Cutting speed value during plant material grinding in food industry

Alina Sheyina, Victor Goots

Donetsk National University of Economics and Trade "Mykhailo Tugan-Baranovsky", Ukraine

Keywords:

Cutting
Food
Vegetables
Speed
Quality

Article history:

Received 22.02.2016
Received in revised form 17.06.2016
Accepted 30.06.2016

Corresponding author:

Alina Sheyina
E-mail:
sheyinaalina@rambler.ru

Abstract

Introduction. The influence of cutting speed factor on elastic and frictional properties of plant materials is investigated and justified. The dependence of cutting force on cutting speed is determined. The choice of rational parameters of the process is justified by the qualitative indicator of the ground product.

Materials and methods. The elastic properties of vegetables have been studied by the standard method of sample compression between two plane-parallel plates. Compression force has been recorded. Frictional properties were measured on the setup of disk type: the test material was in contact with a rotating steel disk, the friction force was recorded. Cutting forces were measured by the tensometric method during plate blade penetration into the material layer. The cutting speed varied within the range of 0.4–2.5 m/s.

Results and discussion. With the increase of cutting speed the elastic properties of the material appear to a lesser degree, due to the spread of elastic deformations in the layer. Within the cutting speeds range from 0.4 m/s to 2.5 m/s the elasticity modulus is reduced by a factor of 1.2.

Frictional properties that are characterized by a friction coefficient are reduced by a factor of 1.2–1.5 with the increase of sliding speed of friction pairs from 0.75 to 2.66 m/s. The nature of these changes depends on the structural configuration of the material, the moisture content, contact surfaces quality, the pressing force of friction pairs.

Cutting forces of plant materials depend on their structural and mechanical properties. The increase of cutting speed within the ranges under study will contribute to their reduction by a factor of 1.4–2, depending on the product type. In this regard, it is appropriate to use higher cutting speeds of plant materials for vegetable cutting equipment in order to reduce specific cutting forces.

To get high quality cutting it is necessary to consider the influence of cutting speed, cutting thickness, structural characteristics of the products to be ground.

Conclusion. Taking into account the factor of speed influence on cutting forces of plant materials, the optimal and the recommended range of circumferential cutting speeds for the products under research is from 300 to 600 rev/min.

Introduction

The task of this article is to study the cutting speed factor influence on elastic and frictional properties of plant materials; to define the dependence of cutting force on the speed of blade cutting edge penetration into viscoelastic product; as well as to justify the expediency of high cutting speeds use with qualitative indicator of the ground product.

Cutting force of food material is a major energy component of the cutting process. The effectiveness and the expediency of the chosen grinding method will depend on this indicator value. Reducing the value of cutting force is a priority for the intensification of this process.

In this article, we raised the issue of grinding food products of plant origin (vegetables), which are classified as viscoelastic materials.

At the enterprises of restaurant business vegetable cutting machines of disk type are most widely used when grinding vegetables. In these machines, the product is cut with a rotating blade installed in the working chamber of the machine on a special supporting disk. Depending on the configuration of blade cutting edge the cut shape may change [1].

The conducted analysis of technical and operational performance of vegetable cutting equipment has shown that in machines of different models the grinding speed ranges from 0,4 up to 2.5 m/s [2]. The analysis of the literature reference revealed no data on speed factor influence on the cutting process of viscoelastic plant materials in the indicated range. Besides, the factor of cutting speed influence on quality indicators of the ground product has not been studied yet.

Cutting force in vegetable cutting machines of disk type depends on geometrical parameters of the cutting tool (blade thickness, blade sharpening angle, surface roughness of the cutting edge), technical and operational parameters of the machine (cutting speed), and on the structural and mechanical properties of the product being ground, namely – coefficient of product friction on the surface of blade cutting edge, and elasticity modulus [1].

The influence of geometrical parameters of blades on the cutting force is described in works [1, 3, 4, 11]. Structural and mechanical properties of viscoelastic materials are given in works [5–8]. Data on the influence of cutting speed on structural and mechanical properties of the plant material in the indicated range of cutting speeds are not systematic.

Materials and methods

The experiments were carried out with vegetables having a relatively uniform structure: potatoes, onions, carrots, beets, eggplants, zucchini, cucumbers.

