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PHYSICAL CHARACTERISTICS AND MODELING OF SOUR CHERRY FRUIT BY GEOMETRIC FEATURES

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Abstract: *Sour cherry is one of the most common and the most ancient fruit crops in the world due to the availability of anthocyanins and flavonoids in its composition which explain its healing and tonic properties. Along with this, in view of the development of the technical mechanization and automation processes at the enterprises, it becomes expedient to do research aimed at studying some technical characteristics of fruit and their interdependence. It has been found out that sour cherry fruits of different varieties, namely Griot Podbielski, Alfa, Zhadana, Elehantna, Optymistka, Pamiat Artemenko, Chance, Lutovka, Shpanka, have a length and thickness – 10 mm, width – 20 mm, fruit weight – 4.7 g. On the average, by varieties sour cherry fruits have: diameter – 19.5−19.6 mm, projected area – 303.8−320.17 mm^2, surface area −120.67 mm^2, sphericity – 100.9, aspect ration – 1.04; fruit volume − 4036 mm^3. The peeling and lengthening index is 0.95 and 0.97. Specific heat capacity amounts to 3.77−3.79 kJ/kg°C, heat conductivity – 0.56−0.57 kJ/m·c°C, when the content of dry soluble substances is equal to 15.8% and that of titrated acids is 1.7%, pH – 4.1 units, density – 2.7 kg/cm^2 and the light transmittance coefficient is 37.8%. The results of the evaluation of the physical-chemical factors of different sour cherry varieties make it possible to identify the characteristic indicators and their specific features when choosing the equipment for processing companies. The mathematic models to predict sour cherry quality were devised based on the physical indicators.*

Key words: *sour cherry fruit, physical-chemical indicators, weight, surface area, volume, heat capacity.*

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1. Introduction

Sour cherry is one of the most common and the most ancient fruit crops in Ukraine which is successfully grown in various soil-climatic conditions. Its fruits have high taste, as well as healing and tonic properties [7, 22]. They are rich in anthocyanins, flavonoids which add to the red coloring [10, 13].

Also, sour cherry has a considerable content of P-active substances and it is not second to chokeberries, apples, currants [25]. Anthocyanins, 700–2500 mg/100 g, constitute a greater part of these compounds, its quality composition being specific for fruits. Phenol compounds, including anthocyanins, perform protective functions: when tissue is damaged its intensive restoration occurs, the products of oxidative condensations form a protective layer [17].

Sour cherry fruits have a high content of anthocyanins and phenol compounds which together with ascorbic acid show anti-oxidant activity and healing properties [13, 17]. Healing, dietary and tonic properties of this crop result from the availability of vitamin-active compounds. This is why it is necessary for people to have sour cherry fruits in their nutrition the year round.

Quick freezing is one of the techniques of long-term storage of sour cherry fruits. There is one factor which slows down the production of quick-frozen sour cherry fruits and that is the lack of a careful study of the assortment issue of this crop [6, 9].

At the first stage, after harvesting and transportation, sour cherry fruits undergo post-harvest treatment: sorting, processing with anti-microbial and other substances (chitosan, salicylic acid), washing, packaging, storing [12]. It is of great importance to study the issue of physical, thermal, mechanical and chemical properties of sour cherry fruits [16, 24].

Fruit physical characteristics are important when one chooses the equipment for transportation, sorting and packaging [5] and placing the produce into storage. Such indicators as density and shrinkage play an important role in the optimization of the technological processes, namely transportation and packaging [18].

To study fruit physical indicators is a required condition for the development of the equipment for yield harvesting, transportation and post-harvest processing. To study mass, length, width, thickness and volume and fruit surface area is of significance for consumers to choose produce at the market.

Serious fruit damages occur at the transportation stage. In the industrialized countries, including the USA, the standards S 368.4 DECOO:2005 [26]), which include damages of agricultural output, were worked out. According to the data of the food organization [27], quality nutrition is estimated in view of its nutritional value and safety, appearance and freshness of the produce [19].

