EC NUTRITION
Research Article

Increase the Efficiency of Cutting on the Part of Fruit and Vegetable Raw Materials Close to the Spherical Form

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Abstract

The article concerns increasing the cutting efficiency for the fruit and vegetable raw material close to the spherical form and reducing energy consumption for the cutting process and losses of fruit and vegetable raw materials during processing by profiling the cutting edge of the knife blade. The object of the study was fruit and vegetable fruit and raw materials closest in appearance to spherical form, being a mixture of fruits with different contents of cell sap, for example, citrus fruits and tomatoes. The efficiency of the plant, the type of cut with various designs of the cutting tool, the amount of fruit and vegetable juice being lost depending on the cutting speed and the storage time were determined. The interaction of the blade with the material was analyzed in its simplest case of contact interaction of fruit and vegetable raw materials with cutting equipment. The following aspects were investigated: specific deformations in the contact area; development of a principal solution; the creation of a rational cutting unit and working tools for grinding; the design of technology and the manufacturing of a prototype; installation and debugging; operation of the prototype; fine-tuning of knots or individual parts.

In determining the quality of raw materials conventional and special devices were used. It is shown that, when grinding fruit and vegetable raw material with the blade tool of the proposed configuration, minimal contact forces and a minimum specific energy intensity of the process are achieved since shock loads on the product are eliminated by matching the first derivatives of the blade profile and the profile of the elastic line of the deformed fruits. The device with the experimental knife proved to be more effective both in terms of minimizing the loss of cell juice and in terms of economic advantages of manufacturing and maintenance.

Keywords: *Details of Machines and Apparatus; Pretreatment of Food Products; Cutting into Parts; Fruit and Vegetable Raw Materials; Blade Tool; Energy Intensity*

Introduction

At processing enterprises of small and medium tonnage, it is important to equip production lines with equipment of various capacities, including the use of a slicer for fruit and vegetable raw materials in the field of public catering, since the use of slicers does not allow automating this phase of the technological process [1]. Full substantiation of both design parameters and the most effective operating modes of the new proposed type of grinders, the variety of physical and mechanical characteristics of fruit and vegetable materials is not taken into account [2]. A significant place in the mechanical processing of food products during culinary processing is occupied by the process of cutting into separate parts [3]. In the canning and vegetable drying industries, it is often necessary to cut into pieces fruits and vegetables that have a rather delicate and heterogeneous structure (shell and pulp).

The presence of a multilayer structure, for example, in a lemon fruit, is characterized by a different degree of stress concentration distribution at each point of the cutting edge and is one of the factors that determines the choice of the shape of the knife and the mode of the cutting process. There is still no mathematical substantiation of these parameters, so the implementation of this work seems to be relevant and has a high practical significance.

A common disadvantage of existing grinders (slicers and other types) is the destruction of the structure of the processed product, and as a result, significant juice release, which entails a decrease in the concentration of vitamins and nutrients in finished products and increased energy consumption. This problem is partially solved by reducing the degree of crushing of fruits and vegetables due to more effective contact of the cutting edge of the knife with the surface of the separated product, but this approach does not fundamentally solve the problem of creating a knife for gentle cutting of fruit juice, providing a bumpless process of gentle cutting of rather delicate fruits and vegetables.

The paper considers the process of quasi-static introduction of a thin (plate) knife with a double-sided sharpening in the form of a wedge into a material of different physical properties. A fundamentally new task is the creation of such a point mechanical effect, which, when projected onto the surface of the cut material, gives a spot of a small section, conventionally - a point. Such a tool allows you to reduce the amount of elastic deformations on the surface of the material, because there is no need to cut juice-containing fruits and vegetables by sliding cutting, and the reciprocating movement occurs at a constant speed. The second physical basis, excluding dynamic, increased forces in fruits, is the equality of the first derivatives to the profile of the blade edge and the profile of the elastic line of bending of the surface of the fruit at the point of contact.

Let us analyze the physical picture of the process of quasi-static penetration of a thin (plate) knife with a double-sided sharpening in the form of a wedge into a material of different physical properties and give a mathematical description of the required shape of the blade edge.