The study of elastic properties of plant materials was carried out by compressing the product sample between two plane-parallel plates according to standard methods [1, 3, 7]. During the experiment the sample compressing force was recorded.

A linear relationship between compression stress and relative deformation has been assumed in determining the numerical values of elasticity modulus [6, 8, 9].

To conduct the studies of frictional properties of plant materials the experimental setup of disc type has been developed [10, 11, 12]. The setup design allows to study the influence of sliding speed on frictional properties of the product in conditions most closely resembling the actual manufacturing process. The setup consists of a head section, disk of 150 mm in diameter which rotates in a horizontal plane (disk is made of polished food stainless steel), the vertical beam with tensoresistors placed on it, at the lower end of which the box with the product sample is mounted, the amplifier, the analog-digital converter, PC and the package of licensed LGraph software.

Product sample is pre-set the desired geometric dimensions. For each subsequent measurement a new sample of the product in a freshly cut form was used which eliminates the possibility of juice loss. The required speed limit is set with the speed regulator. During disc rotating the product sample is carried away with friction force and bends the measuring beam. Devices record friction force value which is displayed on a monitor in a form of oscillograms in real-time mode. The friction coefficient is defined as the ratio of frictional force to the weight of the sample under research.

Specific efforts of plant materials cutting were determined by measuring the cutting force during plate blade penetration into the sample layer. The research was carried out at a linear cutting speed of 0.005, 0.1, 0.47, 0.75, 1 and 1.25 m/s.

The experimental setup similar to vegetable cutting machine of disk type at food plants was used to study the influence of cutting speed limits on the quality of vegetables cutting. The setup allows to change the circumferential blade speed from 150 to 2000 rev/min. The product portion of 1 kg weight was ground at a predetermined cutting speed, and then the cutting quality was analyzed and the number of substandard particles in the total mass was defined.

The measurement and organoleptic methods were used to evaluate the product quality indicators. The product was sliced 1, 4 and 6 mm thick. Grading was determined in percentage correlation to the total amount of the product to be cut.

Results and discussion

Cutting speed influence on elastic properties of plant materials. Experimental studies allowed to prove the reduction of elastic properties of plant materials pulp with the increase of influence speed on the sample product under research. This is due to the development of slow elastic deformation in the product. Initially, when loading a viscoelastic material, there occur instantaneous and delayed elastic deformations. Instantaneous elastic deformation is developed quite fast, it is almost impossible to be fixed experimentally, that is why it is designated arbitrarily and is assumed to be zero in practice. Delayed elastic deformation is the value that can be numerically determined. The distribution of delayed elastic deformation depends directly on the loading speed.

The increase of deformation speed leads to the fact that viscoelastic stresses in the product sample hardly relax, tensile strength occurs immediately after the yield point, plastic deformation does not occur and brittle fracture is observed. The total deformation work of the product will decrease.

The dependence of elastic modulus E of viscoelastic plant materials on the deformation speed ε in the indicated speed range is of linear character (Figure 1) and is described by the equation (1):

$$E = k_1 \cdot \dot{e}^n , \tag{1}$$

where k_1 and n are the coefficients which are defined by experiment.

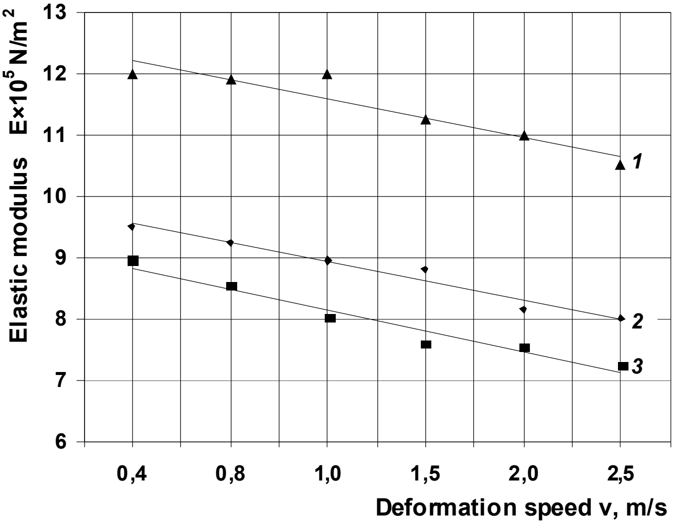

Figure 1. The dependence of elastic modulus on the deformation speed for some vegetables:
1 – potato; 2 – carrot; 3 – onion.

