**Research Paper**

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# Prediction of Cherry Fruit Technological Characteristics by RIDGE-regression Method

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Sour cherry is a valuable fruit crop which is in demand on the European market. At present the interest to sour cherry fruits increases due to their high nutritional value and to sensory properties of a sour cherry. It promotes to the expansion of a cultivar assortment of a fruit crop and stimulates the acquisition of knowledge about the fruits quality. The purpose of the research was to develop the mathematical model for the forecasting of a formation of fruit and stone weight in sour cherry cultivars irrespective of the environmental conditions. The research was conducted during 2007-2019 in the conditions of a Southern-Steppe zone of Ukraine. Theoretical, measuring and weighing, statistical. For the study, fruits from 10 varieties of cherries in the stage of consumer ripeness (100 pieces) were selected from 3-5 typical trees. The fruits were weighed and the weight of one fruit was determined. The average cherry fruit weight during the years of studying equaled 5.93 g, and the average stone weight equaled 0.39 g. Three sour cherry cultivars (Siyanets Turovtseva, Griot Melitopolskyi and Vstrecha) with the biggest average weight of a fruit from 7.48 to 7.87 g were chosen. The sour cherry cultivars Siyanets Turovtsevoi, and Vstrecha were characterized by a big fruit weight under optimal variability of 16.68% and 18.82% respectively. The cultivar Shalunia had the lightest stone weight in sour cherry fruits. The optimal correlation between the stone weight and the cherry fruit pulp (4.8%) was determined in a Vstrecha. According to a two-way analysis of variance, the dominating effects of the environmental conditions on the formation of a fruit weight and on the formation of a stone weight in fruits of sour cherry have been established. The average monthly precipitation in May and the average monthly air humidity during a year, which received the 1st and the 2nd ranks, had decisive effects on the formation of fruit and stone weight in the fruits of a sour cherry.

## 1. Introduction

Healthy diets include increased consumption of fruits and vegetables (Harris et al., 2023). In addition, plant products are a supplier of valuable phytonutrients for the human body, which help fight "hidden hunger"(Hutsol et al., 2023). A sour cherry (*Prunus cerasus* L.) is a valuable fruit from the Rosaceae family, which is grown in many countries (Šebek, 2019; Wojdyło et al., 2014; Yaman, 2022). A study of the quality characteristics of cherries could increase their importance as a potential tourist magnet for the region. This will help to increase the export potential of fruit raw materials and restore the country's economy in the post-war period (Trusova et al., 2020). The fruits of a sour cherry are characterised by an attractive look and flavor. A sour cherry, like a sweet cherry as well (Ivanova et al., 2021; Ivanova et al., 2022), is a source of biologically active or nutraceutical compounds, which are considered to be useful for human health (Bozhuyuk, 2022; Serradilla et al., 2016). Sour cherry fruits contain phenol compounds (Ciccoritti et al., 2018; Kołodziejczyk et al., 2013; Siddiq et al., 2011), which have antioxidant and antiinflammatory properties (Blando & Oomah, 2019; Butu & Rodino, 2019). Due to the antioxidant properties of sour cherry fruits the risk of oxidative stress, cardiovascular diseases, cancer development, type 2 diabetes reduce, the systemic and local inflammation, as well as the arthritis pain decrease, blood glucose level is regulated and the cognitive functions improve (Alba, Daya, & Franck, 2019; Keane et al., 2016; Kelley, Adkins, & Laugero, 2018). Mentioned above facts determine the nutritional, medicinal, dietary and technological value of sour cherry fruits.

