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Research of The Rheological Properties of Melon as An Elastic Deforming Body

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Abstract— *In article the elastic property of melon's pulp is considered from the point of view of the physical laws of the mechanics. In a basis of judgements are applied the laws of Hook-Newton which are included in mathematical model by consideration of elastic - viscous properties of the Central Asian sorts of melon. The basis for the analytical description of model of a vegetative material on time, decompression of pressure(voltage) is incorporated by using mechanical processing of melon.*

Index Terms *melon's pulp, removal (distance) bark, cutting, processing, deformation, mathematical model, differential, equation.*

i. INTRODUCTION

As you know, Uzbekistan melon varieties have a peculiar elastic-viscous property, which must be taken into account when mechanically removing the peel from the surface of the fruit when harvesting dried melon [1], [2]. This is necessary for the correct choice of cutting conditions, the selection of processing tools and the preparation of an adequate mathematical model of this process.

ii. MATHERIALS AND METHODS

To study the elastic properties of many materials, Hooke's law based on spring deformation is acceptable, and the viscosity properties are in the form of a cylinder with a liquid, described by Newton's law [3]. Serial and parallel connection of these elements allows mathematically simulating the deformation of materials of plant origin.

Based on the assumption made, the model of plant material, for example, melon pulp, is as follows (Fig.1).

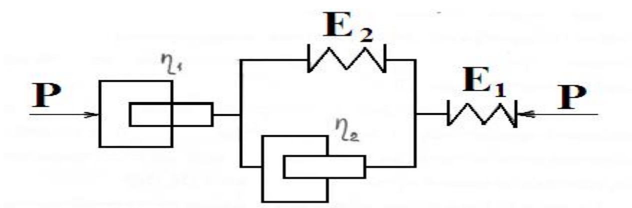

Fig. 1. The technological scheme of the model of plant material

In this case, the total strain ε is the sum of the strains of each element

$$\varepsilon = \varepsilon_1 + \varepsilon_2 \qquad (1)$$

Deformation of an elastic element obeying Hooke's law

$$\sigma_1 = \varepsilon_1 \cdot \mathrm{E} \qquad (2)$$

where is the E-modulus of elasticity.

Viscous fluid flow according to Newton's law

$$\sigma_2 = \eta \cdot \frac{d\varepsilon_2}{dt} \qquad (3)$$

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where η is the coefficient of dynamic viscosity of the fluid (coefficient of internal friction).

With that said, the equation will be true

$$\frac{d\varepsilon}{dt}=\frac{\sigma}{\eta}+\frac{1}{\mathrm{E}}\cdot\frac{d\sigma}{dt} \qquad (4)$$

Flat $\varepsilon = const$ and, integrating the equation, in the range from σ to σ_0 and 0 to t, we obtain the law of change in voltage over time

$$\sigma=\sigma_0\cdot e^{\frac{-E_1}{\eta}} \qquad (5)$$

Here $\frac{E}{\eta}$ represents the relaxation time and at $\frac{E}{\eta}=\infty$, voltage σ will be zero, that is, provided $\varepsilon = const$ and constant strain we have

$$\frac{d\varepsilon}{dt}=\frac{\sigma}{\eta} \qquad (6)$$

This mathematical model (Maxwell's body) behaves like a viscous fluid and illustrates the duration of the force, when, if the duration is short, then the material behaves like a solid (Hooke's body).

Thus, the mathematical model contains three series-connected elements: element E_1 of instant elasticity, element E_2 of retarded elasticity, connected in parallel with the element of viscosity η_2 and flow element η_1, connected with the first two in series, characterizes the properties of the behavior of fibrous materials under load.

If we assume that the deformation of each of the elements E_1 and E_2 in this model obeys Hooke's law, and the elements η_1 and η_2 - Newton's law, it can be applied when considering the process of deformation of viscoelastic materials under load.

An analytical description of the plant material model is reduced to solving a differential equation of the form

$$T\cdot\sigma+H\cdot\sigma+K\cdot\sigma=\eta_2\cdot\varepsilon+E_2\cdot\varepsilon \qquad (7)$$

where T, H, K are some constants whose values are defined as:

$$T=\frac{\eta_2}{E};H=1+\frac{E_2}{E_1}+\frac{\eta_2}{\eta_1};K=\frac{E_2}{\eta_2} \qquad (8)$$

An analysis of the solutions of particular cases of equation (7) allows one to establish to what extent the adopted model has the properties of an elastic-viscous material, in particular, creep and stress relaxation phenomena.