Textural and rheological fruit properties are the important indicators which influence quality and the conditions of storage and processing. Density is one of the indicators of quality. Density is connected with the phase of ripening, which in turn is accompanied by a combination of changes in physical-chemical characteristics: colour, taste and aroma [15].

Sizes, mass, volume etc. are the physical properties which have an effect on the evaluation system and the carrying out of the technical operations. At present the research has already been done on the physical-mechanical properties of apricots, strawberries, apples [2].

Fruits are classified by the indicators of mass or size which belong to a certain variety [21].

Chemical properties of fruits are the following: the content of dry soluble substances, pH, moisture content, ascorbic acid; they all have an impact on product quality.

The optimization of the equipment and the choice of a process facilitate the loss decrease during transportation and storage. This is the reason why in order to understand fruit technical properties it is required to project processes and equipment for post-harvest processing of agricultural output.

The analysis of a consumer's basket shows that buyers prefer the fruits with even colouring, thick consistency, same shape, size and weight. A sorting technological process gets slower for the fruits of the same shape and weight [14]. So, when sorting it is important to define fruit weight taking into consideration their size and colouring.

To determine the correlation between the indicators of fruit weight and size, physical indicators as well as to work out the model of static data prediction (linear, S – curve, power and quadratic models) are of practical importance [5, 23].

Technical dependencies can be depicted with the help of modelling in the form of regressive dependencies of linear, quadratic, S-curve and power models [2].

A finite element method is applied in many engineering issues to analyse the load of various agricultural products and to model (irregular geometric projects). The method connects finite element modelling of fruit firmness after harvesting with the indicators of physical-chemical characteristics such as dry soluble substances, acidity and pH [2].

However, at present there is a necessity to carry out the research which will study fruit technical characteristics and their dependencies.

The purpose of the paper was to study physical-chemical properties of sour cherry fruits, namely weight, size/shape, colour, thickness, volume, surface area, sphericity and also to present the description of models with physical-chemical and mechanical fruit properties.

The research results can be used to understand the concept of technological processes and to reduce losses in the production process.

2. Materials and Methods

2.1. The Equations Used

In 2016-2023 all sour cherry varieties – Griot Podbielski, Alfa, Zhadana, Elehantna, Optymistka, Pamiat Artemenko, Chance, Lutovka, Shpanka – were harvested at a consumer maturity stage at the experimental horticultural station named after L.P. Symyrenko of the Institute of horticulture of NAAS.

The mass of 100 fruits was determined with the help of the scales with the accuracy of 0.01g (*TBE*) (according to the Methodology of conducting the examination of fruit plants in Ukraine – [11].

To determine the percent content of flesh and pit and their correlation, the Equations (1) and (2) was used [1].

$$Flesh = \frac{Wp}{Wf} \cdot 100 \qquad (1)$$

where:

Flech represents the percentage of fruit [%];

Wp – the weight of the fresh [g];

Wf – the weight of the fruit [g].

$$Bone = \frac{Wb}{Wf} \cdot 100 \quad (2)$$

where:

Bone represents the percentage of the fruit [%];

Wb – the weight of the bone [g];

Wf – the weight of the fruit [g].

Fruit sizes were measured with a micrometer (with the accuracy of 0.01 mm). To determine a size, 100 fruits were chosen randomly from a batch. Sizes were determined by three axes: axis x – large axis – fruit length (*L*), axis y – from a right angle of axis x on a seam plane - width (*W*) and thickness was measured along axis z (*T*). The indicators of mean diameter (*dc*), mean arithmetic diameter (*da*) mm, mean geometric diameter (d_d), mm, were determined according to the Equation (3).

$$d_d = (L \cdot W \cdot T)^{\frac{1}{3}} \quad (3)$$

where:

d_d is the mean geometric diameter [mm];

L – the fruit length [mm];

W – the fruit width [mm];

T – the fruit thickness [mm].

$$d_a = \frac{L+W+T}{3} \quad (4)$$

where d_a is the mean arithmetic diameter [mm].

