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Investigation into sugars accumulation in sweet cherry fruits under abiotic factors effects

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Abstract. The level of sugars content in sweet cherry fruit depends on many factors. However, the decisive influence of weather factors is noted. In view of this, the issue of predicting the sugars content in sweet cherry fruit depending on the share of weather factors is relevant for further improvement of transportation technology, storage and processing.
It has been established that according to sugars content and to the variability of their formation the most perspective from the technological point of view were varieties: Zabuta (12.47%), Dachnytsia (15.60%), Krupnoplidna (14.35%). Low and medium variabilities of the selected varieties according to the investigation years were established (Vp = 8.6%–13.0%). It has been shown that weather conditions had dominating effects on sugars accumulation for all varieties groups irrespective of the ripening period. According to the results of a two-factors dispersion analysis it is expedient to prognosticate the sugars content in sweet cherry fruits by medium values for a particular group of sorts but not for each pomological sort.
In the course of the work the average and strong correlation dependence between 14 weather factors (X_i, i = 1..14) and the sugars content for sweet cherries of early, medium, and late ripening period ($\left|r_{Y_j X_i}\right| \geq 0.55,\ i = 1..14,\ j = 1..3$) were defined. The ranges of share of weather factors participation that have the maximum influence on sugars fund formation in sweet cherry fruit are established (Δ_i 9.50% to 30.99%).
Based on regression analysis, it is substantiated that the sugars accumulation in sweet cherry fruit, regardless of the ripening period, is most influenced by weather conditions of the blossoming period, the last month of fruit formation and thermal parameters and humidity index at the stage of fruit picking.

Key words: fruits, sweet cherry tree, weather conditions, total sugar content, simple sugars, saccharose, connection, correlation.

INTRODUCTION

Fruits are of great importance in people's nutrition (Einhorn 2013; Khadivi-Khub, 2015). They are the sources of biologically active and mineral substances, enzymes, carbohydrates, organic acids which are supplied into the organism (Fallahi, 2017;

Serdyuk et al., 2020). The fruits chemical composition is not constant and has its accumulation peculiarities as to the sorts of various ripening periods. The chemical composition is constantly changing in the process of their growing, ripening and depends on a number of factors: variety, sort, rate of ripening, period of ripening, product treatment, conditions and period of storing etc (Koumanova et al., 2016; Dziedzic et al., 2017; Wenden et al., 2017; Lafuente et al., 2018). But it should be mentioned that a negative impact of abiotic factors has a great influence on the formation of the main components of chemical composition. Thus, it is necessary to study the accumulation of the basic biochemical parameters of sweet cherry fruits of different periods of ripening and to select the best sort-samples for further storing and processing; for studying the mechanism of formation of the basic components of fruits chemical composition under the influence of stress abiotic factors and a degree of their impact on the accumulation of fruits basic quality parameters. A considerable attention is paid by the scientists from many countries to the problems and prospects of growing cherries as well as improving the fruits quality of early, middle and late ripening varieties (Jänes et al., 2010; Kask et al., 2010; Sîrbu et al., 2012).

It is well known that the excellent gustatory qualities of sweet cherry fruit is directly correlated with a high content of dry soluble substances. Ranges of dry soluble substances according to Ukrainian and foreign researchers (Long et al., 2008; Basanta et al., 2014; Serdyuk et al., 2020) range from 12.1–19.9%. The main part of dry soluble substances are carbohydrates. They are the primary products of photosynthesis and the main derivatives of the biosynthesis of other substances in fruit crops. In particular, carbohydrates form cell membranes and other structures, take a reaction in the organism's protective reactions, and form immunity. It is carbohydrates that provide nutritional value and special gustatory qualities of the fruit. The level of carbohydrates accumulation in the dry substances can change under the influence of soil and weather conditions, and the degree of fruit ripeness (Slavin & Lloyd, 2012; Wang & Einhom, 2017; Yevlash et al., 2019). Carbohydrates are 70–80% formed by sugars, which are most often represented in fruit raw materials by monosaccharaides - fructose and glucose, disaccharide-sucrose. The complex of monosaccharaides in the fruit of stonecrops exceeds the content of other components in the dry soluble substances (Serdyuk & Stepanenko, 2015). It has been established that fruits sweetness depends on sort characteristics, ripening periods, place of growing etc. (Slavin & Lloyd, 2012; Basanta et al., 2014). The content of monosaccharaides and disaccharides depends on the growing area. As the culture progresses from the north to the south, the sugars content in the fruit of the same varieties usually increases. Thus, in the southern regions of the world, the fruit of the best varieties of sweet cherries contain dry soluble substances - 12.1–23.5%, total sugars - 12.4–17.7%. The content of sugars in sweet cherry fruit grown in the south of Ukraine ranges from 12.82 to 15.00% (Yevlash et al., 2019; Ivanova et al., 2019).