The average fruit weight and the correlation of a stone to a fruit pulp are the most important features of new sour cherry cultivars which determine the fruits competitiveness and technological attractiveness (Rodrigues et al., 2008; Turner et al., 2008). Researchers have found that the average weight of sweet cherry fruit is significantly influenced by the genetic characteristics of the variety and abiotic factors, in particular the climatic conditions of growing the crop (Ivanova et al., 2022b). Fruit mass formation occurs due to the accumulation of free and bound water and dry substances in the cells. Dry soluble substances in cherries are represented by organic acids, sugars, vitamins, biologically active substances, and compounds with antioxidant properties (Ivanova et al., 2021a; Ivanova et al., 2021b; Ivanova et al., 2023b). Therefore, the analysis of the formation of parameters of the size and weight components of cherry fruit is carried out in parallel with many studies related to the study of the accumulation of fruit weight components. The fruit weight affects the harvest cost, attractiveness for the consumers and fruit processing into the food products (Grafe & Schuster, 2014; Wang et al., 2021; Wojdyło et al., 2014). Big cherry fruits are applicable for consumption and for further processing. Sometimes processing enterprises prefer small cherry fruits for the production of chocolate products and confectionery (Wojdyło et al., 2014). The fruit size and weight are estimated paralally with many studies connected with growing, realization or further processing. The study of the weather factors influence on the formation of key technological parameters of fruits will allow predicting the quality of fruits and increasing the competitiveness of fruit raw materials in the modern market. Therefore, the identification of weather factors that have the greatest impact on the formation of fruit and stone weight is becoming increasingly important. A comparative analysis of the degree of influence of these factors on the studied indicator will help to form a waste-free chain of fruit raw materials use. This approach will contribute to solving the problem of food security by providing the population with a sufficient amount of fresh fruit with predictable technological indicators in the conditions of climate change. Weather factors which have a maximal impact on the formation of fruit and stone weight, as well as a comparative analysis of the degree of influence of these factors on the parameter under study are very topical. The problem of cherry fruits quality is widely discussed by the researchers in the scientific literature (Ivanova et al., 2023; Ivanova et al., 2023; Viljevac Vuletic et al., 2017). Taking into account sour cherry value as a food product and as a raw material for the processing industry, most researchers study the biological composition of fruits and their flavor (Bozhuyuk, 2022; Picariello et al., 2016). The Polish researchers studied the content of sugars, organic acids and phenol compositions in the fruits of 21 sour cherry cultivars. The researchers established that the basic acids of a sour cherry were apple and malonic acids, and the basic sugars were glucose and fructose. The fruits of the cultivars Wieluń 17, Sokówka Nowotomyska, Grosenkirch, Meteor had the biggest content of phenolic compounds. They confirmed the dependence of antioxidant capacity on the phenolic substances composition. The researchers found the connection between the fruit ripening terms on the one hand, and the content of flavonoids and anthocyanins on the other hand (Sokół-Łętowska et al., 2020).

The study of the biochemical composition of sour cherry fruits of the cultivars Kelleris 16, Nefris and *Łutówka*, depending on the varietal features, was conducted under the conditions of central and eastern areas of

Poland (Borowy, Chrzanowska, & Kaplan, 2018). The study of the biochemical composition of sour cherry fruits depending on species and varietal composition of the plantation of four cultivars of Prunus genus was conducted by J. Cao et al. under China conditions. The researchers designated the applicability of cherry fruits to their processing due to a high content of ascorbic acid and anthocyanin's (Cao et al., 2015). As many as 39 clons of a sour cherry cultivar Oblačinska were assessed under the conditions of Serbia (Alrgei et al., 2016). A total carbohydrate, phenols and anthocyanins content as well as antioxidant activities and polyphenolic profiles in sour cherry fruits were studied. German researchers C. Grafe and Schuster studied the physical and chemical characteristics (fruit weight, fruit pulp density, dry substances and titrating acids content) of fruits of 78 sour cherry genotypes from the Fruit genebank of Julius Kühn-Institut in Dresden. A significant difference between sour cherry cultivars in each of the fruit quality signs, which are under study, was established (Grafe & Schuster, 2014).

According to M. Viljevac Vuletić et al. the biochemical composition of sour cherry fruits, except the varietal features, depends on the environmental conditions, vegetation period and geographical location. The researchers inform that the biggest source of variability of a parameter under study is a cultivar. Irrespective of the variation caused by a year or an area of growing, one and the same cultivar Maraska had the biggest polyphenols and anthocyanin's content, the cultivar Oblačinska had the least content (Viljevac Vuletic et al., 2017). The assessment of 26 wild-grown sour cherry genotypes was conducted according to morphological and biochemical fruit quality indicators under conditions of Turkey. It was established that the genotypes exhibited wide variation in most of the parameters under study: term of ripening, fruit weight (2.04–3.16), total content of phenols and anthocyanins, antioxidant effect, in particular (Bozhuyuk, 2022). Many scientists inform that the fruits quality is greatly dependent on the environmental conditions, genotype and sour cherry cultivation (Di Matteo et al., 2017; Ivanova et al., 2021; Kołodziejczyk et al., 2013). The influence of clonal rootstocks on both cherry quality indicators and antioxidant effect was established by T. Milošević. The biggest fruit and stone weight, fruit size as well as ripening index value under conditions of Serbia were registered in the cultivar *Šumadinka* on rootstock Gisela 5 especially on Gisela 6 (Milošević, Milošević, & Mladenović, 2020). According to K. Rutkowski an increase in pruning intensity of a tree promotes to an increase in cherry fruit weight (Rutkowski, Zydlik, & Pacholak, 2015).