Other parameters were determined using Equations (5) – (14), and the aspect ratio, the sphericity, the surface area [mm], and the volume [mm^3] were determined according to [23].

$$d_e = \left[\frac{L \cdot (W+T)^2}{4}\right]^{\frac{1}{3}} \quad (5)$$

where d_e is the equivalent mean diameter [mm].

$$\varphi = \frac{(L+W+T)^{\frac{1}{3}}}{3} \cdot 100 \quad (6)$$

where φ is the sphericity of fruits [%].

$$A_r = \frac{W}{L} \quad (7)$$

where A_r represent the aspect ration.

$$f_r = \frac{T}{W} \quad (8)$$

where f_r is the peeling index.

$$E_r = \frac{L}{W} \quad (9)$$

where E_r is the elongation index.

$$P_w = \frac{\pi \cdot W \cdot T}{4} \quad (10)$$

where P_w is the projected area perpendicular to fruit length [mm^2].

$$P_L = \frac{\pi \cdot L \cdot W}{4} \quad (11)$$

where P_L is the projected area perpendicular to fruit thickness [mm^2].

$$P_W = \frac{\pi \cdot W \cdot W}{4} \quad (12)$$

where P_W is the projected area perpendicular to fruit width [mm^2].

$$CPA = \frac{P_L \cdot P_T \cdot P_W}{3} \quad (13)$$

where *CPA* is the criterion of the projected area [mm^2].

$$S_A = \pi \cdot d_g^2 \quad (14)$$

where S_A is the fruit surface area [mm^2].

$$V_{pro} = \frac{4\pi}{3} \cdot \left[\frac{L}{2}\right]^2 \cdot \left[\frac{W}{2}\right] \quad (15)$$

where V_{pro} is the elongated spheroid volume [mm^3].

$$V_{obl} = \frac{4\pi}{3} \cdot \left[\frac{T}{2}\right] \cdot \left[\frac{W}{2}\right]^2 \quad (16)$$

where V_{obl} is the flattened spheroid volume [mm^3].

$$V_{ellip} = \frac{4\pi}{3} \cdot \left[\frac{L}{2}\right] \cdot \left[\frac{W}{2}\right] \cdot \left[\frac{T}{2}\right] \quad (17)$$

where V_{ellip} represent the ellipsoid volume [mm^3] of the fruit.

Fruit thermal characteristics (heat capacity, heat conductivity, temperature conductivity) were determined by established mathematic models, according to Bibwe et al. [4].

Specific heat capacity was defined with help of Equation (18), and other important parameters with Equations (19) and (20).

$$C_p = 1.667 + 0.025 \cdot M \quad (18)$$

where:

C is the specific heat capacity [kJ/kg·°C];
M – the moisture content [%]

$$k = 0.148 + 0.00493 \cdot M \quad (19)$$

where *k* is the heat conductivity [J/m·c·°C].

$$\alpha = \frac{k}{\rho \cdot C_p} \quad (20)$$

where:

α is the heat conductivity [J/m·c·°C];
C – the specific heat capacity [kJ/kg·°C];
ρ – the density [kg/m^3].

2.2. The Chemical Characteristics

Dry soluble substances were determined using a refractometer (PAL-3 ATAGO, Japan), the pH, by using a pH meter, the titrated acids were determined through titration standard DSTU 4957:2008 [8], and the colour was determined on a photo-electro-calorimeter (PEC-2).

The research was conducted in three replications, average values of each sample were determined.

2.3. The Statistical Analysis

The statistical analysis – minimum, maximum, and average values – were calculated with the help of the Excel, Statistica.10 software. The modelling was conducted with the use of linear, quadratic, power, S-curve, exponential models. The model was built based on the data concerning fruit mass. Unprocessed data was used based on the mass models of regression coefficient (R^2), standard error by F test and t test, with a p-value of 0.05.

The model with the highest regression coefficient (R^2) was chosen as the model of optimal mass [19, 21].