The dynamics of elastic modulus change from the deformation speed is somewhat different for different kinds of vegetables, which is associated with the structural configuration of the products under study, and their moisture content.

Summarizing the results of the experiment, we should point out that for the investigated plant materials within the range of loading speeds of 0.4–2.5 m/s, the elasticity modulus is decreased by a factor of 1.2.

The influence of cutting speed on frictional properties of plant materials. Frictional properties of plant materials are normally described with friction coefficient. According to the results of experimental studies, the change of friction coefficient from the sliding speed has linear function (2):

$$f = k''\cdot v + C'', \tag{2}$$

where f is a friction coefficient ;
v is sliding speed, m/s;
k'', C'' are the coefficients which are defined by experiment.

With the increase of the sliding speed from 0.75 to 2.66 m/s we may observe the friction coefficients of the vegetables under study decrease by a factor of 1.2–1.5 at average (Figure 2).

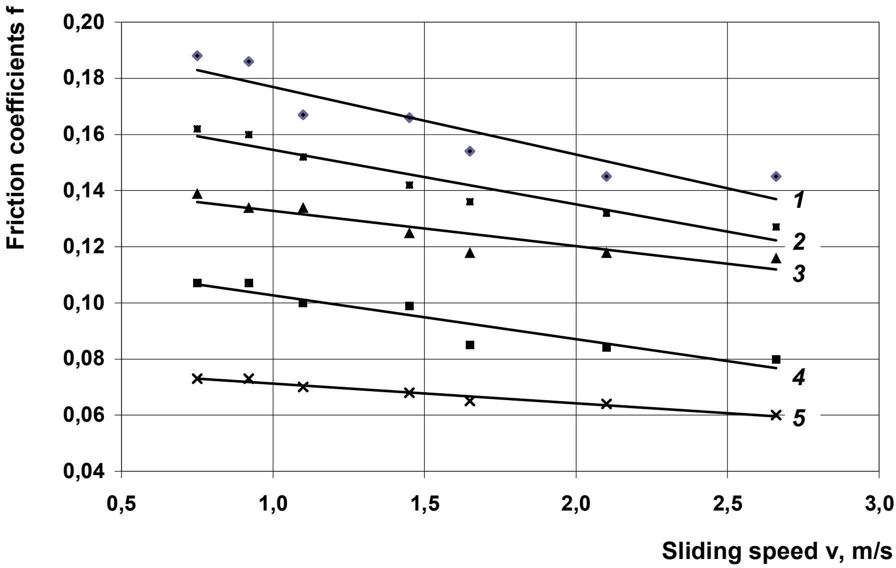

Figure 2. The influence of sliding speed on friction coefficients of vegetables:
1 – beet; 2 – potato; 3 – carrot; 4 – cucumber; 5 – zuccini

The decrease of friction coefficients value with the increase of sliding speed is associated with the change of roughness of contacting surfaces. When two solid bodies contact there occurs a discrete contact, which causes the constant change of the individual elementary contact points. In addition, each elementary contact has three stages of evolution: interaction, change, and destruction [10, 11]. The lifetime of elementary contact depends on the rate of relative movement of the friction pair, physical and mechanical properties of the contacting materials, and the conditions of the sliding surfaces.

Upon elastic contact the individual surface projections have significantly greater roughness in tangential direction than in normal one. With the enlarging of adjacent material areas they are deformed. Under the influence of elastic forces the projection is rectified and, oscillating, collides with other projections. Upon imperfect contact elasticity with the increasing sliding speed the time between two impulses is no longer sufficient to fully rectify the projection. This leads to the change of surface roughness. As the actual contact area grows in time, then with sliding speed increase the contact time is decreased, and respectively, the contact area is reduced. This leads to friction coefficient decrease.

Since the increase of cutting speed will help to reduce the influence of frictional properties of plant materials on the cutting forces, then it is economically feasible to use higher cutting speeds.