A number of authors have established that during the years with a maximal precipitation there were less dry substances in fruits, including those of sugars, but more acids. In dry years the total volume of nutrients in fruits was low, but the volume of sugars increased due to the decrease in humidity level (Bizjak et al., 2013).

Thus, the level of sugars content in sweet cherry fruits, their accumulation and further storing depend on many factors. That is why, the tasks which have not been solved within this problem are: for different regions, where fruits are grown, the degree of biochemical indices accumulation is different, the potential of sugars accumulation in varieties of different ripening periods and the impact degree of stress climatic factors are different as well. There are no data as to the degree of impact of stress weather factors on sugars formation in sweet cherry fruits in terms of different ripening periods and which were grown under conditions of a Southern Steppe Subzone of Ukraine. It has conditioned the purpose of our research. With this in mind, the problem of sugars content prognostication in sweet cherry fruits depending on the degree of weather factors impact by using a Method of Principal components (Kelechi, 2012) is topical for a further improving of the technology of fruits transportation, storing and processing.

MATERIALS AND METHODS

The goal of the research was to develop a mathematical model in order to improve the sugars content prognostication in sweet cherry fruits depending on weather factors. The received mathematical model can be used under the conditions of the regions with similar hydrometrical parameters of Southern Steppe Zone of Ukraine. The purpose of the research program was to select the sweet cherry varieties of three periods of ripening with high sugars index for maintaining the fruits quality and biological value.

The expedience of sugars content prognostication in sweet cherry fruits by using mean values for a separate varieties group was substantiated by conducting a two-factor dispersion analysis during the research, and the factor which maximally affects the sugars accumulation in sweet cherry fruits has been found out as well.

To realise the goal, it was necessary to solve the following problems: to analyse the weather conditions for fruits formation; to determine the mass fraction of sugars in sweet cherry fruits in the period of economic maturity as to each period of fruit ripening; to select the best varieties according to test-index; to determine the interconnections between the processes of sugars accumulation and stress weather factors; to develop he mathematical models of sugars content dependence on weather factors; to analyse the developed model in order to determine the degree of each factor's impact on sugars fund accumulation in sweet cherry fruits of three periods of ripening.

The research was conducted during 2008–2019. Daily meteorological data of Melitopol meteorological station, Ukraine, were used. Horticultural farms of the study region are located in the Southern steppe subzone of Ukraine. The landscape of the territory is flat with an Atlantic-continental climate and a high temperature regime. The range of average annual air temperature is 9.1–9.9 °C. The average monthly air temperature in the warmest months ranges from 20.5 to 23.1 °C. The sum of active temperatures above 10 °C from April to October is 3,316 °C. The average annual precipitation is 475 mm. The region in terms of precipitation belongs to the area with insufficient humidification. The average annual relative humidity is within 73%. The average annual wind speed is 3.7 m s^{-1}. The climate is arid with the dominance of dry east and northeast winds. The value of the hydrothermal coefficient is in the range of 0.22–0.77 (Serdyuk et al., 2020).

The agrophone at the experimental sites during all research years met the requirements of agricultural technology (Table 1). The accumulation of moisture in the soil occurs mainly in autumn, partly in winter and early spring. The soils of the experimental sites where the culture is grown are light loam black soil. Soil-forming solid is forest. This type of soil in terms of grain size composition has a high content of physical sand.

Table 1. Agrochemical characteristics of soil

Type of soil	Depth of arable layer, cm	Humus content, %	pH of salt extract	Nutrient content, mg kg^{-1} of soil		
				Easily hydrolyzed nitrogen (N)	Mobile phosphorus (P_2O_5)	Potassium exchange (K_2O)
Light loam black soil	40.0	1.38	6.9	27.0	90.0	154.0

Sweet cherry fruit of 33 varieties were selected for the study, which are divided into three groups according to the ripening period: Group 1 - 7 varieties of early ripening period - Sweet Erliz, Merchant, Bigaro Burlat, Rubinova Rannya, Valeriy Chkalov, Kazka, Zabuta; Group 2 - 13 varieties of medium ripening perio - Kordia, Octavia, Vinka, Pervistok, Temp, Uliublenytsia Turovtseva, Talisman, Dilemma, Melitopolska Chorna, Orion, Chervneva Rannia, Dachnytsia, Prostir; Group 3 - 13 varieties of late ripening period - Karina, Regina, Mirazh, Krupnoplidna, Udivitelna, Zodiak, Surpriz, Kolkhoznytsia, Kosmichna, Prazdnichna, Anons, Temporion, Meotyda.