3. Results and Discussions

It was found that the average percentage of flesh and pit of sour cherry fruits ranged within 93.06 and 93.4% (Table 1), taking into consideration Equations (1) and (2). It was the lowest for varieties Optymistka (93.06%) and Alfa (92.55%), and it was the highest for varieties Shpanka (93.4%), Pamiat Artemenlo (93.33%) and Elehantna (93.33%) therefore they do not significantly differ from a statistical point of view.

Sour cherry variety Zhadana had the largest pit (7.69%), the Shpanka variety had the smallest one (6.6%). The indicators of sour cherry flesh and pit were calculated; they are necessary for the companies to project and choose equipment to be used for sorting and stoning machines.

Physical properties of cherry fruits Table 1

Variety	Fruit weight [g]	Pit weight [g]	Flesh weight [g]	Percentage of flesh [%]	Percentage of pit [%]
Griot Podbielski	4.6±0.1	0.31±0.12	4.29±0.18	93.26	6.74
Alpha	5.1±0.3	0.38±0.13	4.72±0.20	92.55	7.45
Zhadana	5.2±0.2	0.40±0.14	4.80±0.21	92.31	7.69
Elehantna	4.5±0.3	0.30±0.12	4.20±0.17	93.33	6.67
Optymistka	4.9±0.1	0.34±0.11	4.56±0.19	93.06	6.94
Pamiat Artemenko	4.8±0.2	0.32±0.14	4.48±0.18	93.33	6.67
Chance	4,2±0.3	0.29±0.11	3.91±0.16	93.10	6.90
Lutovka	4.4±0.2	0.30±0.12	4.10±0.14	93.18	6.82
Shpanka	4.7±0.1	0.31±0.12	4.39±0.17	93.40	6.60

Fruit sizes are very important among physical indicators (Table 2). It has been established that the average length values for sour cherry fruits of different varieties differ and on average they are as follows: length - 19 mm, width - 20 mm and thickness - 19 mm. The indicators of average diameter (considering Equations (3) to (5)) will be 19.5 and 19.6 mm. The received indicators are very important when it is necessary to choose sorting and washing machines.

Based on the calculations and Equations (10) to (13), the average area indicators were identified as 303.68, 308.38 and 320.17 mm^2, respectively.

The average fruit surface area was measured and it amounted to 1205.67 mm^2. The area indicators are necessary to estimate the index of ripeness, the index of transpiration intensity and to determine the losses of fruit mass.

By Equations (6) and (7), average sphericity of sweet cherry fruits was 100.9, and aspect ratio – 1.04. So, sweet cherry fruits have a convex spheric rounded form. The indicators of aspect ratio and sphericity influence fruit abscission.

The index of peeling and the index of elongation (Equations (8) and (9)) are shown in Table 2; on average they are 0.95 and 0.97 for sour cherry fruits, respectively. The received indicators are of great importance for choosing a stoning machine.