The analysis of the impact of weather factors on the cherry fruit quality is made using the methods of correlation-regression analysis (Ivanova et al., 2021). But using the least squares method in this case is not efficient. It can be explained by the fact that there is a significant correlation connection between the individual factors, that is – the multicollinearity effect. The regularization methods are used when there is a multicollinearity effect between factors. Ivanova et al. in their work suggested using LASSO method when analyzing the degree of factors influence (Ivanova et al., 2021). We have suggested to build a regression model on the basis of another regularization method – RIDGE-regression.The analysis of literary sources indicates the need to find improved methods for predicting the influence of abiotic factors on the weight of fruits and stone in cherry fruits. The optimal solution to this problem may be to study the quality of cherry fruit depending on varietal characteristics and weather conditions during the growing season and ripening. This will make it possible to predict the quality of fruit at the stage of growing and harvesting, which will ensure the safety of fruit raw materials during the sale, storage and further processing of fruit.

## 2. Materials and Methods

The purpose of the research was to develop a mathematical model of forecasting the fruit and the stone weight in sour cherry fruits depending on the varietal features and weather factors. The research program envisaged the selection of the cultivars with maximal indicators of fruit weight and with optimal indicators of a stone weight, which have scientific and practical value as to the parameters under test.

To achieve the research goal, it is necessary to solve the following tasks:

1. To determine the weight of stone and fruit, their ratio in cherry fruits;
2. To investigate the relationship between the processes of formation of fruit and stone weight of cherries and weather factors;
3. To build mathematical models of cherry fruit and stone mass formation depending on weather factors and variety;

4. To determine the influence share of the dominant weather factors on the formation of fruit weight and stone weight of cherries.

The object of the study is the process of formation of the cherry fruit and stone mass depending on weather factors and varietal characteristics. The subject of the study is the regularities of changes in quality indicators in fruit raw materials of different varieties of cherries under the influence of abiotic factors; construction of a RIDGE regression model of the fruit and stone weight dependence in cherry fruits depending on weather factors with a high level of correlation. The hypothesis of the study is as follows. Ranking of the degree of influence of the studied weather factors on the weight of fruit and stone in cherry varieties will allow predicting the quality of fruit raw materials at the stage of its ripening. This, in turn, will improve the supply of processing companies and the market with the required volume of quality fruit products and balance their supply to consumers. It is also expected to improve the scheme of waste-free sale and cherries processing, minimising losses of fruit raw materials and reducing the risk zone from an economic point of view. The following methods were used to perform the research tasks: theoretical, laboratory, measuring and weighing, and statistical.

The research was conducted on black southern light loamy soils during 2007-2019. Sour cherry plantations were located in Southern Steppe sub-zone of Ukraine (46°46'N, 35°17'E). The meteorological data of Melitopol meteorological station in Zaporizhia oblast (Ukraine) were used for conducting the research. The climate in the region where the research was conducted is Atlantic Continental with a high temeperature mode and lack of moisture. There are eastern and north-eastern winds with an average wind speed of 3.7 m/s on the territory of a region. The average annual air temperature is within 9.1-9.9°C. The warmest months are July and August with average monthly temperatures from 20.5 to 23.1°C. The average annual sum of active temperatures from April to October is 3316°C. The average annual amount of precipitation on the territory of a region is 475 mm. The average annual relative air humidity is 73%. Hydrothermal coefficient (HTC) according to G.T. Selianynov is in the range from 0.22 to 0.77 (Ivanova et al., 2020).