To determine the sugars content, a sample was taken for each pomological variety from 100 fruit from 6 trees that came into full fruiting. Trees typical of a certain pomological variety, of the same age, with a medium intensity of fruiting were selected for the research. A threefold repeatability. The trees were planted in 2010 on the pattern 5×3, row spacing's were under black fallow Fruit were weighed and counted directly at harvest time (Serdyuk et al., 2020).

The sweet cherries fruits of each pomological sort were carefully picked on a stage of economic maturity when the fruit pulp is firm, but the flavor and the color are typical for a given pomological sort.

The fruits were picked from the trees from four different sides of a crown. The fruits from each pomological variety were of the first commercial sort and picked with fruit-stalks. The date of picking fruits will be established according to the following quality indices of sweet cherry fruits: visual appearance (fruits analysis in terms of form and colour which must be typical for a given pomological variety, fruit-stalk availability, determining the rate of mechanical damages of fruits, their infestation with pests and fungus diseases), the fruits size in cross-section diameter. The fruits were stored and transported to the laboratory, provided that the fruit in the period of the indicator determination had the appearance and taste inherent for the pomological variety.

The content of sugars mass concentration (S, %) was determined by ferricyanide method (Yevlash et al., 2019). The ferricyanide method for determining the mass fraction of sugars is based on the property of reducing monosaccharides to renew ferricyanide potassium - K3[Fe(CN)6] (potassium ferricyanide) to ferrocyanide potassium (ferrocyanide) potassium - K4[Fe(CN)6] (potassium ferrocyanide). Methylene blue is used as an indicatorin alkaline environment. When potassium ferricyanide is restored, the color changes from blue to colorless or light yellow. The amount of sucrose is determined by pre-converting it to invert sugar.

Models construction of sweet cherry sugars dependence on weather factors was carried out according to the following scheme (Ivanova et al., 2019):

1. Determination of sugars content by ferricyanide method.
2. Creation of an information system of weather and climatic factors indicators in the years of research and their analysis. At this stage, the following indicators were

selected: average minimum air temperatures, average air temperatures, average maximum air temperatures, absolute minimum air temperatures, absolute maximum air temperatures, precipitation, average relative air humidity, minimum relative air humidity, absolute minimum relative air humidity.

3. Based on the above-mentioned indicators, the following indicators were calculated: hydrothermal coefficient, temperature differences for certain periods, the sum of active temperatures, the sum of effective temperatures.

4. To select weather and climatic factors that are the most meaningful ones which influence the research indicator we used the test of statistical hypothesis about the meaningfulness of calculated coefficients of correlation between factors and sugars content indicator in sweet cherry fruit. We checked the statistical hypothesis according to Student's test.

5. The share and degree determination of each of the factors influence selected in item 4 by studying the regression model constructed on the basis of the principal components analysis.

Correlation analysis (calculation of paired correlation coefficients and verification of their significance) is the initial stage of the analysis, which allows to identify the most significant influencing effects. The analysis of correlation coefficients gives a basic picture and allows selecting those factors, which most strongly correlate with the studied indicator.

However, other, more accurate methods of analysis should be used to compare the degree of factors influence between themselves and rank them in order of influence.

On the other hand, when constructing a regression model by method of least squares, we encounter the problem of the limited number of experiments, which directly depends on the number of years of research.

Due to the fact that the number of studied factors significantly exceeds the number of years of research, it is not possible to apply the classical regression analysis scheme.

Another important reason that imposes restrictions on the possibility of using the classical approach of regression analysis is the strong correlation of factors between themselves, which leads to the effect of multicollinearity and violation of the premises of the Gauss-Markov theorem (Damodar, 2004).

Therefore, it is suggested to use the principal components analysis (PCA) for constructing a regression model under conditions of a significant excess of the number of independent variables over the number of experiments.

Based on the principal components analysis, fictitious factors (principal components ($PC_i,\ i = 1 \dots n$), which are a linear combination of the initial factors, are constructed. An important advantage of the principal components is the fact that they provide maximum variance and at the same time weakly correlate with each other (Kelechi, 2012; Chen & Ma, 2015).