Physical properties of cherry fruits Table 2

Physical properties	Variety							
	Griot Podbielski	Alpha	Zhadana	Elehantna	Optymistka	Pamiat Artemenko	Chance	Average
Length [mm]	20± 1.82	21± 1.94	22± 1.26	18± 1.43	20± 1.68	18± 1.79	17± 1.63	19
Width [mm]	18± 1.44	21± 1.88	22± 1.27	20± 1.68	21± 1.88	21± 1.84	18± 1.23	20
Thickness [mm]	19± 1.83	20± 1.55	20± 1.83	18± 1.79	20± 1.89	20± 1.74	17± 1.68	19
Geometric mean diameter [mm]	19.0	20.7	21.3	18.6	20.3	19.6	17.3	19.5
Arithmetic mean diameter [mm]	19.0	20.7	21.3	18.7	20.3	19.7	17.3	19.6
Equivalent average diameter [mm]	19.0	20.7	21.3	18.7	20.3	19.6	17.3	19.6
Sphericity [%]	94.9	98.4	96.9	103.6	101.6	109.0	101.9	100.9
Aspect ratio	0.9	1.00	1.00	1.11	1.05	1.17	1.06	1.04
Peeling index	1.06	0.95	0.91	0.90	0.95	0.95	0.94	0.95
Elongation index	1.11	1.00	1.00	0.90	0.95	0.86	0.94	0.97
Projected area perpendicular to the length of the fruit [mm^2]	268.47	329.70	345.40	282.60	329.70	329.70	240.21	303.68
Projected area, perpendicular to the thickness of the fruit [mm^2]	282.60	346.19	379.94	282.60	329.70	296.73	240.21	308.28
Projection of the area perpendicular to the width of the fruit [mm^2]	254.34	346.19	379.94	314.00	346.19	346.19	254.34	320.17
Criteria of the projected area [mm^2]	268.47	340.69	368.43	293.07	335.20	324.21	244.92	310.71
Surface area of the fruit [mm^2]	1131.5	1340.9	1426.2	1091.4	1297.5	1209.51	942.71	1205.7
Volume of the elongated spheroid of the fruit [mm^3]	3768.0	4846.6	5572.5	3391.2	4396.0	3560.7	2722.4	4036.8
Volume of the flattened spheroid of the fruit [mm^3]	3391.2	4846.6	5572.5	3768.0	4615.8	4154.2	2882.5	4175.8
Ellipsoidal volume of the fruit [mm^3]	3579.6	4615.8	5065.9	3391.2	4396.0	3956.4	2722.4	3961.1

It can be seen from Table 2 that the ellipsoidal, elongated and flattened spheroid volume of sour cherry fruits (Equations (15) to (17)) is equal to 3961.04, 4036.77 and 4175.83 mm^3, respectively.

The discovered values of volume, area and average diameters are very important when there is a need to define the rate of heat exchange in the fridge, to dry raw materials, to estimate fruit thickness for packing and storing of the produce.

Physical properties of food products also include thermal properties (Table 3).

Thermal and mechanical properties of cherry fruits Table 3

Properties	Variety							Average
	Griot Podbielski	Alpha	Zhadana	Elehantna	Optymistka	Pamiat Artemenko	Chance	
Moisture content [%]	84.74	84.16	84.46	84.16	84.41	84.10	84.36	84.34
Specific heat capacity [kJ/kg·°C]	3.79	3.77	3.78	3.77	3.78	3.77	3.78	3.78
Thermal conductivity [J/m·c·°C]	0.57	0.56	0.56	0.56	0.56	0.56	0.56	0.56
Thermal conductivity coefficient [m²/s]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15

Fruit thermal properties play the main role in such technological processes as freezing and drying. An important criterion for the estimation of thermal indicators is moisture which is 84.1 - 84.7% for sour cherry fruits. Fruit thermal properties of different sour cherry varieties are shown in Table 3. For instance, the average thermal value of specific heat capacity was 3.77 - 3.79 kJ/kg·°C. For the sake of comparison, lime fruits had a heat capacity equal to 3.861 kJ/kg·°C, it was a bit higher than that of sour cherry fruits. So, they require more heat for cooling.

Heat conductivity is very important in food industry to define the rate of heat transmittance of food products. It has been established that heat conductivity of sour cherry fruits amounts to 0.56 - 0.57 J/m·c·°C. The results of the research data are consistent with [3]. Chemical indicators, together with physical ones, make it possible to find out whether fruits are suitable for storage and processing. The Table 4 shows that the average weight of sour cherry fruits is 4.7 g. The content of dry soluble substances was 15.8%. Active acidity was 4.1 units; it confirms that sour cherry fruits belong to the class of highly acidic products.

Thickness is also important during the transportation of the produce. On the average, it was 2.7 kg/cm^2 in sour cherry fruits.

Colouring defines fruit quality and it has an effect on the consumer's choice of the produce. The coefficient of light transmission of sour cherry fruits was 37.8, on the average.