The influence of cutting speed on specific cutting forces. According to experimental studies, the dependence of specific cutting force on the cutting speed is described by the exponential function (3):

$$q_{sp} = kv^{-m}, \quad (3)$$

where q_{sp} is specific cutting force, N/m;

v is the cutting speed, m/s;

k and *m* are the coefficients which are defined by experiment.

Figure 3 shows the diagrams of specific cutting force change within the cutting speeds range from 0,005 to 1,25 m/s.

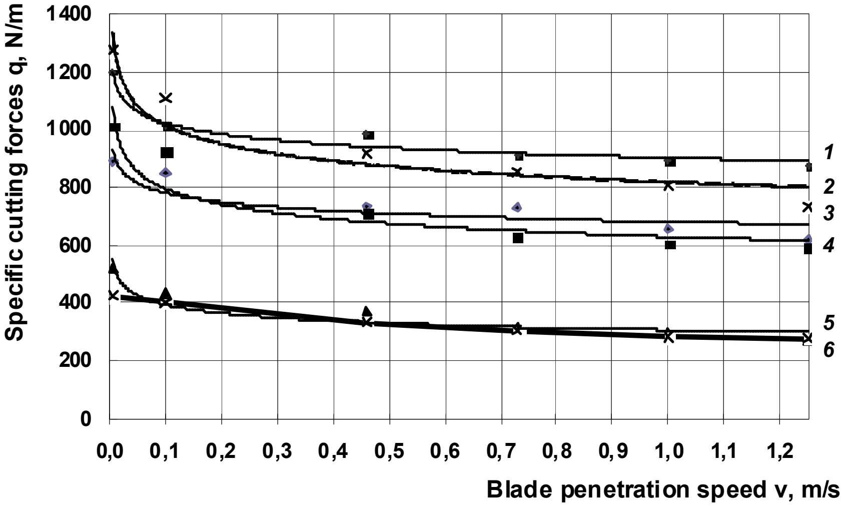

Figure 3. The dependence of specific cutting forces of vegetables on blade penetration speed:
1 – beet; 2 – eggplant; 3 – potato; 4 – carrot; 5 – cucumber; 6 – zuccini

In the speeds range under study there is a decrease of specific cutting force of vegetable raw materials by the factor of 1.4 – 2. The most significant decrease of q_{sp} value is observed within the speeds range from 0.005 to 0.2 m/s, after which the curve has a smooth flow. The decrease of specific cutting force with the increase of cutting speed is associated with the influence on the process of frictional and rheological properties of the product sample to be ground. Thus, we consider the dependence $R_{cut} = f(v)$ as a change of some physical and mechanical property of the product, since it is a proven fact that the speed of the working tool influences the nature of the plant material properties change.

Statistical studies, corresponding the minimum cutting speeds, show that the grinding of plant materials under such conditions is not economically feasible. With the increase of cutting speed exceeding 1.5 m/s there are difficulties with rapid removal of the ground product from the cutting area and its excessive deformation due to the increase of centrifugal forces effect. This has a significant impact on the quality of cutting as a whole and reduces the competitiveness of the equipment.

Analyzing the above-mentioned experimental results, we can conclude the feasibility of using high cutting speeds to reduce the specific cutting forces and, accordingly, reduce the energy component of the process.

The influence of cutting speed on the ground product quality. It should be noted that the quality of manufacturing operation is an important indicator when grinding plant materials in food industry. The quality of the ground product is determined by the cut smoothness, slice thickness constancy, the amount of defective products, juice losses etc.

Figure 4 shows the thickness influence of the products being cut on the cutting quality at circumferential cutting speed of 1250 rev/min.

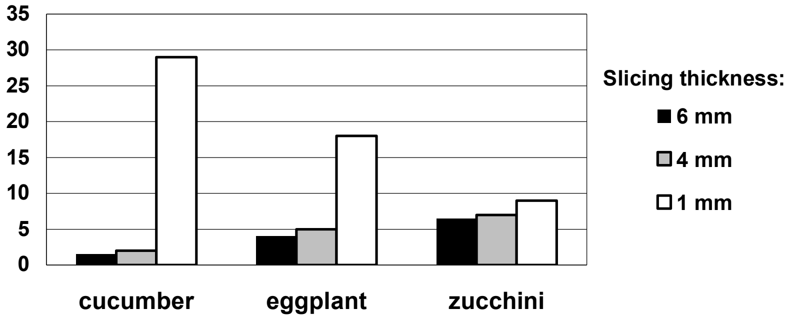

Figure 4. The histogram of grading amount change from vegetables slicing thickness at the grinding speed of 1250 rev/min