Thus, the research is suggested to be carried out according to the following algorithm:

1. Based on the experimental data $x_{ij}, (i = 1 \dots n-$ is the number of the weather factor, $j = 1 \dots m$ is the number of the year of study), we constract the set of principal components($PC_i, i = 1 \dots n$) in the form

$$PC_i = \sum_{j=1}^{m} p_{ij} \cdot x_{ij},\ i = 1 \dots n, \qquad (1)$$

2. We single out a set of principal components ($PC_i, i = 1 \dots k$), which provide a cumulative variance of 90%.

3. Using the method of least squares, we construct the equation of the test parameter Y dependence (sugars content in sweet cherry fruit) on the principal components in the form

$$\hat{Y} = b_0 + \sum_{i=1}^{k} b_i \cdot PC_i, \quad (2)$$

4. We carry out the transformation of the model by substituting the expression of the principal components into the equation (2), through the initial set of factors and obtain the equation of the sugars content dependence in sweet cherry fruit on the indicators of the initial weather and climate factors of the form:

$$\hat{Y} = a_0 + \sum_{j=1}^{n} a_j \cdot X_j, \quad (3)$$

where X_j – are factors; a_j – model parameters; $\hat{Y}$ – an indicator of sugars content in sweet cherries.

5. We carry out the analysis of the constructed regressions (3) in order to determine the influence degree of each of the factors on the resulting indicators. To estimate the share of the influence of individual factors in the total effect of all factors, we use the delta coefficients Δ_j.

The coefficients Δ_j are determined according to the formula:

$$\Delta_i = \left| \frac{\tilde{a}_i \cdot r_{yx_i}}{R^2} \right| \quad (4)$$

where $\tilde{a}_i$ – parameters of the regression model in standardized factors $\tilde{X}_i$; r_{yx_i} – pair correlation coefficients; R^2 – coefficient of determination.

To make the statistical analysis, we used means of up-to-date computer technologies DataMining – the softwear environment RStudio.

RESULTS AND DISCUSSION

The average sugars content in sweet cherry fruits of 33 varieties under study, grown under conditions of an analyzed region of Ukraine was on the level of 12.63% (Table 2). A maximal average sugars content on the level of 12.85% was registered in sweet cherry fruits of a varieties group of an early ripening period of Sweet Erliz sort. Among the varieties of two other groups the fruits of Talisman, Kordia, Oktavia, Krupnoplidna, Meotyda varieties were characterised by the highest average sugars content. They accumulated 14.59–13.78% of sugars. The results of the research point at a high variability of sugars content according to the years of study in a varieties group of an early period of ripening. The varieties Rubinova Rannia and Valeriy Chkalov were exposed to the greatest impact of abiotic factors (with variation coefficients 24.6 and 23.6% respectively) on the sugars content in the fruits of a given group. The most resistant as to sugars content are Zabuta, Merchant and Bigaro Burlat varieties. The variation coefficients are in the range of 13.0–15.6%. The variability of these varieties as to sugars content under the weather factors impact is considered to be medium. The variability of sugars content in sweet cherry fruits of varieties group of a medium period of ripening according to the years of study was high (*Vp* = 20.6%). The variability coefficient for the fruits of a late period of ripening as to sugars content was on a medium level (Vp = 19.0).

Table 2. Sugars content in sweet cherry fruits of three periods of ripening, % (2008–2019), $\bar{x} \pm s\bar{x}$, n = 5

Pomological variety	Average sugars content, %	Min sugars content, %	Max sugars content, %	Variation according to years, Vp, %
Early peirod of ripening				
Rubinova Rannia	12.35 ± 3.04	8.22	15.87	24.6
Valeriy Chkalov	12.55 ± 2.96	8.56	15.94	23.6
Sweet Erliz	12.85 ± 2.83	9.52	16.91	22.1
Merchant	10.55 ± 1.64	8.21	12.56	15.6
Kazka	11.63 ± 2.03	8.65	14.17	17.4
Bigaro Burlat	11.11 ± 1.68	8.15	13.05	15.1
Zabuta	12.47 ± 1.62	9.58	14.58	13.0
Average value	11.93 ± 2.39	8.15	16.91	20.0
LSD_{05}	0.764	–	–	–
Medium period of ripening				
Vynka	12.24 ± 2.42	8.35	16.39	19.8
Pervystok	12.40 ± 2.94	7.98	17.81	23.70
Temp	13.16 ± 3.00	7.55	17.51	22.8
Uliublenytsia Turovtseva	10.82 ± 1.36	8.78	13.65	12.6
Talisman	14.59 ± 1.59	12.61	17.91	10.9
Dilema	12.86 ± 1.99	9.02	15.21	15.5
Melitopolska Chorna	11.16 ± 2.76	9.00	16.81	24.7
Kordia	13.79 ± 2.37	9.56	17.21	17.2
Oktavia	13.78 ± 2.87	9.02	17.45	21.4
Orion	13.43 ± 2.09	9.65	16.88	15.5
Chervneva Rannia	11.00 ± 1.48	8.27	14.54	13.50
Dachnytsia	15.60 ± 1.35	13.53	17.67	8.6
Prostir	12.67 ± 3.36	7.98	17.84	26.6
Average value	12.85 ± 2.64	7.55	17.91	20.6
LSD_{05}	0.363	–	–	–
Late period of ripening				
Krupnoplidna	14.35 ± 1.77	10.20	16.51	12.3
Karina	12.53 ± 1.97	9.56	17.21	15.7
Regina	11.90 ± 2.05	9.06	15.22	17.2
Mirazh	13.89 ± 2.67	9.24	17.21	19.2
Udivitelna	13.03 ± 2.75	8.31	18.21	21.08
Zodiak	13.14 ± 2.48	9.12	16.56	18.8
Surpryz	13.43 ± 2.30	9.21	17.56	17.11
Kolhoznytsia	12.64 ± 2.67	8.51	17.21	21.0
Kosmichna	13.55 ± 2.81	8.11	16.98	20.72
Prazdnichna	12.73 ± 2.45	8.15	17.05	19.3
Anons	12.36 ± 2.62	7.86	17.42	21.2
Temporion	12.82 ± 2.95	8.96	17.95	23.0
Meotyda	14.05 ± 2.76	7.96	17.45	19.6
Average value	13.11 ± 2.50	7.86	18.21	19.0
LSD_{05}	0.532	–	–	–