Ten cherry cultivars (*Prunus cerasus* L. / *Prunus mahaleb*) were chosen for the research – Vstrecha, Ozhydanie, Shalunia, Siyanets Turovtsevoi, Griot Melitopolskyi, Solidarnist, Igrushka, Melitopolska Purpurna, Modnytsia, Expromt. Sour cherry was grown in an experiment according to standard technology for a region under test. The scheme of planting sour cherry trees was 5×3 m. The soil in sour cherry plantings was kept under autumn fallow. The moisture in the soils of the given region is accumulated mostly in autumn, winter and early spring. The rock on which the soil of this region was formed is loess. The sour cherry trees in the experiment were typical for a specific pomological cultivar, they were of the same age and had average fruiting intensity. The sour cherry fruits were taken from 3-5 typical trees in the amount of 100 units from each tree during the period of cherry ripeness. A three-time repetitiveness. Fruit accessions were taken from four different areas of a tree crown. The selected fruits conformed to the first commercial grade. All the selected cherry fruits were weighed. To estimate the weight of one sour cherry fruit, the total sample weight was divided into the number of fruits (100 units). After the fruits had been weighed, the stones were taken out. Then the stones were washed from the pulp and the rest of moisture was taken away from the stone surface by means of a filter paper. The stones of one accession were weighed and the average weight of one stone was determined (Ivanova et al., 2022).

The study of the dependence of fruit and stone weight of sour cherry cultivars on the weather factors was conducted in the following order (Ivanova et al., 2022):

1. The analysis of weather data during the research years was made.
2. The temperature and air humidity indices were determined.
3. The weather factors with a high correlation level as to the parameters under test (fruit and stone weight) were chosen.
4. The regression models of dependence of fruit and stone weight on weather factors with a high correlation level were built.
5. The degree of influence of the chosen weather factors on the fruit and stone weight in cherry cultivars was ranged.

A database of weather factors indicators, which were determined during the research period, was created to analyze the impact of these factors according to a general scheme of analysis.Among all these weather factors were chosen the ones which showed a significant correlation level with the indicators under study. For this purpose, a statistical hypothesis on the significance of the calculated correlation coefficients between the factors and the indicators under study was tested using Student's criteria under the significance level of 0.05. Then a RIDGE-regression model on the dependence of a fruit and a stone weight in sour cherry fruits on the selected weather factors was built.

A function minimum was estimated using RIDGE-regression method for determining the model parameters by the Equation (1):

$$L = \sum_{i=1}^{n}(y_i - \hat{y}_i)^2 + \lambda \sum_{i=1}^{n} \beta_i^2 \quad (1)$$

where $y_i$ is the experimental values of regressor indicators, and $\hat{y}_i$ is the theoretical values of regressor indicators, which are calculated using a received regression equation, and $\lambda$ is the a set parameter, and $\beta_i$ is the regression model coefficients.

Then the analysis of the regression models coefficients was done and the indicators $\Delta_i$ were determined. It allowed to determine the degree of influence of weather factors on the fruit and stone weight in sour cherry fruits and to rank them according to the degree of their influence on the parameters under study.

The coefficient $\Delta_i$ was calculated in order to determine the impact rate of weather factors on fruit and stone weight in sour cherry fruits according to Eq. 2:

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

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

To determine the coefficients of a corresponding regression model in normalized factors Equation 3 was used:

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

where $a_i$ is the calculated regression model coefficients (Eq. 2), and $\bar{s}_{X_i}$ is the standard factors $(X_i)$ deviation, and $\bar{s}_Y$ is the standard deviation of fruit and stone weight in sour cherry fruits $(Y_i)$.

The statistical analysis was done using a two-way analysis of variance. While doing the analysis we determined the statistical difference between the cultivars using ANOVA for each year separately. The comparison of the significant difference between the indicators was made using the least significant difference test with a statistical significance level of P<0.05.

## 3. Results

Under the conditions of a southern region of Ukraine the average indicator of fruit weight of sour cherry cultivars during 13 years of study equaled 5.93±1.19 g (Table 1).

