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THE FORECASTING OF POLYPHENOLIC SUBSTANCES IN SWEET CHERRY FRUITS UNDER THE IMPACT OF WEATHER FACTORS

Iryna Ivanova[1], Marina Serdyuk[1], Vira Malkina[1], Tetiana Tymoshchuk[2], Anna Kotelnytska[2], Vira Moisiienko[2]

[1]Dmytro Motornyi Tavria State Agrotechnological University, 18B Khmelnytsky Ave, UA72312 Melitopol, Zaporizhzhia region, Ukraine

[2]Polissia National University, 7 Staryi Blvd, UA10008 Zhytomyr, Ukraine

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Vastutav autor: Corresponding author: Tetiana Tymoshchuk

E-mail: tat-niktim@ukr.net

ORCID:
0000-0003-2711-2021 (II)
0000-0002-6504-4093 (MS)
0000-0002-2076-2093 (VM)
0000-0001-8980-7334 (TT)
0000-0001-7419-6374 (AK)
0000-0001-8880-9864 (VM)

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ABSTRACT. It has been proved that during the period of research the weather factors had dominating effects on the formation of phenolic substances fund for the fruits of early and late groups of cultivars. The cultivar features affected the accumulation of the phenolic substances in the fruits of a group of cultivars of a medium-term ripening. It has been established that the fruits of 'Kazka' cultivar (203.17 mg 100 g^{-1}) were selected from among the cultivars of an early-term ripening according to the average phenol substances content. The fruits of 'Rubinova Rannia' (175.27 mg 100 g^{-1}) are characterized by the optimal variation indices as well as by the average content of polyphenolic substances. From the technological point of view, the most perspective from among the cultivars of medium- and late-terms of ripening was: 'Uliublenytsia Turovtseva' (226.85 mg 100 g^{-1}), 'Udivitelna' (288.55 mg 100 g^{-1}). The results of experimental analysis for the fruits of early- and late-terms of ripening as well as their dispersion analysis allow us to forecast the content of the phenolic substances by the average indices but not separately for every pomological cultivar. Based on designed regression models, the analysis of the degree of impact of each weather factor on the rate of the phenolic substance has been made. The humidity index (the average monthly amount of rainfalls in May) had maximal effects on the accumulation of phenolic substances fund for the cherry fruits of three terms of ripening. The humidity indices of the last months of fruits formation (May and June) had the greatest effects on the accumulation of phenolic substances for a test group of plants of all terms of ripening.

Introduction

Increasing interest in biologically active compounds of stone fruits necessitates the selection of not only crops but also cultivars with a higher content of endogenous antioxidants. Natural phenolic compounds, including anthocyanidins, are considered the most important natural antioxidants (Xu *et al.*, 2017). Their composition and concentration affect the organoleptic characteristics of fruits and determine the antioxidant activity (Fu *et al.*, 2011; Nowak *et al.*, 2018). From among the most important kinds of fruit plants with corymbose inflorescences, which belong to sub-genus *Cerasus*, *Prunus avium* L. is of special importance. Cherry fruits are one of the most popular fruits of a moderate climate, they are much valued by the consumers and studied by scientists due to high taste qualities, attractive fruit appearance, valuable biochemical composition (Lovato *et al.*, 1994; Kask, Jalakas, 2004; Bastos *et al.*, 2015; Pissarda *et al.*, 2016). Sweet fruits have cellulose, vitamins, the compounds of the polyphenolic group, vitamin C, that provide good taste qualities and resistant characteristics (He *et al.*, 2007). The anti-tumour action of the extractions of fruits *P. avium*, which was caused by available phenolic compounds, has been established (Li *et al.*, 2016; Xu *et al.*, 2017).

The researchers pay much attention to studying the phenolic compounds of the fruits, which affect the fruits colour and the taste qualities like bitterness and astringency. Polyphenolic substances can be found in plants in the form of glycosylated derivatives, though a conjugation with non-organic acid is also known. These molecules take part in the protection against ultraviolet radiation or aggression from plants pathogens. As follows from the results of the research carried out on animal and man simulations, the phenols are bio-accessible and have a protective action against oxidative stress and against the damage caused by free radicals (Prior, 2003; Szajdek, Borowska, 2008; Lobo *et al.*, 2010; Alkadi, 2020). Phenolic compounds present secondary metabolites of plants, which are characterized by the availability of at least one aromatic ring with one or few affiliated hydroxyl groups. The phenols vary from simple low-molecular compounds with one aromatic ring to tannins, which contain a great number of hydroxyl groups (-OH). They can be classified according to the amount and to the location of carbon atoms (de la Rosa *et al.*, 2019). Some researchers have established that phenolic substances reduce vitamin C oxidation, and the vitamin, in its turn, has a stabilizing action on bioflavonoids (Díaz-Mula *et al.*, 2010; Smeriglio *et al.*, 2017).

According to the data, the sugars can serve as a material for the synthesis of phenolic substances in sweet cherry fruits. The total sugar content, as a substrate for the phenols formation, is in the range of 10.55–14.59% (Ivanova *et al.*, 2021b). The fruit ripening stage in sweet cherries, like in other red fruits, is connected with the change of primarily green colour for a red one due to the accumulation of polyphenolic compounds, anthocyanidins. Biologically active phenolic compounds are concentrated in the skin and have beneficial effects on the sensor and organoleptic characteristics of fruits, such as flavour (Jakobek *et al.*, 2009). The accumulation of substances that colour the sweet cherry fruits red (with different shades) during the last period of ripening are due to an increase in the content of anthocyanins. They are the main phenolic substances in the fruits of dark-coloured cultivars (Karaaslan *et al.*, 2016). As it has been stated in the research, the sweet cherry cultivars show high changeability of phenolic compounds rates. According to the data of some researchers, it has been found that the total amount of sweet fruits anthocyanidins is from 30 ('Black Gold' cultivar) to 79 ('Cristalina' cultivar) mg of the cyanidin-3-glycosidic equivalent of (CGE) 100 g^{-1}, when a total amount of cherry anthocyanidins is from 45 ('Balaton' cultivar) to 109 ('Sumadinka' cultivar) mg CGE mg 100 g^{-1} (Serrano *et al.*, 2009; Ferretti *et al.*, 2010).