Objects and Methods of Research

The object of research was selected fruit and vegetable raw materials, which in appearance are the closest to a spherical shape. The raw material selected for cutting is a mixture of fruits with different content of cell juice, for example, lemon, kiwi, tomatoes with a diameter of 40 to 60 mm. The physical and mechanical properties of these fruits differ in properties and structure. After preparation, fruit samples 60 - 90 mm long were cut on a specially designed and created (at the Department of Technological Machines and Equipment of the Smolensk Power Engineering Institute) device. Size and mass indicators include such characteristics of fruits as their weight, size and shape factor, which are of greatest interest in fruit processing. The experiments were carried out during the period of full ripeness of the fruit. For this, 100 - 150 fruits of each species were selected by visualization, which served as the initial material for taking the numerical values of the characteristics of interest to us [4].

The most significant physical and mechanical properties of fruit and vegetable raw materials are highlighted: structure, strength indicators, material moisture, bulk density, the value of the coefficient of friction in contact with the cutting tool. It should be noted that moisture and density are the most significant factors affecting the properties of fruit and vegetable raw materials. The moisture content of the raw materials under study is proportional to the number of liquid filler, the bulk density depends on the moisture content, the subspecies of the fruit or vegetable and their geometric dimensions. Strength properties include specific indicators of cutting work, as well as the rate of distribution of elastic deformations, as a result of the loss of juice, breaking stress. The specific work required for cutting the fruit characterizes the energy intensity of the separation into parts of the starting material.

Individual fetal weight was determined by weighing each fetus using a balance, after which the data obtained were tabulated and processed. Sizing was carried out using a caliper. More than 600 fruits have undergone statistical processing. In this case, both the weight of the fruits and their sizes are subject to the normal Gaussian distribution with the corresponding characteristics of mathematical expectations and variances.

Results and Discussion

Within the framework of theoretical studies, three main factors were identified that affect the minimization of energy consumption of the cutting process: cutting speed, sliding angle, shape of the blade tool.

As a result of the analysis of theoretical and experimental data, a new design solution was proposed for a chopper of fruits and vegetables into parts - a block of knives made in the form of a plate with supporting shelves located in a vertical groove (Figure 1). The total length of the knife block, the width of the cutting part of the blade of the knife block, the length and width of each shelf are made with geometric dimensions related to the radius of the fruit. The described design for cutting fruits and vegetables allows you to improve the process of cutting fruit and vegetable raw materials by combining in one device continuous and simultaneous feeding and cutting of material [5].

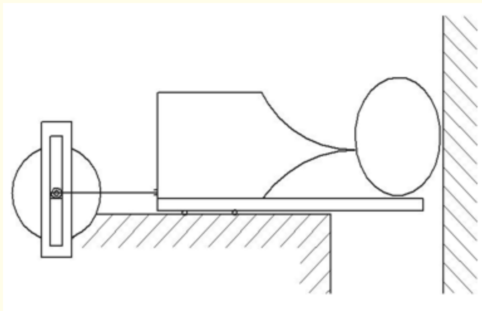

***Figure 1:** Block of knives, made in the form of a plate with supporting shelves.*

Increasing the efficiency of cutting on a part of fruit and vegetable raw materials close to a spherical shape is achieved by eliminating rotating elements, thereby greatly simplifying the design [6]. Fruit centering is greatly simplified by the cylinder-shaped support surface. Accurate adjustment relative to the center of the cut product is provided by a cross-shaped cutout, in the vertical groove of which the knife block is located. For dividing the fruit into predetermined parts, the device contains several pairs of reference planes, placed sequentially along one vertical axis, and each subsequent plane of the cutting blade is displaced relative to the previous one by an angle α [7].

In the apparatus for cutting on a part of fruit and vegetable raw materials, a plate knife with a shape in the form of a double-sided concave wedge with a pointed sharpening is proposed as a working tool. For a comparative experiment, a model of a straight two-sided and one-sided wedge was used. Optimization of the wedge shape with straight descents is based on a legitimate assumption based on the results of statistical processing of experimental data and the shape of the elastic line of the deformable surface of the fruit, a certain curve was obtained (Figure 2).

