits [19]

The device for removing the peel of melon fruits (Fig. 2.) contains mirror-positioned grips made in the form of disc-shaped lower 1 and upper 2 lodgments made of elastic material (for example, silicone) and having studded surfaces facing the fruit and equipped with rods 3,4 mounted vertically with the possibility of synchronous rotation in one direction around its axis from single drive (not shown). In the center of the lower bed 1, a needle-type retainer 5 is installed, and in the upper bed 2 and its rod 4, a hole is made in the center from the side of the fetus, coaxially with the retainer 5, while the upper bed 2 is equipped with a spring 6. The equipment has working elements 7 with cutting edges 8, which are spring-loaded and pivotally mounted on the rod 9 with the possibility of reciprocating motion, both in the vertical and horizontal direction, they are made in the form of a floating head 10 equipped with a ball roller 11, installed with the possibility of multidirectional rotation.

The disadvantages are the complete removal of the epidermis, as well as the fact that the device does not allow separating the subcortex from the pulp, getting juice and seeds separately. A device for obtaining watermelon pulp has been developed (Fig. 3) [19].

Fig. 3. Watermelon pulp extraction device

The device works as follows, a mechanical device is lowered onto a pre-cooked watermelon and cuts off only the core, thus the disadvantage is the irrational use of the fruit: loss of juice, pulp, subcortical part, crust and seeds.

The physical method of cleaning is carried out under the influence of steam, which is supplied under considerable pressure and relaxes the surface layer of the fetus. Then the steamed layer is cleaned and washed off in washing and cleaning machines. This method is energy-consuming, does not provide high-quality cleaning and has not been widely used in industry [20].

The analysis of the developed methods of separating the peel from the fruit of melons has shown that it is necessary to improve existing technologies and installations for separating the pulp from the peel. A lot of unsolved problems and a lack of designs have been identified. For example, solving the issues of mechanization of manual labor [16], the installation turned out to be cumbersome and, most importantly, the separated peel is crushed in layers and is unsuitable for further use. And the device for separating the pulp of watermelon [19] is easy to maintain, but there is an incomplete cleaning of the pulp from the peel (significant loss of pulp). Also, the rapid wear of the cutting tool in the device for removing the peel of melons [17, 19]. Unresolved issues are related to the peculiarity of plant designs depending on the size and shape of melons. Melon crops (watermelon and pumpkin) are mainly spherical, ellipsoid, pear-shaped, which significantly complicate their processing. Consequently, the main disadvantages include the complexity of the design and high material consumption [6], damage to the pulp and incomplete cleaning [17, 19], incomplete separation of the subcortex from the pulp [18], rapid wear of the cutting tool – knife [19, 21], and issues of safety when working with installations [16] have not been resolved.

All this allows to assert that it is advisable to conduct research on the development of an installation for separating the peel from the pulp of melons (for example, watermelon and pumpkin). The developed installation should solve the above disadvantages: it is easy to maintain, completely separate the pulp from the peel, at the same time the peel should be cut into large pieces, and not crushed.

3. The aim and objectives of the study

The aim of the study is to develop an installation for separating the peel of watermelon and pumpkin, which will make it possible to use it in the production of new types of food, as well as to reduce the negative impact on the environment.

To achieve the aim, the following objectives were solved:

– to develop an the general concept of the installation scheme;

– to justify of the principle of operation of the installation.

4. Materials and methods of research

The object of the study is to installation for separating the peel from the pulp of melons.

The hypothesis of the study is to possibility of create an installation for the qualitative separation of the pulp from the peel while preserving the peel suitable for further processing. The assumptions in this work are the division of the procedure for separating the pulp from the peel into 2 stages. At the first stage, it is possible to divide the watermelon/pumpkin fruit into equal parts. At the second stage – high-quality separation of the pulp without damaging the peel. When calculating the design of the knives and the entire installation, the strength characteristics were calculated according to data from research sources [16, 22].