If at time $t=0$ strain strain begins to act, then equation (7) takes the form

$$\sigma=\eta_1\cdot(\frac{\eta_2}{E_2}\cdot\frac{d^2\varepsilon}{dt^2}+\frac{d\varepsilon}{dt} \qquad (9)$$

The solution of this equation gives the dependence of the change in strain over time, which is called the creep equation

$$\varepsilon=\sigma\left[\frac{1}{E_1}+\frac{1}{E_2}(1-e^{-kt})+\frac{t}{\eta_2}\right] \qquad (10)$$

On condition $\varepsilon = const$ the right side of equation (7) vanishes, i.e.

$$T\cdot\sigma+H\cdot\sigma+K\cdot\sigma=0 \qquad (11)$$

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The general solution to this equation is

$$\eta = Ae^{-\alpha_1 t} + Be^{-\alpha_2 t} \qquad (12)$$

and the analytical equation will be written as

$$\alpha^2 + \frac{H}{T}\alpha + \frac{K}{T} = 0 \qquad (13)$$

Arbitrary constants A and B of equation (12) are determined from the initial conditions for $t = 0$

$$A = \varepsilon \frac{E_1^2(\frac{1}{\eta_1} + \frac{1}{\eta_2}) - \alpha_2 E_1}{\alpha_1 - \alpha_2} \qquad (14)$$

and

$$B = \varepsilon E_1 - A \qquad (15)$$

From equations (14) and (15) it follows that A and B depend on the final strain ε.

The solution of equation (11) gives the dependence of stress relaxation, the analysis of which at $t = const$ shows that it matters $\sigma = A + B$. As t increases, the voltage decreases exponentially.

Based on these theoretical propositions, we developed and manufactured a device for determining the mechanical properties of melon fruits, by analogy with a device for determining the properties of apples [4]. The device consists of a fixed table, stand, movable carriage, fixed table, load device and a device for recording the magnitude of the load and deformation. As load sensors were used: cylinders of various diameters, a wedge-shaped strut with an angle α=15° and a width of 10 mm, a plate with a cross section S=9 см^2, and interchangeable knives 100 mm wide, 1.2 thick; 1.4; 2.0; 2.2 mm and a sharpening angle of 12 ° when tilting the blade 30°, 45° and 60°.

The analysis of the working process of cutting when cutting the peel, cutting the fruit into slices was subjected to the fruits of melons of the varieties: Ak-Uruk, Ich-Kizil and Assate.

I. EXPERIMENTAL RESULTS

The results of experiments to determine the size and mass characteristics of the melon fruit of the Ak-Uruk variety are presented in Table 1. [5].

Table 1. Size and mass characteristics of melon fruit

№	Name of indicator	Units	Numerical values
1	Fetal mass (average)	kg	6.18
	Standard deviation	kg	0.873
	The coefficient of variation	%	32.8
2	Fetal Length (Medium)	mm	297
	Standard	mm	28,4

	deviation		
	The coefficient of variation	%	15.9
3	Fetal Diameter (Medium)	mm	191.5
	Standard deviation	mm	15.36
	The coefficient of variation	%	14.8
4	Diameter of the seminal cavity	mm	94.2
	Standard deviation	mm	6.8
	The coefficient of variation	%	14.2

The residual deformation on the fruits, depending on the current load when a cylinder with a diameter of 50 mm and a length of 60 mm is introduced into the body of a melon, is shown in Fig. 2.

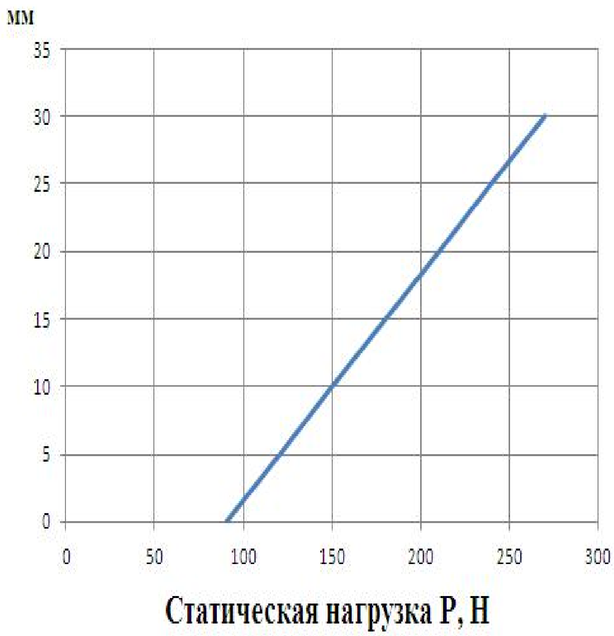

Fig. 2. Residual deformation under the influence of a static load on the melon fruit of the working surface in the form of a cylinder with a diameter of 50 mm and a length of 60 mm