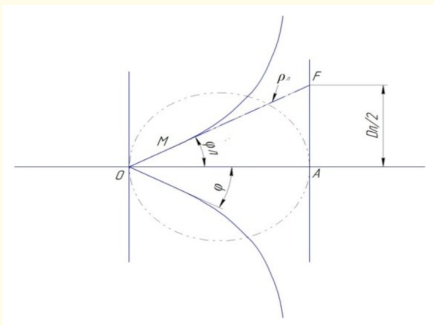

***Figure 2:** The shape of the elastic line of the deformable surface of the fetus.*

This curve shape can be most closely approximated by an equidistant curve by the Diocles cissoid. The possibility of eliminating stress concentrations at different points of the cutting edge to ensure the quasi-static process [8] can be provided by the same derivatives at the cutting point for the elastic line of the curved surface of the lemon and the line represented by the expression.

This expression is a real equation of displacement of the curve in xpolar coordinates to determine the rational shape of the blade tool in the boundary conditions $0 \leq \varphi \leq 90°$ under the action of a concentrated load.

Analysis of the results of such studies of the localization and concentration of stresses in the blade and material models by means of the SolidWorks graphics program made it possible to optimize the shape and parameters of cutting tools, including the profile of the blade tool [9]. To cut fruit and vegetable raw materials and reduce the cost of setting up the experiment, a test bench was made, as well as sets of replaceable flat knives made of 65X13 steel. Replaceable flat knives were placed one at a time in a specially prepared groove on the knife block plate.

This design made it possible to freely move the knives between the plates when choosing their location in the knife wall, rigidly fix them at each cutting option and completely visually control the process under study. As a criterion for assessing the efficiency of the installation, we chose the type of fruit cut with various designs of the cutting tool (Figure 3), as well as the amount of fruit and vegetable juice lost depending on the cutting speed and storage time of the fruit. The greater the loss, the greater the deformation of the fetus, which means the lower the cutting efficiency for this type of material [10].

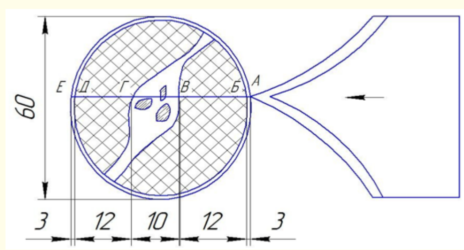

Figure 3: *Scheme of the cut lemon fruit.*

Let us analyze a schematic section of a lemon fruit, close to a spherical shape (Figure 3), corresponding to the deepening of the knife into the fruit along the width of the fruit (transversely) [11]. In this diagram, five previously considered areas are visible, and their linear dimensions in mm are determined with accuracy and are presented as a percentage of the total diameter of the cut fruit (lemon fruits were taken with a diameter of 60 to 80 mm): AB - 0.3%; BV - 17 - 27%; VG - 4.5 - 12.4%; HD - 11.2 - 19.6%; DE - 44.3 - 54.3%.

Point A corresponds to the beginning of the process of deepening the knife into the material [11, 12]. In this section of the AB, which corresponds to the lemon peel, there is a layer compaction and stress concentration (deformation) under the edge of the blade tool. Under a concentrated load, the working blade is pressed into the surface of the lemon and uniaxial compression occurs in the plane of the knife. The upper part of the fruit bends slightly and a depression forms under the knife blade. As mentioned earlier, the area of propagation of deformation changes depends both on the properties and structure of the material itself, and, for example, on the cutting mode and geometric properties of the working tool. The storage time also has an effect on the deformation of the fetus, since the skin of the fruit shrinks and the consistency of the pulp ("lethargy") changes further in favor of increasing the plastic properties, as well as the process parameters [13].

