ENGINEERING SCIENCES

RESEARCH OF THE EFFECT OF THE VELOCITY COEFICIENT ON THE CUTTING FORCE OF VEGETABLES

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Abstract. *This paper presents a study of the influence of the velocity coefficient on the cutting force and their components – the horizontal component Fx and the vertical component Fy when cutting vegetables. Two well-known vegetables, pumpkin and beetroot, were used in the experiments. The experiments were carried out with feed rate of the food sample 0,083 m/s and frequency of rotation of the disc knife in a range from 110 min*$^{-1}$ *to 414 min*$^{-1}$*. It was found that when the velocity coefficient grows, the cutting force and the components of the cutting force decrease. The lowest values of cutting force of pumpkin and red beet (131 N and 115,2 N respectively) were recorded for the highest value of velocity coefficient λ (54,8).*

Keywords: *pumpkin, beetroot, velocity coefficient, cutting force, disc knife.*

Introduction. Pumpkin and beetroot are two widely distributed vegetables used in food processing and human diet.

Pumpkin (*Cucurbita*) belongs to the family *Cucurbitaceae*. It is used for food - boiled or baked. Pumpkin puree and powder are commonly used as an ingredient in sauses, soups, bread, mixed nectars with apples. Pumpkin powder and extracted pigments (carotenoids) are used as a natural coloring agent in various flour mixes. Pumpkin contributes to consumers′ health because of its rich substance of biologically active components: carotenoids, proteins, peptides, polysaccharides, phenolic compounds, sterols.[1] It is found out that fruit pulp has antidiabetic effect [2], it increases plasma insulin and reduces the blood glucose [3].

Beetroot (*Beta vulgaris*) is from *Chenopodiaceae* family. The most common for human consumption are deep red-colored to purple beet roots. The plant pigment that gives beetroot its rich purple-red colour is betacyanin. The main betacyanin – betanin, is used as natural food colour, listed as E162 on food labels in Europe. Beetroot is of exceptional nutritional value, rich in vitamins (A, B_1, B_2, B_3, B_6, C), minerals (calcium, iron, manganese, potassium), folic acid, fibers. It suppresses the development of some types of cancer, stimulates the liver detoxification processes, helps to lower blood pressure, increases the number of white blood cells. Beetroot is used fresh for salads and juice, after thermal processing and in cunning industry.[4]

In the food industry the cutting is one of the most frequent process, which products are large or small pieces, slices, small cubes of fruits and vegetables, flakes, pulp [5]. The factors that have considerable impact on the quality and efficiency of the food cutting process are: structure and mechanical properties of the product, type of cutting equipment, cutting conditions.

Mechanical properties of vegetables are affected on turgor, cell sizes, shapes and firmness of cell walls, cell adhesion, as well as the stage of maturity.

Turgor is the water pressure inside plant cells. Increasing of osmosis pressure in the cells and thence in the tissues causes their firmness. Water content in pumpkin is 91%, in beet root – 88 % [6]. One of the functions of the cell wall is to create together with middle lamella the mechanical "skeleton" of the tissue. Primary cell walls are composed predominantly of polysaccharides. There are three major categories of wall polysaccharides: pectic polysaccharides, hemicelluloses, and cellulose [7]. Pectin is the major component of the middle lamella, which determines, in a great measure, the mechanical properties of the parenchyma, as strength, elasticity, etc. Pumpkin contains 14% of pectin on a dry matter basis, which is up to 26,8%, beet root - 1% pectin on a basis of 15,7% dry matter. Cellulose and hemicellulose are the other main components of the cell wall which influence its strength. Cellulose is the compound that gives the rigidity and tensile strength of the cells.[8] The bonds between each cellulose molecule are very strong, which makes cellulose very hard to break down. Cellulose fibres are the fibrous elements of the cell wall whereas hemicellulose fit their microfibrils together in an intricate network. The content of cellulose and hemicellulose in pumpkin is 4,2 ÷ 22,7 % and in beet root - 0,6 ÷ 3% [8]. The rising of cellulose and hemicellulose contents leads to form rougher vegetable texture which is the reason for increasing their cutting resistance.

The cutting devices with disc knife are wide-spread in the food industry, the catering, the shops. Disc knife works under the sliding type of cutting. As a basic kinematic factor which characterizes its work is accepted the velocity coefficient λ, which is the ratio between the cutting speed V_p and the feed rate V_n. The effect of velocity coefficient on the cutting forces of food was researched by a lot of scientists [9]. It was found that when the value of λ increases, the cutting forces decrease, the quality of the cutting surface improves, the deformation of the cutting product becomes smaller. Furthermore, the normal component of the cutting force decreases in more considerable degree then the tangential component, however the degree of the lessening depends on the adopted cutting scheme and the type of the processed product.