Physical-chemical properties of cherry fruits Table 4

Properties	Variety									Average
	Griot Podbielski	Alpha	Zhadana	Elehantna	Optymistka	Pamiat Artemenko	Chance	Lutovka	Shpanka	
Dry soluble substances [%]	1.27 ± 0.23	15.8 ± 0.28	15.53 ± 0.34	15.83 ± 0.31	15.63 ± 0.24	15.90 ± 0.26	15.6 ± 0.36	15.5 ± 0.23	17.0 ± 0.38	15.8
pH	4.30 ± 0.10	3.90 ± 0.10	4.29 ± 0.20	3.80 ± 0.10	4.30 ± 0.20	4.40 ± 0.20	4.20 ± 0.20	3.70 ± 0.10	3.70 ± 0.10	4.1
Density [kg/cm^2]	2.5 ± 0.28	2.5 ± 0.23	2.60 ± 0.30	2.80 ± 0.46	2.70 ± 0.28	2.30 ± 0.18	2.70 ± 0.21	3.10 ± 0.28	2.90 ± 0.34	2.7
Color (Light transmit-tance) [%]	42.3 ± 0.23	38.5 ± 0.28	36.2 ± 0.24	34.20 ± 0.26	37.30 ± 0.27	40.9 ± 0.21	36.4 ± 0.23	40.7 ± 0.28	34.0 ± 0.23	37.8
Fetal weight [g]	4.6 0 ± 0.10	5.1 ± 0.30	5.20 ± 0.20	4.50 ± 0.30	4.90 ± 0.10	4.80 ± 0.20	4.20 ± 0.30	4.40 ± 0.20	4.70 ± 0.10	4.7
Titrated acids [%]	1.87 ± 0.05	1.74 ± 0.01	1.90 ± 0.08	1.67 ± 0.03	1.92 ± 0.23	2.02 ± 0.13	1.83 ± 0.03	1.13 ± 0.08	0.92 ± 0.06	1.7

The results of the conducted research are consistent with the results received by Panda et al. [20]; and they give a complete estimation of sour cherry quality concerning a practical application of the obtained knowledge in food industry.

The method of modelling was used to identify the interconnection of the received indicators and to study their effect for the description of the technological processes. The models were developed to predict fruit mass by means of establishing correlation between mass and physical indicators, such as area and volume.

The following was established: the correlation between mass and the indicators of length, width and thickness of a fruit, and also an equivalent average diameter, an average geometric diameter and an arithmetic diameter. Also, the correlation of mass with a surface area, a criterion predicted area, perpendicular to length, width and thickness of fruit, was determined.

The correlation of mass with its ellipsoid volume, elongated spheroid volume and flattened spheroid volume was defined.

The model to predict mass was based on getting four models with physical properties, namely regression, linear, quadratic, and S-curve.

Based on the research, three regression models (Equations (21) to (23)) which can be used for modelling sour cherry fruits, were worked out: linear, quadratic and power (Figure 1 and 2).

$$\mathrm{M} = b_0 + b_1 \cdot x \qquad (21)$$

$$M = b_0 + b_1 \cdot x \cdot x^2 \quad (22)$$

$$M = b_0 \cdot x \quad (23)$$

where:
- *M* is the fruit mass [g];
- *X* the independent change;
- b_0, b_1, b_2 – parameters which are used for a curve.