Among the varieties group of a medium period of ripening the most stable sugars content was in the fruits of Dachnytsia variety (Vp = 8%), and the most variable one in Prostir variety (Vp = 26.6%). In the varieties group of a late period of ripening the highest variability in sugars content was registered in fruits of Temporion variety (Vp = 23.0%), and the lowest one in Krupnoplidna variety (Vp = 12.3%).

Thus, according to the sugars content and the variability of their formation under the weather factors impact under the analized region conditions, the most perspective from technological point of view were Zabuta variety (of an early period of ripening), Dachnytsia (of a medium period of ripening) and Krupnoplidna (of a late period of ripening). These varieties differed in high sugars content and in their low variability during the years of study.

A two-factors dispersion analysis (Table 3) was made in order to establish the degree of weather factors impact as well as of sort characteristics on sugars fund formation in sweet cherry fruits. As follows from the results of the research, weather conditions during the years of the study (Factor A) had a dominating impact on sugars formation for all varieties groups irrespective of a period of ripening. The degree of impact of (Factor A) for varieties groups under study equaled from 74.5% to 61.9%. The impact of sort characteristics (Factor B) was less significant. The degree of this factor's impact was from 3.1% to 12.4% for a group of varieties which were analized by M. Ye. Serdyuk, I. Ye. Ivanova et al. (2020).

Table 3. Results of two-factors dispersion analysis under sugars fund formation in sweet cherry fruits

Source of variation	Sum of squares	Degree of freedom	Dispersion	F_{fact}	$F_{table\ 095}$	Impact, %
Sweet cherry varieties group of an early period of ripening						
Factor A (year)	2,074.4	11	188.6	2,892.5	1.8	74.5
Factor B (variety)	346.2	6	57.7	885.0	2.2	12.4
Interaction AB	351.4	66	5.3	81.7	1.4	12.6
Sweet cherry varieties group of a medium period of ripening						
Factor A (year)	3,226.4	11	293.3	3,753.0	1.8	61.9
Factor B (variety)	409.7	12	34.1	436.9	1.8	7.9
Interaction AB	1550.5	132	11.8	150.3	1.3	29.7
Sweet cherry varieties group of a late period of ripening						
Factor A (year)	3,254.9	11	295.9	1,947.6	1.8	69.4
Factor B (variety)	144.6	12	12.0	79.3	1.8	3.1
Interaction AB	1237.2	132	9.4	61.7	1.3	26.4

Thus, according to the results which were received, the prognostication of sugars content in sweet cherry fruits by medium values for a particular varieties group but not for a separate pomological sort has been shown to be expedient.

Then, the presence of correlation connections between the sugars fund accumulation indicator in the sweet cherry fruit of early (Y_1), medium (Y_2), late (Y_3) ripening period, and a set of weather conditions (factors) - X_i was analyzed.

The most significant factors are selected based on the calculated pair correlation coefficients $r_{Y_1X_i}$, $r_{Y_2X_i}$, $r_{Y_3X_i}$. Then, we test the significance of these correlation coefficients by checking the statistical hypothesis $H_0\colon \rho = 0$ (where ρ is the correlation coefficient of the general totality) with the alternative hypothesis $H_1\colon \rho \neq 0$ at the significance level $\alpha = 0.05$. Verification of the statistical hypothesis is carried out using Student's test. As calculations showed, the significant correlation coefficients at a significance level of 0.05 and the number of degrees of freedom $k = 10$ are within the range [-0.55; 0.55]. As a result, there were selected 14 indicators of weather factors (X_i,) which during the indicated growing season can significantly affect the sugars accumulation in the sweet cherry fruit of early (Y_1), medium (Y_2), and late (Y_3) ripening periods (Table 4).