The experiment was conducted only for those products, the grading amount of which was the largest. With the increase of cutting thickness from 1 to 4 mm the number of substandard product particles is significantly reduced and reaches optimal performance. With the increase of cutting thickness up to 4 mm the grading amount for eggplants decreased by a factor of 3.6, for cucumbers – by a factor of 15.5, zucchini – by a factor of 1.3. The increase of cutting thickness up to 6 mm has no significant influence on the number of substandard particles. Consequently, with the thickness increase of the slices being cut the product breaks up less on impact with the structural elements of the machine; and the presence of chips in the volume under study largely depends on the structural features of the blade, the discharging device, and the degree to which the product is pressed to the blade at the cutting moment. For such products as eggplants and cucumbers with shallow cutting thickness, it is advisable to use cutting speeds up to 350 rev/min.

Figure 5 shows a histogram describing the change of the substandard products amount when cutting certain types of vegetables in slices with the increase of cutting speed from 280 to 2000 rev/min. The cutting thickness in this experiment was 1 mm.

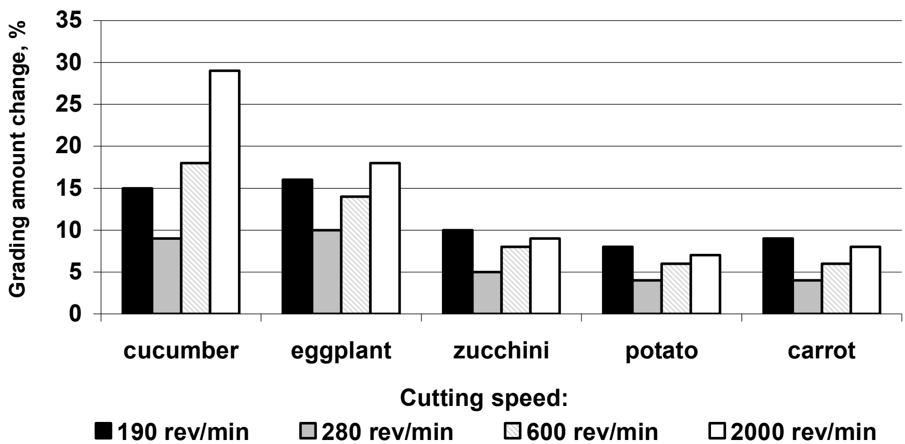

Figure 5. The histogram of grading amount change with the increase of cutting speed

According to Figure 5 and the results of the experiment as a whole, we conclude that at the cutting speed of less than 280 rev/min the cutting quality of the vegetables under study is deteriorating. The integrity of the end surfaces of the slices is disturbed, which is manifested in the formation of fractures and cracks, which impair the product appearance and lead to excessive juice loss. Low cutting speeds are not recommended for the products that are cut with the peel, especially if the peel elasticity is significantly different from the core elasticity (eggplant, zucchini, some varieties of cucumber). When cutting such vegetables the peel cutting force is much larger, and when cutting at low speeds there is an excessive crushing of the product layers under the peel. This significantly reduces the cutting quality. Cutting speeds under 280 rev/min are recommended for grinding the boiled vegetables.

At cutting speed above 1000 rev/min, we can observe the increase of the grading amount in the total volume of the ground mass. This is caused by the destruction of the product on impact with the walls of the discharging device of the vegetable cutting machine at the time of discharge. Such cutting speeds significantly degrade the cutting quality and they are not recommended for the grinding of brittle and juicy products with thickness of the slice being cut of less than 4 mm.

When cutting brittle vegetables of 1–2 mm thick it is necessary to select the cutting mode more carefully. These vegetables are more susceptible to deformation upon contact with structural elements of the equipment and the ground mass. When cutting vegetables into slices over 4 mm thick it is allowed the use higher cutting speeds (over 600 rev/min). It should be taken into account that the increase of cutting speed leads to additional juice loss when cutting products with high moisture content.