As can be seen from the graph, it obeys a linear dependence, which is described by an equation of the form

$$\varepsilon = -3{,}44 + 0{,}037P, мм \qquad (16)$$

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In fig. 3 shows a diagram of the specific tensile strength at a pressure of a plunger with an area of 1 cm2 from the pulp side.

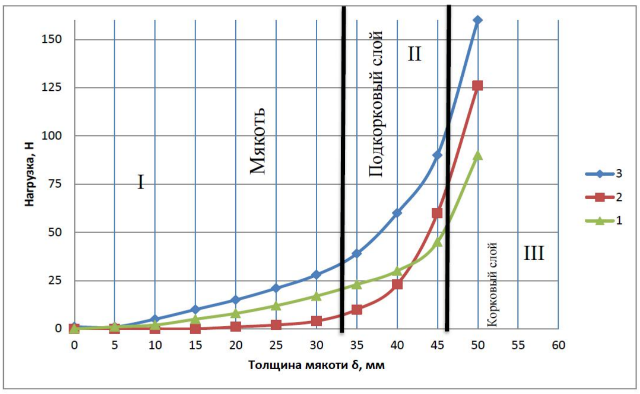

Fig. 3. The diagram "load-deformation" to determine the hardness of the pulp with the peel from the side of the seminal cavity: 1-Ak-Uruk; 2-Ich-Kizil; 3-Assate

Three characteristic zones are highlighted in the diagram:

I zone (approximately 80% of the thickness) - zone of low strength;

II zone - zone of increasing the strength of the pulp layer;

Zone III – zone of high strength – cortical layer.

Obviously, the III zone is a cut-off layer of the peel to be removed during mechanical processing.

In fig. Figure 4 shows the dependence that determines the value of the static insertion force of a wedge with a sharpening angle at the top of 15° into the fruit to the depth of the pulp, subcortical layer and cortical layer of melon fruits of different varieties.

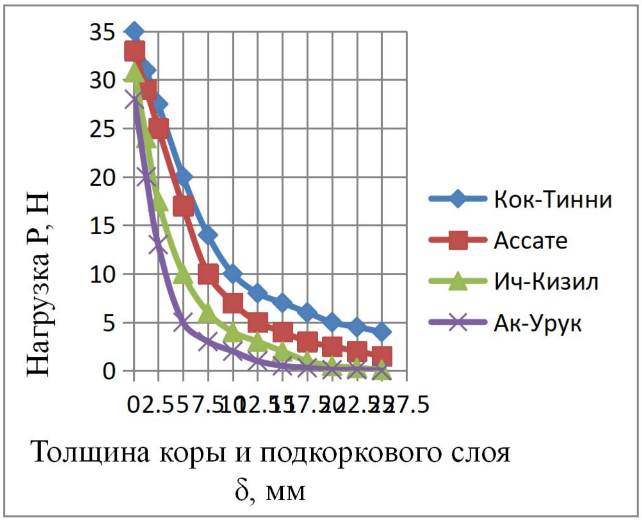

Fig. 4. The force of static cutting a wedge with a sharpening angle of 15 ° into the body of a melon

The data obtained are approximated by equations of the form:

For the Ak-Uruk variety

$$P = 27{,}45 \cdot \delta^{-0{,}903}, H \qquad (17)$$

For Ich-Kizil

$$P = 41{,}04 \cdot \delta^{-1{,}028}, H \qquad (18)$$

For grade Assate

$$P = 70{,}66 \cdot \delta^{-1{,}051}, H \qquad (19)$$

The obtained dependences show that with an increase in the thickness of the studied layer, the force of cutting a wedge into the body of a melon fruit significantly decreases. Particularly noticeable differences when embedding in the subcortical layer. At the exit from the subcortical layer and the introduction of the wedge into the pulp of the fetus, the value of the resistance to penetration into the material practically does not change. For the studied melon varieties, the thickness of the cut layer can be recommended within $\delta = 8 - 12 мм$.

iii. CONCLUSION

Thus, the results of experimental studies confirm the adequacy of theoretical judgments. The results can be very useful in the development of technical means for machining melon fruit.

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