The middle layers of the fruit are more dense. An increase in the effort P is practically not observed due to the insignificant resistance of the fetal structure. The deformation of the material layers is also small. On average, the size of the AB area of the relatively total fruit size is 6 mm or 0.3% of the total diameter (depending on the variety) of the lemon. Further introduction of the knife blade into the lemon fruit (section BV) - the tension increases, an increase in the effort P is observed, at point C the first maximum is reached (the critical value of the force, Pcr). Compression deformation is minimal and relative. The upper layers of the material structure are more compacted. At some point, the indicators of crushing, compression and stretching reach their maximum values and the upper layers of the fruit begin to collapse, and the blade of the knife goes further into the structure. At this moment, the process of cutting the fruit takes place.

The size of the BV area varies from 17 to 27.2% with an average of 23% relative to the total size of the fetus.

Due to the peculiarity of the structure of the lemon fruit, it is necessary to note the VG area (internal pulp, seeds, pome chambers), which gives additional resistance to the deepening of the knife into the structure of the fruit. Relative to the total size, the VH region varies from 4.5 to 15.5% with an average of 9%. Considering the above, it is possible to single out the main factors affecting the cutting force of the lemon fruit: the cutting speed in the layer of material, the displacement of the knives relative to the cutting axis of the lemon fruit, the coefficient of friction of the material against the blade tool. It is also necessary to take into account the possibility of getting hard seeds of the fruit when cutting, but since this value is small, we will neglect this value.

Cutting force as a factor taking into account energy costs was taken as the basis of laboratory research [14]. The interaction of the tool with the material being cut can be more clearly shown using the graph of the change in the relative deformation of the lemon fruit, kiwi from the cutting force with different shapes of the cut tool (Figure 4 and 5).

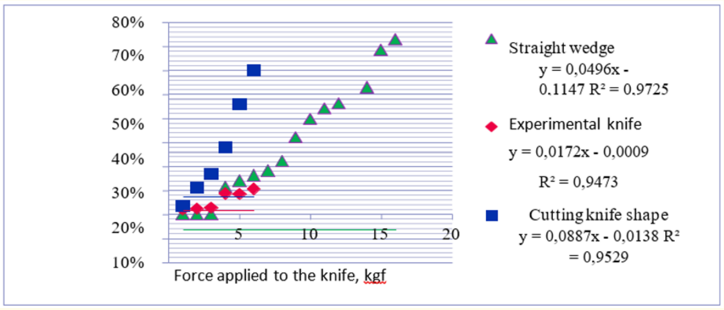

Figure 4: *Dependence of the relative deformation of the lemon fruit on the cutting force at different the shape of the cut tool.*

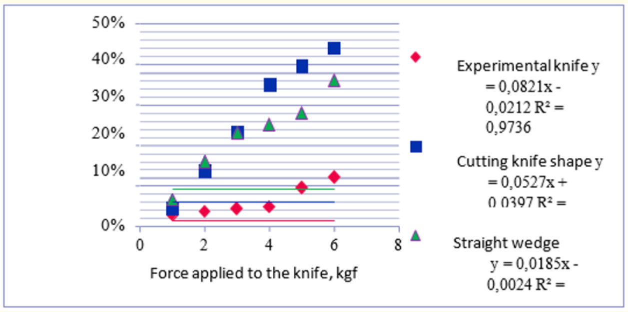

Figure 5: *Dependence of the relative deformation of the kiwi fruit on the cutting force for different shapes of the cut tool.*

The calculation of the economic efficiency is carried out by comparing the devices for cutting into pieces using three different knife shapes.

Conclusion

Analyzing the data obtained, it can be concluded that the device with the use of an experimental knife turned out to be effective both in terms of minimizing the loss of cell juice and more cost-effective in terms of manufacturing and maintenance, which once again confirms the correctness of the approaches based on the work [15].

The efficiency of the device using a knife with a single-sided wedge, in view of the highest material costs in its manufacture due to the shape of the cutting edge, turned out to be the least.

Analysis of theoretical and experimental data allows us to conclude that the use of a knife with a curved shape in the apparatus for cutting on a part of fruit and vegetable raw materials reduces the energy consumption of the grinding process by 15% compared with using a single-sided wedge knife and by 30% compared with using a straight wedge knife.

At the same time, the loss of juice in lemon during sliding cutting was 3.9 and 4.1% of the mass of the original fruit, and when cutting with the developed knife block - 1.4 and 1.5%, respectively.

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