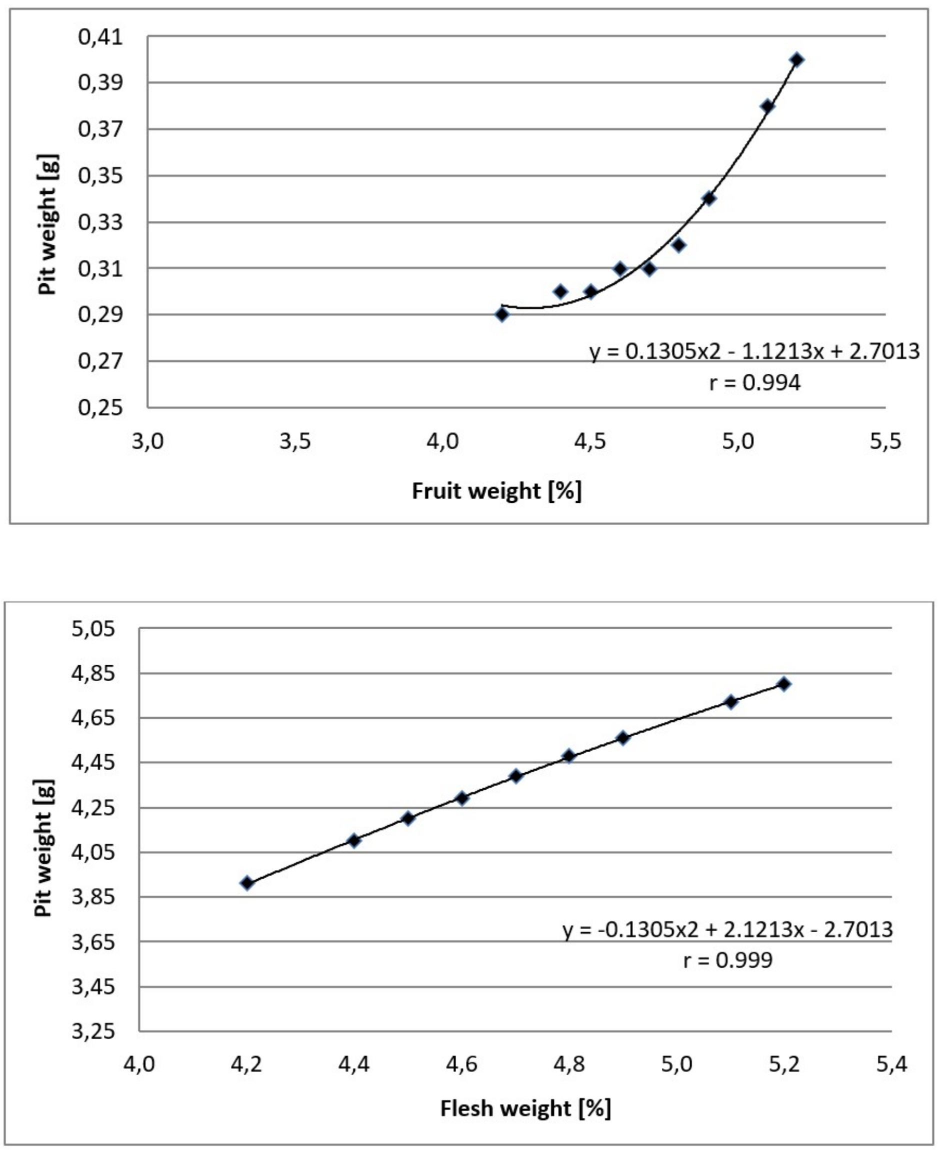

Fig. 1. *Correlation between the weight of the fruit and pulp and the weight of the stone of cherry fruit*