The research has proved that the fruits of 13 sweet cherry cultivars had the total phenols content from 44.3 to 87.9 mg in the equivalent of gallic acid g^{-1} 100 FW and the antioxidant activity ranged from 8.0 to 17.2 mg the equivalent of the antioxidant capability of the ascorbic acid, mg 100 g^{-1} FW. The authors suppose that the correlation of the antioxidant activity of the total amount of phenols and anthocyanidins depended on the cultivar (Usenik *et al.*, 2008). However, it has to be noted that the cultural genetic factors and the weather conditions affect the formation of macroelements, micronutrients and phytonutrients in the fruits (Bureau *et al.*, 2009; Iglesias *et al.*, 2012). The temperature, lightning intensity and fruit ripening (Pissarda et al., 2016) can affect the content and the stability of phytochemical substances, as well as sweet cherry and cherry nutritional value.

There are some investigations, which show that the temperature fluctuations during the day (in a daytime or at night) affect the phenol total content (Pissarda *et al.*, 2016). When sweet cherry fruits grow under high temperatures (25–30 °C) it increases the amount of anthocyanidins as well as phenol (Ferretti *et al.*, 2010). The research conducted by Lakatos *et al.* (2010; 2014) showed that the content of biochemical indices depended on climatic characteristics (average maximal and minimal temperatures, humidity) during the period of blooming up to the period of stone fruits ripening. The weather factors, such as the sum of the effective temperatures and the amount of precipitation 10–15 days before harvesting, had a significant impact on the fruits quality indices (Revell, 2009; Lakatos *et al.*, 2014). The nature and the phenol compounds distribution vary depending on plant fibre. Thus, the rate of content of polyphenolic substances in sweet cherry fruits, their accumulation and further storage depend on many factors.

Based on literature references it can be stated that there is a strong correlation between the content of polyphenolic substances and the weather conditions of the region where the fruits are growing (de Souza *et al.*, 2014; Skrovankova *et al.*, 2015). In the regions similar to the Southern Steppe sub-zone of Ukraine it is expedient to determine the degree of impact of stress weather factors on the formation of polyphenolic substances fund in sweet cherry fruits. In literature sources, the question of the formation of the polyphenolic substances fund of a given region and similar ones (according to weather conditions) under the condition of global climate changes has not been covered. In literature sources, the problem of the formation of phenolic substances fund in a tested region and similar ones according to the weather factors and to the global climate changes is inadequately treated. The amount and the content of polyphenols in sweet cherry fruits differ depending on genotype impact, ripeness, climatic conditions, term of fruits ripening (Vuletić *et al.*, 2017). The data as to seasonal as well as to the geographic differences in the accumulation of polyphenols content in sweet cherry fruits are not available. That is why singling out of particular weather factors which have a maximal impact on the accumulation of phenolic substances in different (as to the term of ripening) sweet cherry cultivars is a topical matter.

Material and Methods

The goal of the research was to develop a mathematical model, which will help to improve the prediction of phenolic substances content in sweet cherry fruits under different weather conditions. The designed mathematical model can be used under the conditions of the regions with hydrometrical indices, which are similar to the Southern part of Ukraine. The program of the research prognosticates choosing of the cultivars of sweet cherry fruits of an early, medium- and late-terms of ripening with a maximal index of polyphenolic substances for the further storing of fruits with high-quality parameters and with biological value.

To realize the goal it is necessary to do the following tasks:

- to analyses the weather conditions during the period of fruits formation; to determine the content of the phenolic substances in sweet cherry fruits during the period of economic maturity of the cultivars of each term of ripening;
- to select the best ones according to test characteristic;
- to establish the correlation between the processes of phenolic substances accumulation and stress weather conditions;
- to develop the mathematical models of dependence of phenolic substances content on weather factors or varietal features;
- to analyse the designed model to determine the degree of impact of each factor on the accumulation of phenolic substances found in sweet cherry fruits of three terms of ripening.

By making a two-factor dispersion analysis the expediency of predicting the content of the phenolic substances in sweet cherry fruits by average indices for a definite group of cultivars will be justified and factors (factor A – climatic conditions of a year or factor B – cultivar features) which have maximal effects on phenolic substances accumulation in sweet cherry fruits will be revealed.

The research was conducted from 2008 to 2019 on horticulture farms of a Southern Steppe sub-zone of Ukraine. Sweet cherry fruits were chosen at a research commercial farm unit of a horticulture station named after M.F. Sydorenko (town of Melitopol) and at farm enterprises of Melitopol district (46° 49'N, 35° 22'E). Daily meteorological data of Melitopol meteorological station of Zaporizhia oblast (Ukraine) was used. The climate of the region is continental with a high-temperature regime and insufficient humidity. The relief of the territory is flat with eastern and north-eastern winds. The average annual air velocity is 3.7 m s^{-1}. The average annual air temperature in a test zone is 9.1–9.9 °C. In the warmest months of summer, the temperature is from 20.5 °C to 23.1 °C. The sum of active temperatures above 10 °C in the period from April to October is equal to 3316 °C. The average amount of precipitation during a year is 475 mm. The average annual relative air humidity in the region is within 73%. The readings of a hydrometrical index are in the range of 0.22–0.77 (Serdyuk *et al.*, 2020a; Ivanova *et al.*, 2021a,b). During the years of the research, the soil preparation in all areas satisfied the agrotechnological demands. Moisture accumulation in soil occurs mostly in autumn, partly in winter and in early spring. Black southern loamy soil was the soil on the test areas where the crop was grown. Loess was a soil-forming rock. This type of soil, by its particle-size distribution, has a great content of physical sand. The sweet cherry fruits of 33 cultivars were chosen for the research. They were divided into 3 groups according to the term of ripening (Table 1).