5. Development of a highly efficient plant for separating the peel from the pulp of gourds

5. 1. Development of the general concept of the installation scheme

The concept of separating the peel from the pulp of watermelon and pumpkin is based on the principle of simple operations: cutting and separating. Therefore, an installation is proposed (Fig. 4, 5) consisting of 2 separate devices performing the following operations: cutting watermelon and pumpkin into equal parts (the first stage); separating the pulp from the crust (the second stage).

The proposed concept of the installation scheme for separating the pulp without damaging the peel in two stages will eventually allow to get watermelon and pumpkin juices with pulp and large parts of the peel. The installation devices perform simple and safe operations.

The second stage – the installation for separating the pulp of melons from the peel is shown in Fig. 5.

The technical characteristics of the equipment for cutting melons are presented in Table 1.

Table 1

Technical characteristics of equipment for cutting melons

Name of indicators	Indicators
Welded frame, mm	Profile pipes 20×40×2.00
– height, m	2.30
– width, m	0.79
– length, m	1.26
Number of working bodies, pcs.	1

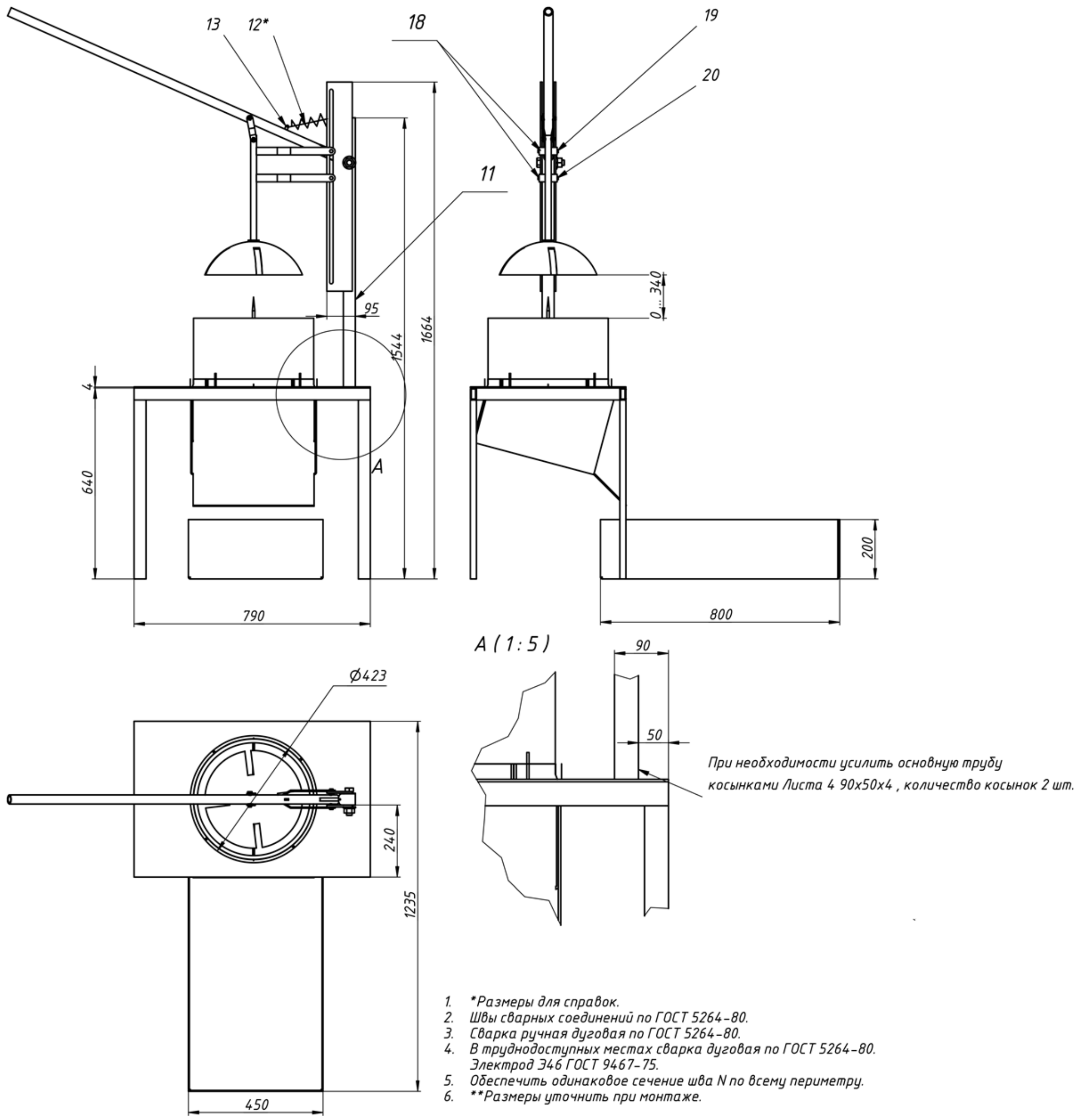

Fig. 4. Device for cutting watermelon and pumpkin into equal parts

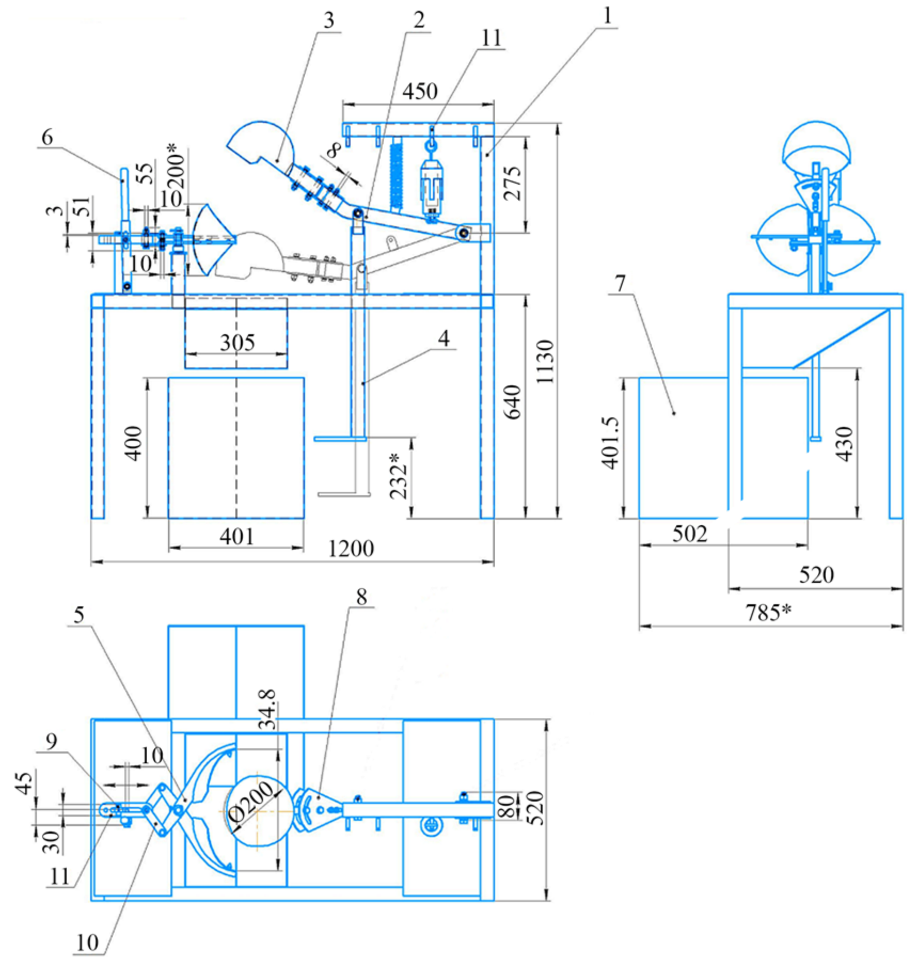

Fig. 5. Installation diagram for separating the pulp of melons: 1 – frame; 2 – bracket assembly; 3 – knife made in the form of a hemisphere; 4 – pedal for pressing; 5 – locking teeth; 6 – lever of the compression mechanism; 7 – box for processed products; 8 – neck for adjusting the direction of the cutting part; 9 – plates; 10, 11 – traction

5. 2. Justification of the principle of operation of the installation

The device works as follows. The fruit of a melon culture, for example, a watermelon cut into quarters intended for processing by hand, is placed piece by piece on a retainer 5, while the teeth enter the skin of the watermelon, where the lever of the compression mechanism 6 will fix and hold the slices. With the help of a pedal device 4, the knife 3, made in the form of a hemisphere, is lowered by pressing. At the same time, the knife cuts off the core of melons. For a few clicks of the pedal 4 hemisphere knife 3 completely separates the pulp from the peel. The cut pulp of melons will be supplied to the pulp collection container 7.