Table 4. Table of pair correlation coefficients between weather factors (X_i,) and sugars content in early ($r_{y_1x_i}$), medium($r_{y_2x_i}$), and late($r_{y_3x_i}$) ripening periods

Symbol of the (X_i,)	Factors	Paired correlation coefficients $r_{Y_jX_i}$ for group varieties		
		Early	Medium	Late
		$r_{Y_1X_i}$	$r_{Y_2X_i}$	$r_{Y_3X_i}$
X_1	The average temperature in June, °C	-0.534*	-0.664	-0.654
X_2	The difference between the average maximum and minimum temperatures in May, °C	0.520*	0.569	0.359*
X_3	Absolute minimum relative air humidity during blossoming, %	0.965	0.958	0.615
X_4	The absolute maximum temperature during the fruit picking, °C	0.401*	0.464*	0.864
X_5	The amount of precipitation during the blossoming period, %	-0.649	-0.626	-0.284*
X_6	The average temperature in April, °C	0.621	0.705	0.192*
X_7	The total number of days with precipitation in April, %	0.714	0.743	0.414*
X_8	The average maximum temperature during the fruit picking, °C	0.785	0.851	0.546*
X_9	The average minimum relative air humidity during blossoming, %	0.528*	0.637	0.512*
X_{10}	The difference between the average maximum and minimum temperatures in the period of fruit picking, °C	0.624	0.653	0.589
X_{11}	Average temperature per year, °C	-0.581	-0.638	-0.480*
X_{12}	The difference between the absolute maximum and minimum temperatures during the fruit picking, °C	-0.300*	-0.380*	-0.763
X_{13}	The average minimum temperature during the fruit picking, °C	-0.658	-0.720	-0.685
X_{14}	The average temperature in May, °C	-0.588	-0.637	-0.729

*insignificant paired correlation coefficients $\left|r_{Y_jX_i}\right| \leq 0.55,\ i = 1..25,\ j = 1..3$ | (according to the hypothesis of the correlation coefficients significance checking in terms of Student's test at the significance level of 0.05).

These are thermal indexes of air (°C): average temperature of April (X_6), May (X_{14}), June (X_1); the difference between the average maximum and minimum temperatures in May (X_2) and during the fruit harvest (X_{10}); average temperature for the year (X_{11}); absolute maximum temperature (X_4), average maximum temperature (X_8), average minimum temperature (X_{13}), the difference between the absolute maximum and minimum temperatures (X_{12}) during the harvest. Air humidity indexes (%) during the blossoming period are: absolute minimum relative air humidity (X_3), average minimum relative air humidity (X_9) and the amount of precipitation (X_5), as well as the total number of days with precipitation in April (X_7).

Thus, for early, medium, and late varieties, 14 weather factors were determined, for which the average and strong linear correlation dependence with the analyzed indicator - sugars - was established.

Further research is carried out according to the scheme given above.

The first step. Five principal components were identified by the principal components analysis ($PC_i, i = 1..5$). These five principal components provided more than 92.12% of the Cumulative Proportion of Variance.

The second step. Regression models of the sugars indicator dependence for each group of varieties on the principal components ($PC_i, i = 1..5$) of the kind (2) were constructed.

The regression equation for early varieties has the form:

$$\hat{Y}_1 = 11.9533 + 0.6637PC_1 - 0.2324PC_2 - 0.2822PC_3 - 0.3528PC_4 + 0.3165PC_5$$

The regression equation for medium varieties has the for

$$\hat{Y}_2 = 12.853 + 0.6316PC_1 - 0.1546PC_2 - 0.2603PC_3 - 0.1628PC_4 + 0.2776PC_5$$

The regression equation for late varieties has the form:

$$\hat{Y}_3 = 13.1095 + 0.5884PC_1 + 0.6733PC_2 - 0.5537PC_3 + 0.0574PC_4 + 0.0111PC_5$$

The values R – squared for early varieties are 0.9209, for medium varieties 0.8159, for late varieties 0.8588, which indicates a strong influence of independent variables on dependent variable. P – value is less than 0.05 for all regression models, which indicates the adequacy of the models based on the Fisher criterion at a significance level of 0.05.

Third step: After going over to the initial factors, we obtain a model of the form (3). This regression model characterizes the dependence of the sugars indicator (for $\hat{Y}_1, \hat{Y}_2, \hat{Y}_3$) on weather factors. The coefficients of the models (in standardized factors $\tilde{x}_i$) are given in Table 5.