Table 1. The list of cultivars taken for studying

1st cultivar group (early-term of ripening)	2nd cultivar group (medium-term of ripening)	3rd cultivar group (late-term of ripening)
'Merchant', 'Swit Erliz', 'Rubinova Early', 'Bigaro Burlat', 'Kazka', 'Zabuta', 'Valeriy Chkalov'	'Oktavia', 'Vynka', 'Temp', 'Kordia', 'Pervistok', 'Talisman', 'Uliublenytsia Turovtseva', 'Melitopolska Chorna', 'Dilema', 'Orion', 'Dachnytsia', 'Chervneva Early', 'Prostir'	'Regina', 'Karina', 'Mirazh', 'Mirazh', 'Zodiak', 'Udivitelna', 'Kolhoznytsia', 'Ciurpryz', 'Temporion', 'Prazdnichna', 'Anons', 'Meotyd'

For each pomological cultivar, the samples of 100 fruits from six trees in a fruiting stage were taken for determining the content of the phenolic substances. The trees typical for a definite pomological cultivar of the same age, with average fruiting intensity were taken for the research. Three-fold frequency. The trees of 2001 were planted on the scheme 5×3, the spacings were under autumn fallow. The fruits were weighed and counted when picking (Serdyuk *et al.*, 2020b).

The sweet cherry fruits of each pomological cultivar were picked when the pulp was firm enough, but the flavour and the colour were typical for a given pomological cultivar. The fruits were picked from the trees from 4 different sides of the crown. The fruits of each pomological cultivar were harvested with a fruit stalk and of the first commercial quality. The harvest date of picking fruits was determined according to the following quality indices of fresh sweet cherry fruits which are common to each pomological cultivar: fruit appearance (fruit analysis by their shape and colour which must be typical for a given pomological cultivar, availability of fruit stalk, the degree of mechanical damages of fruit skin, the degree of fruit vermin damage, fungus disease affection) fruits size by the largest transverse diameter. When estimating the polyphenolic substances, the fruits in a state of a consumer ripeness were characterized by their appearance and flavour typical for a consumer sort of a corresponding term of ripening.

Polyphenols content was estimated by Folin-Denis' reagent. The method encompasses conducting polyphenols complexation reaction by Folin-Denis' reagent, as well as the formation of stained substances with further optical density determination. As standard, rutin was used to estimate polyphenols content in sweet cherry fruits. The optical density of the received test solutions and the solution of the standard rutin sample was estimated with a spectrophotometer under a wavelength of 670 nm in a cuvette and 10 mm distance between active areas.

The mass portion of polyphenols was estimated by Equation (1).

$$X = \frac{C \times V \times A \times 100}{M \times V_1}, \quad (1)$$

where C is the rutin mass concentration, which is determined by calibration graph (mg cm^{-3}), and V is the extract volume (cm^3), and V_1 is the extract volume for analysis (cm^3), and M (g) is the mass of a product assay sample (sweet cherry fruits), and 100 is the coefficient of polyphenols content determination per 100 g of product, and A is the coefficient of a rate of reconstitution of the extract of a sample (Ivanova *et al.,* 2019, Serdyuk *et al.,* 2020b).

The design of the models of dependence of phenolic substances in sweet cherry fruits of three terms of ripening depending on weather factors was as follows (Ivanova *et al.,* 2021a,b):

1. The determination of phenolic substances content by Folin-Denis' reagent.
2. The development of the informational data system of the indices of weather-climatic factors in the research years: average minimal air temperatures, average air temperatures, average maximal air temperatures, amount of precipitation, average relative air humidity, minimal relative air humidity, and absolute minimal relative air humidity.
3. The hydrothermal coefficient, the temperature difference during definite periods, the sums of active temperatures, the sums of effective temperatures were determined based on mentioned above indices.
4. The selection of weather-climatic factors, which showed the indices of correlation coefficients, are meaningful according to Student's test under the significance level of 0.05. The factors, which are logically substantiated from the point of view of their impact on the test characteristic (the accumulation of phenolic substances in sweet cherry fruits) but did not show a high correlation with it, were selected as well. For this purpose, we run a check on a statistical hypothesis about the significance of the calculated correlation coefficients between the factors and the index of polyphenolic substance content in sweet cherry fruits. We run a check on a statistical hypothesis by Student's test.
5. We build the regression model of dependence of the index of polyphenolic substances content in sweet cherry fruits from the selected factors in item 4.
6. Based on a designed regression model we determine the degree of impact of each factor.

The first stage of correlation analysis is the estimation of matching correlation coefficients and further checking their significance. It helps to find the most significant weather factors. The analysis of correlation coefficients presents the basis and makes it possible to select the factors, which strongly correlate with a test characteristic. However, it is necessary to use more accurate methods for comparing the degree of impact of the factors among themselves and their ranking in terms of the degree of impact. Such analysis is often made based on regression model coefficients. As a rule, a method of the least squares is used to design a regression model. One more reason, which entails some restrictions on using the algorithm of regression analysis, is a multicollinearity effect. But it is necessary to satisfy the conditions of the Gaus-Markov theorem for the calculated coefficients to be effective and unbiased evaluations of the parameters of a generalized regression model (Gujarati, 2004).

If the factors, which have some impact, correlate among themselves, the multicollinearity effect is manifested. It is a violation of the Gaus-Markov theorem. In this case, the evaluations of the coefficients of the model designed by the least-squares method are not biased. According to this model, the results of the analysis of the degree of impact of each factor separately is not reliable.