The goal of this study is to establish the influence of the velocity coefficient on the resultant cutting force F and on their components Fx (horizontal component) and Fy (vertical component) when cutting vegetables with disc knife. The results can be of use for the improving of cutting disc devices and for choosing a properly cutting conditions of fruit and root vegetables.

Materials and methods. Pumpkin variety "Samson" and beet root variety "Libero" were chosen from the local market in Plovdiv, Bulgaria. The vegetables were in middle sizes, healthy and defect-free. Before the experiments they were kept 24 hours under laboratory conditions with environmental parameters: temperature of 20-25°C and relative humidity of 50-55%. Parallelogram samples were prepared with sizes 100/50/10 mm from the pulp by using a hand knife after their preliminary washing, peeling and removing of seeds. The samples were fixed immovably on the platform of the laboratory device [10] and were fed in the cutting zone with feed rate of 0,083 m/s. The disc knife used in the tests with parameters: diameter 0,210 mm, thickness 0,8 mm and wedge angle 15°, was turned with frequency in the range of 110 – 410 min^{-1}. The determination of the components of the cutting force Fx and Fy was carried out by tensometers.

Results and discussion. The results of the influence of the velocity coefficient on the components of the cutting force Fx and Fy are shown on Fig.1 and Fig.2 when cutting pumpkin and red beet respectively. The obtained graphs are logarithmic curves. For both products the increasing of the velocity coefficient shows the decreasing of the components of the cutting force Fx and Fy.

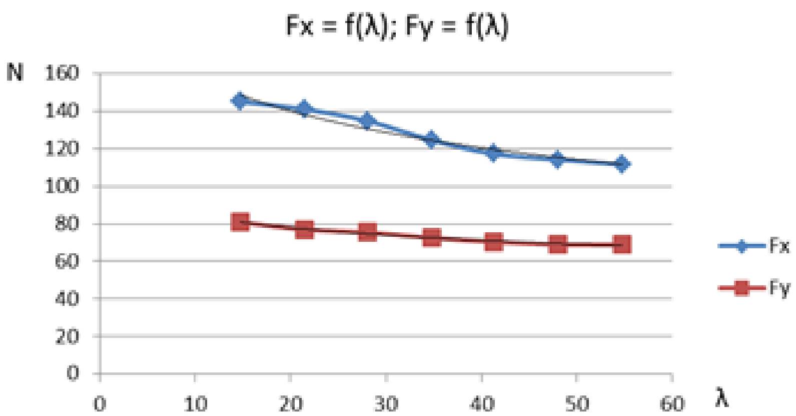

Fig.1. Relation of components Fx and Fy of cutting force of pumpkin to velocity coefficient

The relations presented in Fig.1are described by equations (1) and (2):

$$Fx = -28{,}18\ln\lambda + 224{,}43 \quad (1)$$

$R^2 = 0{,}9559$

$$Fy = -9{,}58\ln\lambda + 106{,}58 \quad (2)$$

$R^2 = 0{,}9887$,

where: Fx – horizontal component of the cutting force Fx of pumpkin;
Fy – vertical component of the cutting force F of pumpkin;
λ – velocity coefficient;
R – correlation coefficient.

When cutting pumpkin samples the lowest values of the components of the cutting force 111,6 N (for horizontal component Fx) and 68,8 N (for vertical component Fy) were recorded at the highest value of velocity coefficient λ (54,8), and the highest values (145 N for Fx and 80,8 N for Fy) at the lowest value of λ (14,7).

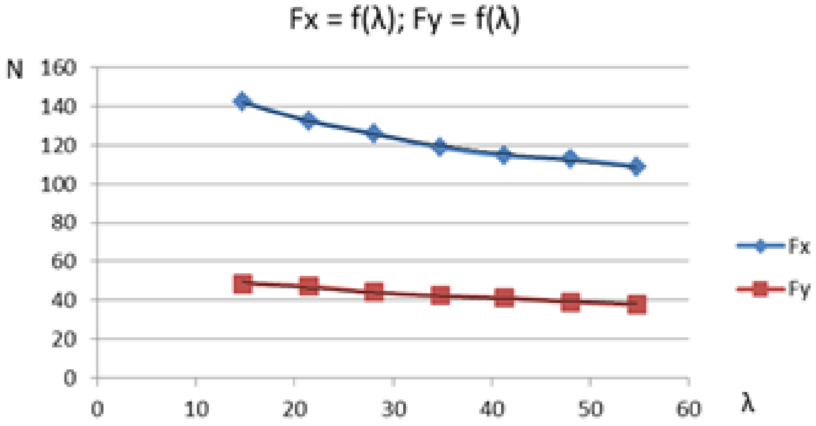

Fig. 2. Relation of components Fx and Fy of cutting force of red beet to velocity coefficient

The relations presented in Fig.2 are described by equations (3) and (4):

$$Fx = -25{,}54\ln\lambda + 210{,}58 \quad (3)$$

$R^2 = 0{,}9954$

$$Fy = -8{,}525\ln\lambda + 72{,}453 \quad (4)$$

$R^2 = 0{,}9774$,

where: Fx – horizontal component of the cutting force Fx of red beet;
Fy – vertical component of the cutting force Fy of red beet;
λ – velocity coefficient;
R –correlation coefficient.