Conclusions

Experimental research has allowed to study the influence of speed factor on the process of viscoelastic plant materials cutting within the range of cutting speeds used in modern vegetable cutting equipment.

It has been found out that with the increase of cutting speed the elastic properties of the material appear to a lesser degree, due to the spread of elastic deformations in the layer. Within the cutting speeds range from 0.4 to 2.5 m/s the elasticity modulus is decreased by a factor of 1.2.

Frictional properties that are characterized by a friction coefficient of the material under study are decreased by a factor of 1.2–1.5 with the increase of sliding speed of friction pairs from 0.75 to 2.66 m/s. The structural configuration of the material under study, its moisture content, contact surfaces quality, as well as the pressing force will additionally influence the nature of these properties change.

Cutting forces of plant materials largely depend on its structural and mechanical properties. Therefore, the increase of cutting speed in the ranges under study will contribute to their decrease, as studies have shown, by a factor of 1.4–2, depending on product type. Therefore, basing on research results, we can conclude about the expediency to use higher cutting speeds of plant materials in vegetable cutting equipment in order to reduce the specific cutting forces.

To obtain products of high-quality cutting with a minimum amount of substandard particles it is essential to select the speed mode more carefully. The cutting speed has significant influence on cutting quality of brittle materials and materials having the most heterogeneous structure (presence of peel, seeds etc). Here, the product cutting thickness is an important factor that determines this or that mode. Taking into account all the above-mentioned factors, the optimal and the recommended range of circumferential cutting speeds for using in vegetable cutting machines of disc type will be 300–600 rev/min. Under this condition, the ratio of "cut quality – grading" remains optimal.

Experimental research data and the relations obtained are valid only for the specified cutting conditions. When changing the cutting speed range the rheological properties of plant materials can vary significantly.

Thus, considering the factor of speed influence on the structural and mechanical properties of the plant materials and, as a result, cutting force, the optimal and the recommended range of circumferential cutting speeds for the products assortment under research is from 300 to 600 rev/min.

References

1. Andras Fekete (2007), Development Of Sensing System For Product Grading, *Annual report*, pp. 44–49.
2. Zapletnikov I. N., Sheina A. V. (2011), Ocenka kachestva ovoczherezatelnogo oborudovanya, predstavlenogo na rynke Ukrainy, *Visnyk HNTUSG*, 119, pp. 156–160.
3. Yiu H. H. (2006), Handbook of Food Science, Technology and Engineering, *Taylor & Francis*, p.712.
4. Emadi, et al., (2009), Mechanical properties of melon measured by compression, solar and cutting modes, *International Journal of Food Properties*, 12, pp. 780–790.
5. Malcolm C. Bourne (2002), Food Texture and Viscosity: Concept and Measurement, *Academic Press*, p. 427.
6. Herppich W. B., B. Herold, O. Schluter, K. Ilte, M. Geyer, B. Borsa, Z. Gillay (2006), Beurteilung der mikrotopograftschen Beschaffenheit von Schnittflachen, *Landtechnik*, 61(5), pp. 256–257.
7. Rao M. A, Syed S. H. Rizvi, Ashim K. Datta (2005), Engineering Properties of Food, *Taylor & Francis*, p. 761.
8. Ibrahim Gezer (2007), Post harvest chemical and physical–mechanical properties of some apricot varieties cultivated in Turkey, *Journal of Food Engineering*, 79, pp. 364 – 373.
9. Zare. D., Safiyari H., Salmanizade F. (2012), Some Physical and Mechanical Properties of Jujube Fruit , *International Scholarly and Scientific Research & Innovation*, 6(9), pp. 672 – 675.
10. Shirmohammadi M., Yarlagadda P. K. D.V., Gudimetla V. (2011), Mechanical Behaviours of Pumpkin Peel under Compression Test, *Advanced Materials Research*, 337, pp. 3–9.
11. Puchalski C., Brusewitz G.H., Dobrzañski B. (2002), Relative humidity and wetting affect friction between apple and flat surfaces, *Int. Agrophysics*, (16), pp. 67–71.
12. Sheina A. (2013), Issledovanie proceca rezanya rastitelnyh materialov v staticheskom i dinamicheskom rezhimah, *Privolzhskyi naychnyi vestnic*, 12, pp. 45–49.