One of the recommended methods for designing the regression model under the condition of multicollinearity is the LASSO method (Least absolute shrinkage and selection operator) (Kutner *et al.,* 2004; James *et al.,* 2013; Hastie *et al.,* 2020).

An algorithm for the analysis of the impact of correlating factors on the final index based on a regression model designed by the LASSO method was suggested in the research (Ivanova *et al.,* 2021a,b):

Thus, it is suggested to research by the algorithm:

1. Based on experimental data x_{ij}, ($i = 1 \dots n$ – the weather factor number, $j = 1 \dots m$ – the number of a research year) we design a regression model by the LASSO method in Equation (2).

$$\hat{Y} = a_0 + \sum_{j=1}^{n} a_j \cdot X_{j,} \quad (2)$$

where X_j is the factor, and a_j is the model parameters, and $\hat{Y}$ is the test characteristic.

2. Calculate the values of the coefficient of a corresponding regression model in standardized factors by Equation (3).

$$\tilde{a}_i = a_i \frac{\bar{S}_{X_i}}{\bar{S}_Y}, \quad (3)$$

where b_i is the calculated coefficients of a regression model, and; $\bar{S}_{X_i}$ is the average quadratic deviation of factors X_i; $\bar{S}_Y$ – average quadratic deviation of a test characteristic Y.

3. Analyze the designed regression to estimate the degree of impact of each of the climatic factors on the content of a polyphenolic substance. To estimate the degree of impact of weather factors in a total impact of all factors, we estimate delta-coefficients Δ_j, by the formula:

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

where $\tilde{a}_i$ is the parameter of a regression model in standardized factors $\tilde{X}_i$, and r_{YX_i} is the matching coefficients of correlation, and R^2 is the determination coefficient.

The means of modern computer technologies DataMining – software environment Rstudio were used to perform statistical analysis.

Results and Discussion

The results received during 12 years give a possibility to state that the average content of phenolic substances in a test plant fruits of all terms of ripening equalled 205.86 mg 100 g^{-1} in rutin equivalent. Similar studies with 13 cultivars of sweet cherry fruits of different terms of ripening were conducted by the researchers from Slovenia (Usenik *et al.*, 2008). According to their data, the total phenols content varied from 44.3 to 87.9 mg gallic acid equivalents 100 g^{-1} FW. The research conducted by Serrano *et al.* (2005) proved that the maximal accumulation of phenolic substances was registered at the 8th stage of sweet fruits ripening.

The average phenolic substances content in sweet cherry fruits of the cultivars of an early-term of ripening was on the level of 177.53 mg 100 g^{-1} (Table 2). It was 13.8% lower as compared to an average cultivar coefficient. Minimal phenolic substances content from among the given group of cultivars has been determined in the fruits of the 'Bigaro Burlat' cultivar (116.01 mg 100 g^{-1}) of 2017. It was lower than the average cultivar index by 27.8%. Maximal phenolic substances content on the level of 274.12 mg 100 g^{-1} was determined in the fruits of the 'Zabuta' cultivar of 2016. Herewith, the excess over the average cultivar index was 48.3%. As follows from the results of 12-year research, from among the cultivars of an early-term ripening 'Kazka' cultivar was characterized by the highest phenolic substances content, and Sweet Earliz was characterized by the lowest content of phenolic substances (Table 2). Among the tested sweet cherry cultivars grown in Alicante (Spain), the highest total phenols content (54,02 mg GAE 100 g^{-1} FW) was registered in the cultivar of an early-term ripening – Brooks (Legua *et al.* 2017).

The phenolic substances content in sweet cherry fruits of the cultivars of a medium-term ripening was lower than the average cultivar index by 3.7%. Thus, from among the analyzed cultivars, the sweet cherry fruits of a cultivar group of a late-term of ripening were characterized by the maximal phenolic substances content. The average phenolic substances content in their fruits exceeded the average cultivar index by 17.5%.

The accumulation of phenolic substances in the fruits of two cultivars of early and medium-terms of ripening was analyzed by Ponce *et al.* (2021). The tested cultivars 'Lapins' and 'Glenred' showed different dynamics of phenolic substances accumulation during the period of fruit ripening. This suggests that the accumulation of phenolic substances depends on cultivar features.

The fruits of 'Dachnitsia' and 'Temp' cultivars which were picked in 2015 and 2017 are characterized by a minimal phenolic substances content among the cultivars of a medium-term of ripening. The amount of phenolic substances was lower than the average cultivar index by 18.8 and 37.6% respectively. The maximal amount of polyphenolic substances was determined in the fruits of 2010 in 'Uliublenytsia Turovtseva' and 'Melitopolska Chorna' cultivars. Herewith, the excess over the average cultivar index was in the range of 30.6–28.6% respectively. From among the cultivars of a medium-term ripening maximal average content of phenolic substances was determined in the fruits of 'Prostir', 'Uliublenytsia Turovtseva' and 'Melitopolska Chorna' cultivars.

The dependence of phenolic substances accumulation in stone fruits, cherry and sweet cherry in particular, on them of cultivar features, was established by the studies conducted by other researchers in Romania (Popescu *et al.*, 2014), Croatia (Vuletic *et al.*, 2017) and Poland (Bieniek *et al.*, 2011; Sokół-Łętowska *et al.*, 2020).

The fruits of 'Prazdnichna', 'Temporion', 'Anons', which were picked in 2008, were characterized by the minimal amount of polyphenolic substances among the cultivars of a late-term ripening. The amount of P-active substances was lower than the average cultivar y index by 27.3–38.8%. The maximal amount of polyphenolic substances was determined in the fruits of 'Zodiak' and 'Udivitelna' cultivars of 2014. Herewith, the excess over the average cultivar index was 13.8 and 10.6 respectively. The maximal average polyphenolic substances contained in the fruits of the cultivars of a late-term ripening was determined in the fruits of 'Udivitelna' and 'Regina' cultivars.