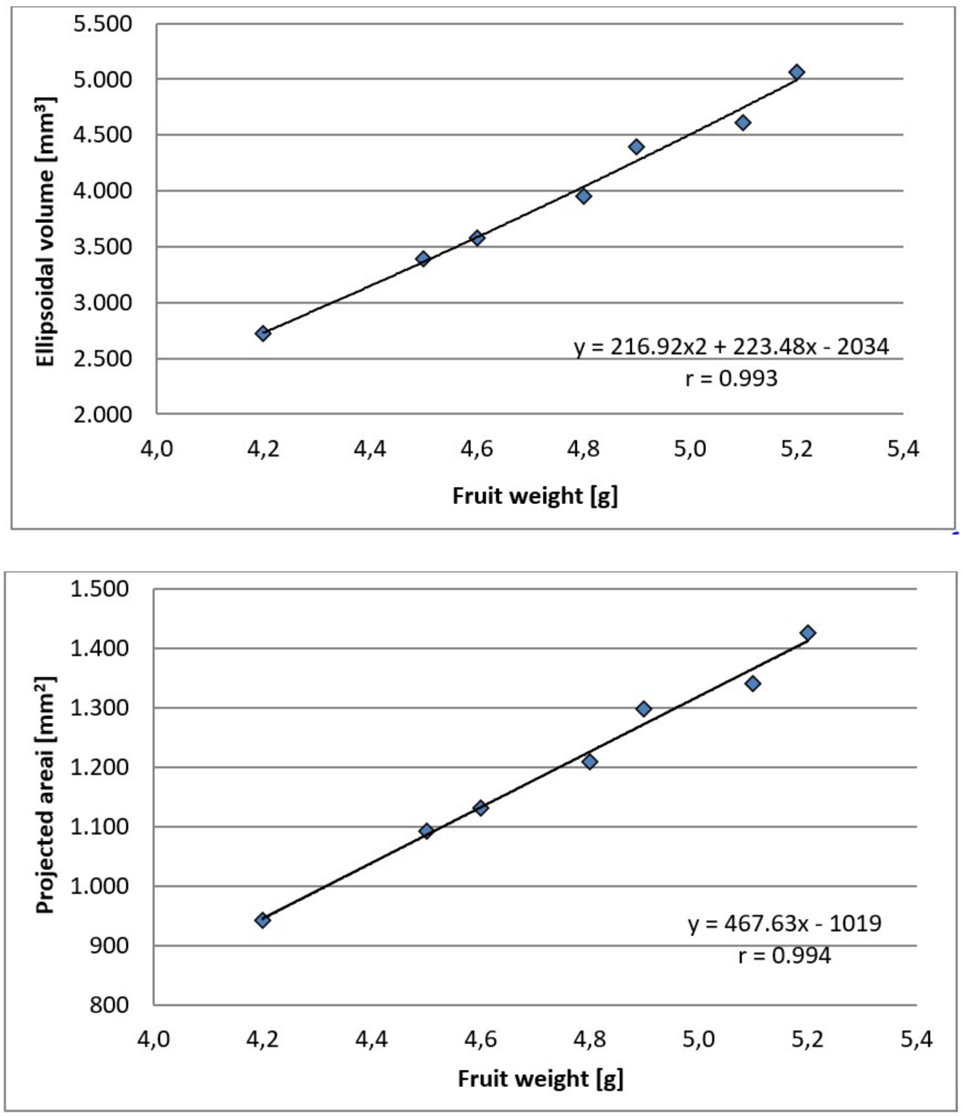

Fig. 2. *Correlation dependence of fruit weight on ellipsoid volume and surface area of cherry fruit*

4. Conclusions:

The estimation results of the physical-chemical indicators of sour cherry fruits enable the discovery of the characteristic indicators and their specific features which are important for processing companies when they choose the required equipment. The mathematic models to predict sour cherry quality were developed based on these physical indicators.

On the average the physical-chemical indicators of sour cherry fruits were the following: length and thickness – 10 mm, width – 20 mm. Fruit weight was 4.7 g.

The average indicators of sour cherry fruits of different varieties are as follows: diameter – 19.5–19.6 mm, projected fruit area – 303.8–320.17 mm^2, surface area –120.67 mm^2, sphericity – 100.9, aspect ratio – 1.04; fruit volume – 4036 mm^3.

The peeling index and that of elongation amounted to 0.95 and 0.97, respectively.

Specific heat capacity was equal to 3.77 - 3.79 kJ/kg·°C. Other indicators were the following: heat conductivity – 0.56 to 0.57 kJ/m·c·°C, content of dry soluble substances - 15.8% and that of titrated acids - 1.7%, pH - 4.1 units, thickness - 2.7 kg/cm^2 and coefficient of light transmittance - 37.8%.

The model used , quadratic and the value of r^2 (0.988; 0.998; 0.986) and linear r^2 (0.988).

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