Table 2 shows the technical characteristics of the plant for cleaning the core of melons.

Table 2

Technical characteristics of the plant for cleaning the core of melons

Name of indicators	Indicators
Welded frame, mm.	Profile pipes 40×40×2.00
– height, m.	1.20
– width, m.	0.52
– length, m.	1.20
Number of working bodies, pcs.	2

The main working organ of all installations for separating the peel from the pulp is a knife. Cutting working tools of vegetable cutters – knives – can be of various shapes: rectilinear, curved (crescent-shaped) and in the form of cutting holes (graters) or knife gratings [23].

The structural strength and wear of the knife depends on the hardness of the fruit of the melon culture, which depends on the variety and shape.

The authors found that the hardness of the watermelon peel varies from 10.12–12.67 N of the peel itself, to 187.9–275.3 N in the area of the flower and peduncle. The hardness of the pulp varied from 5–10 N [24].

The researchers determined the strength characteristics of the components of the watermelon (Table 3).

Table 3

Strength characteristics of the components of the watermelon

Area	Breaking force, H		Cutting force with a flat knife, H			
			along		across	
	Crust	Pulp	Crust	Pulp	Crust	Pulp
Peduncle	472.7	180.5	28.9	13.2	37.6	10.8
Equator	444.0	103.9	37.0	12.6	37.3	12.2
Receptacle	445.4	170.9	27.0	9.4	39.7	8.9

These values depend on the shape and design of the knife and the variety of the melon fruit [23].

So, the average value of the cutting force with a grating knife at a speed of up to 0.5 m/s for watermelon pulp is: in the peduncle area – 84.03 N, in the equator area – 49.67 N, in the flower area – 71.73 N; for pumpkin pulp Volga gray-92: in the peduncle area – 50.80 And, equator – 55.95 B, in the flowering area – 60.72 I; for the pulp of melon Bykovskaya-735: in the peduncle area – 18.44 N, equator – 11.05 N, flowering area – 12.28 N (24).

Cutting consists in the destruction of a certain layer of material directly under the cutting edge of the tool under the influence of pressure on it from the tool. A collapsing layer of material is sometimes called a boundary zone. As the tool progresses, this layer is first subjected to elastic, and then plastic deformation (Fig. 1). If the stress exceeds the tensile strength, its destruction occurs and the cutting edge of the tool moves through it [25]. The work in the cutting process is spent on creating elastic and plastic deformation, as well as on overcoming the friction of the tool on the separated parts of the material. The distribution scheme of the cutting zone is shown in Fig. 6, the values of cutting forces and specific work are presented in Table 4 [26].

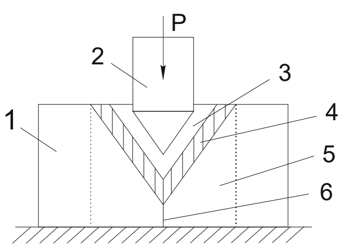

Fig. 6. Diagram of the cutting zone of the material: 1 – the material being cut; 2 – the cutting tool; 3 – the zone of plastic deformations; 4 – the zone of elastic deformations; 5 – the zone of impact of the tool; 6 – the line of destruction

Table 4

Characteristic values of cutting force and specific work

Cutting material	Cutting force P, N/m	Specific cutting work Aud, J/m^2
Carrots	1380...1570	1380...1570
Beetroot	885...1580	885...1580
Watermelon peel	1720...1960	1720...1960
Pumpkin peel	1870...2080	1870...2080

The values of the forces P can be significantly (5 times or more) reduced if the normal stresses on the circuit are partially replaced by tangents. To do this, the movement of the cutting tool is replaced by a tangent to the same extent. In common terms, this corresponds to a change in the slashing movement of the knife to a sliding one. In some cases, it is enough to bend the cutting edge of the knife. At the same time, the knife sometimes takes a complex shape. The results of the study of the effect, thickness and shape of the chip on the cutting force are presented in Table 5 [26]. For example, when studying the determination of the cutting force of beets, it was found that the value depends on the thickness and shape of the chips, the design of the knives and the state of the cutting edge [27].