Similar studies as to the content of the phenolic substances in the fruits of cherry cultivars (21 cultivars) were conducted under conditions of Poland. The analysis of the research results testifies to the fact that stone fruits of mid- and late-terms of ripening contain more flavonols and anthocyanins than early ripening cultivars. The tested mid-ripening and late-ripening cherry cultivars had a higher antioxidant capacity as compared with early ripening cultivars (Sokół-Łętowska *et al.*, 2020).

The results of the research (Table 2) testify to a significant and average variation of polyphenolic substances content by the years of research in a group of cultivars of an early-term of ripening. The fruits of the 'Zabuta' cultivar (with the variation coefficients of 23.1%) were exposed to the greatest impact of abiotic factors on the content of the polyphenolic substances among the fruits of a given group. The cultivars 'Merchant' 'Bigaro Burlat' are the most resistant according to the test characteristic. Corresponding variation coefficients are in the range of 14.2–14.7 %. The variation of given cultivars under the weather factors impact in terms of polyphenolic substances content is considered to be average, and the fruits have a minimum average index of phenolic substances content during the years of research.

The variation of phenolic substances content by the years of the research in the sweet cherry fruits of the cultivar groups of medium and late-terms of ripening was average in a range of Vp = 11.1–19.9%. 'Mirazh' and 'Surprise' cultivars of late-term ripening are an exception (Vp = 20.7–26.2% respectively). Among the group of cultivars of a medium-term of ripening the most stable content of phenolic substances was in the fruits of 'Pervistok' cultivar (Vp = 11.8%), 'Uliublenitsia Turovtseva' (Vp = 12.6%), and the most changeable content was in 'Vynka' cultivar (Vp = 19.9%). The least variability in a group of cultivars of a late-term ripening was determined in 'Udivitelna' and 'Zodiak' cultivars (Vp = 11.1–11.2%).

Thus, within the cultivars of an early-term of ripening 'Kazka' cultivar was selected by the average content of phenolic substances; 'Rubilnova Rannia' and 'Bigaro Burlat' cultivars were selected by the variation of polyphenolic substances formation under the weather factors impact and the average content of polyphenolic substances. Under conditions of an analyzed region, the most perspective from the technological point of view in a group of cultivars of medium- and late-terms of ripening were the fruits of 'Uliublenytsia Turovtseva' cultivar (of a medium-term of ripening) and 'Udivitelna' cultivar (of a late-term of ripening). These cultivars had a high content of phenolic substances and minimal variation within the test groups by the years of research.

Table 2. Phenolic substances content in sweet cherry fruits of the cultivars of three terms of ripening in rutin equivalent, mg 100 g^{-1} (2008–2019), $\bar{x} \pm s$, n = 5

Pomological cultivar	Average phenolic substances content, mg 100 g^{-1}	Minimal phenolic substances content, mg 100 g^{-1}	Maximal phenolic substances content, mg 100 g^{-1}	Variation by the years, Vp, %
		An early-term of ripening		
'Rubinova Rannia'	175.27 ± 26.40	131.27	215.03	15.0
'Valeriy Chkalov'	194.07 ± 38.22	145.94	251.28	19.6
'Sweet Erliz'	155.63 ± 24.16	126.09	189.75	15.5
'Merchant'	157.24 ± 22.42	130.32	199.58	14.2
'Kazka'	203.17 ± 38.78	149.71	272.04	19.0
'Bigaro Burlat'	160.78 ± 23.74	116.01	197.90	14.7
'Zabuta'	196.54 ± 45.43	151.15	274.12	23.1
Average value	177.53 ± 36.53	135.78	228.52	17.3
LSD_{05}	28.82	–	–	–
		A medium-term of ripening		
'Vynka'	172.51 ± 34.35	126.69	219.15	19.9
'Pervystok'	171.05 ± 20.25	139.05	210.18	11.8
'Temp'	173.74 ± 32.00	108.42	229.09	18.4
'Uliublenytsia Turovtseva'	226.85 ± 28.59	179.89	296.34	12.6
'Talisman'	216.60 ± 31.56	177.23	280.02	14.5
'Dilema'	185.79 ± 26.64	141.51	222.89	14.3
'Melitopolska Chorna'	227.08 ± 30.38	200.07	292.08	13.3
'Kordia'	239.47 ± 38.93	170.14	289.85	16.2
'Oktavia'	203.33 ± 31.83	167.43	261.37	15.6
'Orion'	210.54 ± 28.10	161.95	251.17	13.3
'Chervneva Rannia'	179.57 ± 51.62	130.17	287.67	13.5
'Dachnytsia'	128.70 ± 24.09	104.41	170.79	18.7
'Prostir'	240.24 ± 41.21	166.83	279.27	17.1
Average value	198.11 ± 44.95	151.80	253.06	13.7
LSD_{05}	27.42	–	–	–
		A late-term of ripening		
'Krupnoplidna'	245.79 ± 39.36	160.09	289.05	16.0
'Karina'	252.17 ± 35.42	170.09	291.19	14.0
'Regina'	273.11 ± 36.82	198.03	305.52	13.4
'Mirazh'	209.73 ± 43.48	111.23	268.65	20.7
'Udivitelna'	288.55 ± 32.16	204.41	319.23	11.1
'Zodiak'	272.95 ± 30.75	207.71	310.65	11.2
'Surpryz'	238.34 ± 62.44	175.65	311.01	26.2
'Kolhoznytsia'	238.84 ± 39.18	175.73	291.34	16.4
'Kosmichna'	246.87 ± 28.89	196.80	290.45	11.7
'Prazdnichna'	225.34 ± 40.80	137.69	283.08	18.1
'Anons'	195.04 ± 31.21	141.71	241.05	16.0
'Temporion'	202.06 ± 32.93	141.01	246.16	16.2
'Meotyda'	256.49 ± 34.55	201.81	299.01	13.4
Average value	241.94 ± 45.89	170.89	288.75	15.7
LSD_{05}	37.09	–	–	–