The lowest values of the components of the cutting force 108,9 N (for horizontal component Fx) and 37,8 N (for vertical component Fy) in the experiments of cutting red beet were recorded at the highest value of velocity coefficient λ (54,8), and the highest values (142,2 N for Fx and 48,7 N for Fy) at the lowest value of λ (14,7).

The analysis of graphs which shows the relation between the components of the cutting force and the velocity coefficient when cutting pumpkin and red beet shows the significant decreasing of the horizontal component for the both products when the cutting speed increases, namely when the velocity coefficient increases. The vertical component decreases slowly then the horizontal component and in the examined range of the velocity coefficient for pumpkin it decreases with 12 N, for red beet – with 10,9 N. For the same cutting conditions the horizontal component of the cutting force Fx of pumpkin decreases with 33,4 N, for red beet – with 33,3 N. That is to say when the velocity coefficient increases within the adopted range the horizontal component of the cutting force of pumpkin and red beet decreases about three times more intensive then the vertical component.

The graphs representing the cutting force of pumpkin and red beet in relation to velocity coefficient are logarithmic curves (Fig.3). They can be described by equations (5) and (6):

$$F_p = -29{,}19\ln\lambda + 247{,}65 \quad (5)$$

$R^2 = 0{,}9653$

$$F_{rb} = -26{,}93\ln\lambda + 222{,}7 \quad (6)$$

$R^2 = 0{,}9969$,

where: F_p – cutting force of pumpkin;
F_{rb} – cutting force of red beet;
λ – velocity coefficient;
R – correlation coefficient.

The increase of the velocity coefficient λ caused the decreasing of the cutting force for both examined vegetables. The lowest values of cutting force – 131 N (pumpkin) and 115,2 N (red beet) were recorded for the highest value of velocity coefficient λ (54,8). However the cutting force and its components has higher values when cutting pumpkin samples than the same when cutting red beet samples. The differences between the values of cutting forces of these products are due to the differences in their structure and morphology. The higher rigidness of pumpkin in comparison with the rigidness of red beet is related to its higher value of osmosis pressure in the cells, higher density of parenchyma, higher contents of cellulose, hemicellulose and pectin.

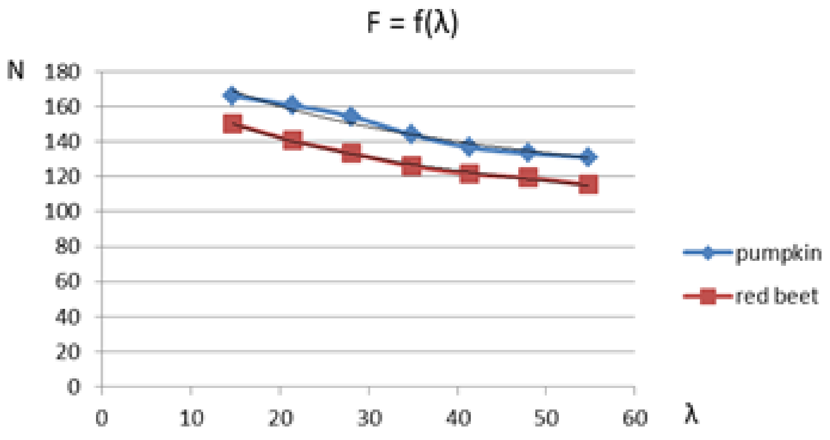

Fig. 3. Relation of cutting force of pumpkin and red beet to velocity coefficient

Conclusions.

The regression equations and regression coefficients were obtained for describing the relation of cutting force and its horizontal and vertical component to velocity coefficient when cutting pumpkin and red beet.

In the range of frequency speed of the disc knife from 110 min^{-1} to 414 min^{-1} and feed rate of the food sample 0,083 m/s were obtained logarithmic relations of cutting force and its components Fx and Fy of pumpkin and red beet to velocity coefficient.

The lowest values of cutting force of pumpkin and red beet - 131 N and 115,2 N respectively were recorded for the highest value of velocity coefficient λ - 54,8.

When the velocity coefficient increases the horizontal component of the cutting force of pumpkin and red beet decreases about three times more intensive then the vertical component. These results are related with characteristics of the process of cutting with disc knife.

The higher value of cutting force of pumpkin in comparison with the cutting force of red beet is related to its higher value of osmosis pressure in the cells, higher density of parenchyma, higher contents of cellulose, hemicellulose and pectin.

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