Table 5. Regression Model Coefficients in Standardized Factors

	$\tilde{a}_1$	$\tilde{a}_2$	$\tilde{a}_3$	$\tilde{a}_4$	$\tilde{a}_5$	$\tilde{a}_6$	$\tilde{a}_7$
$\hat{Y}_1$	-0.2833	-0.0020	0.3623	0.0863	-0.5228	0.1512	0.2950
$\hat{Y}_2$	-0.2537	0.008732	0.296458	0.126151	-0.3590	0.1668	0.2449808
$\hat{Y}_3$	-0.4019	0.029582	0.116499	0.638081	-0.0636	-0.1358	-0.098782
	$\tilde{a}_8$	$\tilde{a}_9$	$\tilde{a}_{10}$	$\tilde{a}_{11}$	$\tilde{a}_{12}$	$\tilde{a}_{13}$	$\tilde{a}_{14}$
$\hat{Y}_1$	0.2930	0.1218	0.2810	0.0317	0.0065	-0.1114	-0.0593
$\hat{Y}_2$	0.253276	0.194473	0.288316	0.010818	-0.00616	-0.12481	-0.09123
$\hat{Y}_3$	-0.00138	0.186504	0.4421	-0.05426	-0.4061	-0.20678	-0.23116

Based on the constructed models for each factor, the coefficients $\Delta_i, i = 1..14$ are calculated according to the formula (4). Coefficients Δ_i determine the share of each factor in the total variance of the sugars content indicator in the sweet cherry fruit. Based on the calculated indexes $\Delta_i, i = 1..14$, we rank all the factors according to the degree of their influence, from the most significant (rank 1) to the weakest influence (rank 14). Table 6 shows the values of the index Δ_i, % and the rank of factors.

Table 6. Index of the share of factors Δ_i influence and their rank

Factor (X_i,)	Symbol of factors (X_i,)	Coefficients of the share of factors (Δ_i) influence and factors rank indexes for varieties of early, medium and late groups					
		Early		Medium		Late	
		rank	Δ_i, %	rank	Δ_i, %	rank	Δ_i, %
X_1	The average temperature in June, °C	6	8.50	6	9.47	3	14.77
X_2	The difference between the average maximum and minimum temperatures in May, °C	14	0.06	13	0.28	13	0.60
X_3	Absolute minimum relative air humidity during blossoming, %	1	19.66	1	15.97	8	4.03
X_4	The absolute maximum temperature during the fruit picking, °C	11	1.95	10	3.29	1	30.99
X_5	The amount of precipitation during the blossoming period, %	2	19.06	2	12.64	12	1.01
X_6	The average temperature in April, °C	7	5.28	8	6.61	11	1.46
X_7	The total number of days with precipitation in April, %	4	11.84	5	10.24	9	2.30
X_8	The average maximum temperature during the fruit picking, °C	3	12.94	3	12.11	14	0.04
X_9	The average minimum relative air humidity during blossoming, %	9	3.62	7	6.96	7	5.37
X_{10}	The difference between the average maximum and minimum temperatures in the period of fruit picking, °C	5	9.86	4	10.58	4	14.64
X_{11}	Average temperature per year, °C	12	1.04	12	0.39	10	1.46
X_{12}	The difference between the absolute maximum and minimum temperatures during the fruit picking, °C	13	0.11	14	0.13	2	17.41
X_{13}	The average minimum temperature during the fruit picking, °C	8	4.12	9	5.05	6	7.97
X_{14}	The average temperature in May, °C	10	1.96	11	3.27	5	9.48

For varieties of early and medium ripening periods $\Delta_i$varies within 0.12–16.06% (Table 6), for fruit of the group of late ripening period varieties - 0.84–13.98%.

For further analysis of the research results, the factors depending on the values of the coefficients $\Delta_i (i = 1 \ldots 14)$ were divided into 3 groups. Where: Group 1 - factors that have a strong influence on the accumulation of the sugars fund ($\Delta_i \geq 9.50\%$) ; Group 2 - factors that have a medium impact (Δ_i $from$ 2.00% to 9.49%); Group 3 - other factors that have a weak impact on the accumulation of the sugars fund ($\Delta_i \leq 2.00\%$). For 1 group of factors that have a strong influence on the sugars accumulation in the sweet cherry fruit of early and medium ripening period, 4 common factors were identified. They have a meaning in the range from Δ_i 9.50 to 19.66%. These are the thermal indexes during the period of fruit picking, namely the difference between the average maximum and minimum temperatures (X_{10}), the average maximum temperature (X_8). Humidity indexes during the blossoming period are the sum of precipitation (X_5), the absolute minimum relative air humidity (X_3), as well as the total number of days with precipitation in April (X_7). For fruit of late ripening period, factors with the range Δ_i from 14.64% to 30.99% are referred to group 1. Namely, these are the thermal indexes during the fruit picking period: the absolute maximum air temperature (X_4), the difference between the average maximum and minimum temperatures (X_{10}), the difference between the absolute maximum and minimum temperatures (X_{12}), and the average June temperature (X_1).