Table 3. The results of two-factor dispersion analysis under the formation of phenolic substances found in sweet cherry fruits

Source of variation	Sum of squares	Degree of freedom	Dispersion	F_{fact}	$F_{table095}$	Impact, %
Sweet cherry cultivars group of an early period of ripening						
Factor A (year)	224 355.2	11	20 395.9	65.0	1.8	53.3
Factor B (cultivar)	81 372.8	6	13 562.1	43.2	2.2	19.3
Interaction AB	46 654.7	66	706.8	2.2	1.4	11.0
Sweet cherry cultivar group of a medium period of ripening						
Factor A (year)	33 6751.6	11	30 613.7	107.8	1.8	31.1
Factor B (cultivar)	467 108.8	12	38 925.7	137.1	1.8	43.2
Interaction AB	136 210.0	132	1031.8	3.6	1.3	12.6
Sweet cherry cultivars group of a late period of ripening						
Factor A (year)	502 235.1	11	45 657.7	87.9	1.8	42.5
Factor B (cultivar)	345 148.2	12	28 762.3	55.4	1.8	29.2
Interaction AB	132 038.2	132	1000.2	1.9	13.0	11.1

A dominating impact of weather factors on the accumulation of phenolic substances fund for a group of cultivars of early- and late-terms of ripening was confirmed by the results of a dispersion analysis (Table 3). The degree of impact of factor A for the cultivars of a group of an early-term of ripening was equal to 53.3%, for a group of cultivars of a late-term it was equal to 42.5%. The impact of cultivar features (factor B) was less weighty. The degree of impact of this factor was equal to 19.3 and 29.2% respectively for the analyzed groups.

The results of our research were proved by the data received by the researchers of Groatia (Vuletic *et al.*, 2017). They established that the impact of weather factors during the years of research on the accumulation of anthocyanins and polyphenolic substances in sweet cherry fruits was dominating. The dependence of fruits quality indices on the years of research was proved by A. Bieniek (Bieniek *et al.*, 2011). For a group of cultivars of a medium-term ripening, cultivar features had greater effects on the accumulation of substances P-vitamin activity. The degree of impact of factor B for the cultivars of the medium-term ripening was equal to 43.2%. The impact of factor A was on the level of 31.1%. A dominating impact of cultivar features on the accumulation of phenolic substances and anthocyanins in sweet cherry fruits of 13 cultivars of different terms of ripening was proved by the scientists of Slovenia (Usenik *et al*., 2008).

Thus, the received results confirm the expediency of determining the amount of phenolic substances in sweet cherry fruits by the average values for a definite group of cultivars of early- and late-terms of ripening, but not separately for each pomological cultivar. As for the cultivars of a medium-term ripening, it is expedient to analyze both the average values for the whole group of these cultivars, and for each cultivar separately, which will be done in further research.

Further, the analysis of the correlation relationship availability between the indicator of phenolic substances found in the fruits of an early-term of ripening (Y_1), medium-term (Y_2), late (Y_3) term of ripening and a complex of weather conditions (factors X_i) was made. The calculated matching coefficients $r_{Y_1X_i}$, $r_{Y_2X_i}$, helped to choose the most important weather factors. The significance of these coefficients is checked by the statistical hypothesis $H_0: \rho = 0$ (where ρ – the correlation coefficient of general totality) under an alternative hypothesis $H_1: \rho \neq 0$ when the significance level $\alpha = 0{,}05$. Student's criteria helped to check the statistical hypothesis As it was determined in our case, the significant correlation coefficients (under the level of significance equal to 0.05 and the number of the degrees of freedom $k = 10$) were within the interval of [-1; -0.55] and [0.55; 1].

As a result, based on the data taken from Table 4, 13 weather factors indices (X_i), which is a definite vegetation period that can significantly influence the accumulation of the phenolic substances in sweet cherry fruits of an early (Y_1), medium (Y_2), and late (Y_3) term of ripening, were selected.

These indices are: air humidity indices (mm; %; per day), the average monthly amount of precipitation in May (X_1), the number of days with precipitation more than 1 mm in May (X_6), and in June (X_7), the average relative humidity in May (X_2) and in June (X_3), the amount of rainfalls in blooming period (X_{10}) and during the whole vegetation period (X_{11}), the average minimal relative humidity in May, mm (X_4) and in June (X_5). The thermal air indices (°C): the average air temperature in the period of fruits picking (X_{12}); absolute maximal temperature in the period of fruits picking (X_{13}); the difference between average maximal and minimal temperatures in May (X_8) and June (X_9).

The parameters of the regression models designed by the LASSO method are given in Table 5, view 1. Table 5 shows the dependence of polyphenolic substances index for early $\hat{Y}_1$ medium $\hat{Y}_2$ and late $\hat{Y}_3$ cultivar on weather factors X_i.The model's coefficients are shown in Table 5.