Table 5

Specific cutting force, N/m

Knife design	Chip length, mm						
	7–8	9–10	11–13	14–16	17–21	22–27	28–34
Grooved	1770	1570	1420	1330	1230	–	–
Lamellar	–	–	–	1080	981	882	784

Therefore, when designing a cutting tool, it is necessary to take into account the shape of the cutting tool, the thickness and shape of the chip of the object being cut, as well as the design of the knife to ensure a sliding cut of the peel.

6. Discussion of the results of the development of a highly efficient plant for separating the peel from the pulp of melons

The developed installation has a number of advantages in comparison with analogues. For example, low wear of the knife compared to the design (Fig. 2) is ensured due to the fact that when cutting the fruit, the cutting force is distributed along the entire length of the knife. When cutting (Fig.4) the peduncle, the cutting force is applied closer to the beginning of the knife blade. Then, when the equator of the diameter of the watermelon is reached, the load on the blade is applied at the periphery of the length of the knife and when approaching the flower, the force goes back to the beginning of the blade. Thus, when cutting a watermelon into slices, the force is applied to the entire length (more than 15 cm) of the knife blade evenly. In the installation (Fig. 2), the knife width (1–2 cm), made in the form of a cutting grater, cuts off the entire peel along the outer contour for a long time (up to 60 seconds) for only one fruit. In the proposed design, the separation and into parts occurs within 1–2 seconds. Considering that when cutting a watermelon into pieces (Fig. 5), no great effort is applied to the cutting tool – a knife, no special calculations are required. When developing the design, the blades of kitchen knives for cutting vegetables were used.

If to compare it with the design (Fig. 3) when performing the operation of cutting the pulp from the cut portions of watermelon at stage 2 (Fig. 4). due to repeated cutting of the core, all the pulp is removed without any residue on the peel, unlike the compared design, where the loss of pulp is up to 20 %.

The developed installation is easy to maintain and can be included in the existing technological line for processing melons. Using a two-stage technology, the first stage is the cutting of watermelon and pumpkin into segments (Fig. 4) and the second stage is the separation of the peel from the pulp of watermelon and pumpkin (Fig. 5) allow processing melons, regardless of shape and size, to qualitatively separate the peel from the pulp. Further processing of the peeled peel will expand the possibilities of their industrial use in the production of various food products, thereby significantly reducing the volume of food waste.

However, the proposed two-stage installation involves the use of physical labor. Further research should be aimed at solving the issues of automation of interoperative functions.

7. Conclusions

1. The developed concept is based on the principle of simple operations: cutting and separating. The proposed concept – complete separation of the pulp without damaging the peel in two stages, as a result, allows to get watermelon and pumpkin juices with pulp and large parts of the peel.

2. The use of a two-stage technology for separating the peel from the pulp of watermelon and pumpkin, allows the proposed installations to process melon crops regardless of shape and size and qualitatively separate the peel from the pulp. The qualitative separation of the pulp from the peel is ensured by the simplicity of the proposed design, evenly distributed loads on cutting tools and an effective design of the knife in the form of a hemisphere, which ensures maximum pulp removal without damaging the peel. The proposed installation scheme will solve the issues of reducing the volume of agri-food waste and supply raw materials for the production of food products with a high content of natural antioxidants and various other nutrients in them.

Conflict of interest

The authors declare that there is no conflict of interest regarding this research, including financial, personal, authorship or other nature that could affect the research and its results presented in this article.

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Data availability

Manuscript has no associated data.

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