According to Table 4, the second group includes factors that have an average impact on the sugars accumulation in the sweet cherry fruit of early and medium ripening periods with a value of Δ_i from 3.29% to 9.48%. Four common weather factors for the fruit of early and the medium ripening periods were identified: the average temperature in April (X_6) and June (X_1), the average minimum relative air humidity during blossoming period (X_9), the average minimum temperature during fruit picking period (X_{13}). Also for the group of medium ripening period varieties to weather factors that have an average influence the sugars accumulation such indexes are identified: the absolute maximum temperature during the fruit-picking period (X_4) and the average air temperature in May (X_{14}). For sweet cherry fruit of late ripening period a share of weather factors influence(Δ_i),which have average influence on sugars accumulation are in the range of values of 2.30–7.97%. Namely: the average temperature in May (X_{14}); average minimum relative air humidity during blossoming period (X_9); average minimum temperature (X_{13}) during fruit picking period; the total number of days with precipitation in April (X_7) and the absolute minimum relative air humidity during blossoming period (X_3).

The third group includes other weather factors that have a weak effect on the sugars accumulation. According to Table 4, the values of Δ_i for early ripening period varieties are from 0.06 to 1.9%; for the group of medium ripening period Δ_i 0.13–0.39% for late ripening period 0.04–1.46%. The total percentage of the share of factors influence of this group for the group of varieties of early ripening period is 5.12% (for varieties of medium ripening period it is 0.80%, for the group of varieties of late ripening period it is 4.57%). For all groups of varieties 2 common weather factors that do not significantly affect the sugars fund accumulation of the three ripening periods are: the difference between the average maximum and minimum temperatures in May and the average air temperature per year.

Thus, the sugars accumulation in sweet cherry fruit, regardless of the ripening period, is most influenced by weather conditions of the blossoming period, the last month of fruit formation and thermal parameters and humidity indexes at the stage of fruit picking.

CONCLUSIONS

1. According to sugars content and to the variability of their formation under the conditions of Southern Steppe subzone of Ukraine the most perspective from the technological point of view were Zabuta variety - 12.47% (of an early period of ripening), Dachnytsia - 15.60% (of a medium period of ripening and Kripnoplidna - 14.35 (of a late period of ripening). These varieties differed in high sugars content and in their low and medium variability during the years of study (*Vp* = 8.6–13.0%).

A correlation analysis of weather factors influence on the sugars content in the sweet cherry fruit of early, medium and late ripening periods was performed. The average and strong correlation between 14 weather factors (Xi, i = 1..14) and the sugars content for sweet cherry fruit of early, medium and late ripening periods ($\left|r_{Y_j X_i}\right| \geq 0.55$, $i = 1..14,\ j = 1..3$) was determined.

2. Based on the principal components analysis and method of least squares, models of the dependence of sugars funds accumulation on the influence of weather factors for groups of varieties of early, medium and late ripening periods are constructed.

3. On the basis of the constructed regression models the analysis of a share of each of weather factors influence on the indicator of sugars content is executed. The calculated coefficients of relative factors influence Δ_i, % showed that the greatest influence was established for the group of temperature and humidity indexes with the maximum share of $\Delta_i \geq 9.50\%$ in the total influence of factors on the indicator of sugars content in sweet cherry fruit.

4. The ranges of the share of weather factors that have the maximum influence on the sugars formation fund in sweet cherry fruit (Δ_i 9.50% to 0.99%) were identified.

5. For varieties of three ripening periods, the weather parameters that have the maximum impact on the process of sugars accumulation in sweet cherry fruit were determined: for early and medium varieties it is the difference between average maximum and minimum temperatures, average maximum temperature, precipitation amount and absolute minimum relative air humidity during blossoming period, as well as the total number of days with precipitation in April; for late varieties it is the absolute maximum air temperature, the difference between the average maximum and minimum temperatures, the difference between the absolute maximum and minimum temperatures in the period of fruit picking and the average temperature in June.

6. Based on regression analysis, it is substantiated that sugars accumulation in sweet cherry fruit, regardless of the ripening period, is most influenced by weather conditions of the blossoming period, the last month of fruit formation and thermal parameters and humidity indexes at the stage of fruit picking.

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