Table 4. Table of the coefficients of matching correlation between weather factors (X_i,) and the content of the phenolic substances in sweet cherry fruits of an early (r_{YX_i}), medium ($r_{y_2x_i}$), and late ($r_{y_3x_i}$) terms of ripening

Relative factors term (X_i)	Factors	Matching coefficients of correlation ($r_{Y_jX_i}$) for the cultivars groups		
		early	medium	late
X_1	Average monthly amount of precipitation in May, mm	0.9623	0.7693	0.926621
X_2	Average monthly relative air humidity in May, %	0.7322	0.4084**	*
X_3	Average monthly relative air humidity in June, %	*	*	0.325988**
X_4	Average minimal relative air humidity in May, %	0.7678	0.4372	*
X_5	Average minimal relative air humidity in June, %	*	*	0.347651**
X_6	Total amount of days with precipitation more than 1 mm in May, per day	0.8246	0.5631	*
X_7	Total amount of days with precipitation more than 1 mm in June, per day	*	*	0.620387
X_8	Difference between average maximal and minimal temperatures in May, °C	–0.5997	*	*
X_9	Difference between average maximal and minimal temperatures in June, °C	*	*	–0.15941
X_{10}	Amount of precipitation in blooming period, mm	0.6124	0.4589**	*
X_{11}	Amount of precipitation during a vegetation period, mm	*	0.4696**	0.54163
X_{12}	Average air temperature in a period of fruits picking, °C	*	0.5386	0.356956**
X_{13}	Absolute maximal temperature in a period of fruits picking, °C	*	0.7693	0.508837

*insignificant matching coefficients of correlation $\left|r_{Y_jX_i}\right| \leq 0.55,\ i = 1-25, j = 1-3$ (according to checking a hypothesis on the significance of the correlation, coefficients by Student's criteria under significance level of 0.05).
**factors whose impact is hard to study from the point of view of the expediency and logic of the experiment, paying no attention to the insignificance of the coefficients of correlation.

Table 5. The coefficients of a regression model

	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7
$\hat{Y}_1$	82.8707	0.6144	0.1438		0.0717		2.6540	0.5944
$\hat{Y}_2$	69.7499	0.4063	–0.6469		–0.35405		2.1382	
$\hat{Y}_3$	154.0456	0.6671		–0.3377		0.2387		1.9068

	a_8	a_9	a_{10}	a_{11}	a_{12}	a_{13}
$\hat{Y}_1$	1.9414		0.0333			
$\hat{Y}_2$			0.0058	0.0653	0.0672	5.8783
$\hat{Y}_3$		0.55716		0.0063	2.2567	–0.0819

The formula of a regression model for the sweet cherry fruits of an early-term of ripening:

$$\hat{Y}_1 = 82{,}8707 + 0{,}6144X_1 + 0{,}1438X_2 + 0{,}0717X_4 + 2{,}6540X_6 + 0{,}5944X_7 + 1.9414X_8 + 0{,}0333X_{10} \quad (5)$$

The formula of a regression model for the sweet cherry fruits of a mid-term of ripening:

$$\hat{Y}_2 = 69.7499 + 0{,}4063X_1 - 0{,}6469X_2 - 0{,}35405X_4 + 2{,}1382X_6 + 0{,}0058X_{10} + 0{,}0653X_{11} + 0{,}0672X_{12} + 5.8783X_{13} \quad (6)$$

The formula of a regression model for the sweet cherry fruits of a late-term of ripening:

$$\hat{Y}_3 = 154.0456 + 0{,}6671X_1 - 0{,}3377X_3 + 0{,}2387X_5 + 1.9068X_7 + 0{,}55716X_9 + 0{,}0063X_{11} + 2.2567X_{12} - 0.0819X_{13} \quad (7)$$

Thus, according to Table 6, within the group of cultivars, a group of weather factors with average and strong linear correlation dependence with an analyzed index (phenolic substances), has been determined. The number of factors for early cultivars amounted to – 6, for medium cultivars – 7 and late cultivars – 7.

For the cultivars of an early, medium and late-terms of ripening Δ_i varies from 0.26 to 68.63% (Table 6). For further analysis of the results of the research all the factors, depending on the values of the coefficient Δ_i (i = 1–13), were divided into the ranks. According to Table 6, the humidity index (the average monthly amount of precipitation in May (X_1)) had maximal effects on the accumulation of phenolic substances for the fruits of sweet cherries of three terms of ripening. It was first in a rank according to the indices of the degree of factors impact on the accumulation of polyphenolic substances fund $\Delta_{X1}$and is from 43.21% to 68.63%.

The weather temperature indices, as well as humidity indices, had a significant impact on the accumulation of polyphenolic substances in sweet cherry fruits. Second in rank for the varieties of an early-term of ripening goes the index (X_6) – the number of days in May with the amount of precipitation more than 1mm; for the cultivars of medium and late-terms of ripening second in a rank is an index (X_{12}) – the average air temperature in a period of fruits picking. The values of the degree of impact of factors Δ_{X6} and Δ_{X12}were from 17.53% to

22.79%. Some noticeable impact on the test characteristic accumulation in sweet cherry fruits of three terms of ripening on the third rank level had the weather factors like: the number of days in May with the amount of precipitation more than 1 mm (X_6); the number of days in June with the amount of precipitation more than 1 mm (X_7); and the difference between average maximal and minimal temperatures in May (X_8). For the cultivars of an early-term of ripening the degree of impact Δ_{X8} = 3.60%, for the cultivars of medium and late-terms of ripening Δ_{X6} and Δ_{X7} equalled 14.47% and 11.46% respectively.

The cultivars of an early-term ripening maximal impact on the accumulation of phenolic substances had the factors of ranks 1, 2 and 3. The range of Δ_i index for them is 3.60–68.63%. The rest humidity indices: the amount of precipitation in blooming period (X_{10}), the average monthly relative humidity (X_2) and the average minimal relative humidity (X_4) in May had insignificant impact on the formation of phenolic substances found in sweet cherry fruits of an early, term of ripening. The value of the total impact of factors X_{10}, X_2 and X_4 was equal to 5.67%.

For the cultivars of a medium-term ripening maximal impact on the accumulation of phenolic substances had the factors of ranks 1–3. The range of Δ_i = 14.47–43.21%. The rest of weather humidity indices are to a high degree common for early and for medium cultivars of sweet cherry fruits, namely – the amount of precipitation during the vegetation period (X_{11}), average monthly relative humidity (X_2), and average minimal relative humidity (X_4) in May. They had a lower impact on the formation of phenolic substances in sweet cherry fruits. The values of the total impact of factors for a group of cultivars of a medium-term ripening of the 4^{th}–6^{th} ranks (X_{11}, X_2, X_4) was equal to 19.14%. The amount of precipitation in the blooming period (index X_{10}) is rank 7 with Δ_i = 0.39%.

For the cultivars of a late-term ripening maximal impact on the accumulation of phenolic substances had the factors of ranks 1–3. The range of Δ_i = 11.46–66.23%. The rest of the weather factors had a less significant impact on the accumulation of phenolic substances in sweet cherry fruits of a late-term ripening. The value of the total impact of factors X_3, X_5, X_{11}, X_7 on the accumulation of the polyphenolic substances in sweet cherry fruits of a late-term of ripening of 4^{th}–7^{th} ranks was equal to 4.54%. The impact of a surplus rainfall on the anthocyanins and polyphenolic substances synthesis in sweet cherry fruits harvest of two regions was proved by the research conducted by Vuletic (2017). The accumulation of phenolic substances in sweet cherry fruits depended on the humidity indices in the last month of fruit ripening. It was May for early-ripening cultivars and June for mid-ripening cultivars.

Table 6. The indices of the degree of impact of factors (Δ_i, %) on polyphenolic substances accumulation as well as on their rank

Factors (X_i)	Relative factors term (X_i)	The coefficients of the degree of factors impact (Δ_i, %) and the indices of factors rank for the cultivars of early, medium and late-terms of ripening					
		early		medium		late	
		rank	Δ_i, %	rank	Δ_i, %	rank	Δ_i, %
X_1	Average monthly amount of precipitation in May, mm	1	68.63	1	43.21	1	66.23
X_2	Average monthly relative air humidity in May, %	5	2.14	5	6.39		
X_3	Average monthly relative air humidity in June, %					4	1.90
X_4	Average minimal relative air humidity in May, %	6	1.05	6	3.53		
X_5	Average minimal relative air humidity in June, %					5	1.51
X_6	Total amount of days with precipitation more than 1 mm in May, per day	2	22.10	3	14.47		
X_7	Total amount of days with precipitation more than 1 mm in June, per day					3	11.46
X_8	Difference between average maximal and minimal temperatures in May, °C	3	3.60				
X_9	Difference between average maximal and minimal temperatures in June, °C					7	0.28
X_{10}	Amount of precipitation in the blooming period, mm	4	2.48	7	0.39		
X_{11}	Amount of precipitation during a vegetation period, mm			4	9.22	6	0.82
X_{12}	Average air temperature in a period of fruits picking, °C			2	22.79	2	17.53
X_{13}	Absolute maximal temperature in a period of fruits picking, °C					8	0.26

Conclusion

The fruits of 'Kazka' cultivar were selected by the amount of phenolic substances (203.17 mg 100 g^{-1}) among the cultivars of an early-term of ripening. The cultivars 'Merchant', 'Bigaro Burlat' were selected by the minimal variation index (Vp = 14.2–14.7%). The fruits of 'Rubinova Early' cultivar had the optimal variation indices and the average content of polyphenolic substances (175.27 mg 100 g^{-1}; Vp = 15.0). By the amount of phenolic substances and by their variation, the cultivars of medium and late-terms of ripening – 'Uliublenytsia Turovtseva' (226.85 mg 100 g^{-1} under Vp = 12.6 %), 'Udivitelna' (288.55 mg 100 g^{-1} under Vp = 11.1 %) were the best as to their qualitative technological indices. The weather conditions during the period of research (the impact of factor A 53.3% and 42.5% respectively) had a dominating impact on the formation of phenolic substances fund for all groups of cultivar of an early and late-terms of ripening. The impact of cultivar features was less significant and equalled 19.3% and 29.2% respectively. For the cultivars of a medium-term ripening, the accumulation of phenolic substances was under the impact of cultivar features (factor B) with the degrees of impact of factors A, B for the cultivars (31.1% and 43.2% respectively).

The correlation analysis of the impact of weather factors on the content of the phenolic substance in the sweet cherry fruits of early, medium and late-terms of ripening has been made. The average and strong correlation dependence between 13 weather factors (X_i, $i = 1 - 13$ and the phenolic substances content for the cultivars of sweet cherry fruits of early, medium and late-terms of ripening ($\left|r_{Y_j X_i}\right| \geq 0.55$, $i = 1 - 13, j = 1 - 3$) has been determined. The model of dependence of the accumulation of phenolic substances fund on the impact of weather factors for the groups of cultivar of early, medium and late-terms of ripening was designed based on a principal components method and the method of the least-squares.

The analysis of the degree of impact of each weather factor on the phenolic substances index was made based on designed regression models. The humidity index (average monthly amount of precipitation in May) had a maximal impact on the accumulation of phenolic substances fund for the cultivars of sweet cherry fruits of three terms of ripening. It belonged to rank 1 by the indices of the degree of factors impact on the accumulation of phenolic substances fund Δ_{X1} (from 43.21% to 68.63%). During the period of sweet cherry fruits ripening the greatest impact on the formation of phenolic substances content in fruits had the humidity indices in May (for early ripening and mid-ripening cultivars) and in May (for late-ripening cultivars).

Conflict of interest

The authors declare that there is no conflict of interest regarding the publications of this paper.

Author contributions

MS – study conception and design, drafting of the manuscript;
II, MS – author of the idea, guided the research;
II, VM, TT – analysis and interpretation of data and is the corresponding author;
II, VM – acquisition of data, drafting of the manuscript;
VM, AK – performed the literature data analysis and discussion of the results;
TT, AK – critical revision and approval of the final manuscript.
All authors read and approved the final manuscript.

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