**Table 1:** Stone and Fruit Weight and Their Correlation in Sour Cherry Fruits (2008-2019), $\bar{x} \pm s\bar{x}$, N=5

| Cultivar | Fruit weight | | | | Stone weight | | | | Correlation between fruit and stone weight, % |
|---|---|---|---|---|---|---|---|---|---|
| | average, g | min, g | max, g | Vp, % | average, g | min, g | max, g | Vp, % | |
| Vstrecha | 7.87 ± 1.48 | 6.07 | 11.19 | 18.82 | 0.38 ± 0.03 | 0.34 | 0.42 | 0.08 | 4.82 |
| Ozhydanie | 4.41 ± 1.12 | 2.93 | 6.28 | 25.38 | 0.36 ± 0.02 | 0.32 | 0.39 | 0.06 | 7.25 |
| Shalunia | 4.91 ± 1.38 | 3.03 | 8.05 | 27.99 | 0.29 ± 0.02 | 0.26 | 0.34 | 0.07 | 5.90 |
| Siyanets Turovtsevoi | 7.59 ± 1.27 | 6.27 | 9.98 | 16.68 | 0.41 ± 0.02 | 0.39 | 0.45 | 0.05 | 5.40 |
| Griot Melitopolskyi | 7.48 ± 2.01 | 5.18 | 10.89 | 26.88 | 0.39 ± 0.04 | 0.34 | 0.45 | 0.09 | 5.21 |
| Melitopolska Purpurna | 5.99 ± 0.99 | 3.78 | 7.00 | 16.48 | 0.40 ± 0.02 | 0.38 | 0.44 | 0.05 | 6.67 |
| Modnytsia | 4.78 ± 0.82 | 3.43 | 5.89 | 17.20 | 0.38 ± 0.05 | 0.30 | 0.45 | 0.13 | 7.94 |
| Expromt | 4.80 ± 0.75 | 3.24 | 5.89 | 15.68 | 0.39 ± 0.05 | 0.30 | 0.45 | 0.14 | 8.12 |
| Solidarnist | 4.80 ± 0.75 | 3.24 | 5.89 | 15.68 | 0.39 ± 0.05 | 0.30 | 0.45 | 0.14 | 8.12 |
| Igrushka | 6.71 ± 1.33 | 5.22 | 8.96 | 19.85 | 0.50 ± 0.06 | 0.43 | 0.61 | 0.11 | 7.45 |
| Average value | 5.93 ± 1.19 | 4.24 | 8.00 | 20.00 | 0.39 ± 0.04 | 0.34 | 0.45 | 0.09 | 5.87 |
| $LSD_{05}$ | 4.47 | | | | 0.07 | | | | |

The cultivars Griot Melitopolskyi (7.48 g), Ciyanets Turovtsevoi (7.59 g), Vstrecha (7.87 g) had the biggest average fruit weight in the research. It is by 26.14-32.72% more as compared with an average varietal parameters. The cultivar of a sour cherry Ozhydanie had the least fruit mass (4.41 g), it is by 25.63% less as compared with an average varietal parameters.

The sour cherry cultivars which form an optimal fruit and stone weight steadily according to the research years, are very valuable. The variation coefficient (Vp) was used to estimate the stability of the cultivars under study, in relation to weather factors of the years of sour cherry growing. An average and a significant variation for the indicator of fruit mass was established according to the research years (Table 1). It was established that the environmental conditions of the research years had a significance influence on the formation of fruit mass in the cultivars Ozhydanie (Vp=25.38%) and Shalunia (Vp=27.99%). The cultivars Solidarnist and Expromt had a stable variation coefficient (Vp=15.68%). The sour cherry cultivars Siyanets Turovtsevoi and Vstrecha had the biggest fruit mass and the optimal variation coefficients – 16.68 and 18.82% respectively. The average stone weight in sour cherry fruits of ten cultivars during 13 research years equaled 0.39±0.04 g. $LSD_{05}$ index (0.07 g) for fruit stone weight of the cultivars under study was statistically reliable (Table 1). A maximal average stone weight in sour cherry fruits was registered in a cultivar Igrushka (0.50 g), it is by 28.2% higher as compared with an average varietal parameter. A minimal average stone weight in sour cherry fruits was registered in a fruits of Shalunia cultivar (0.29 g), it is by 25.62% higher as compared with an average varietal parameter. The variability of a given indicator according to the years of research in the sour cherry fruits of different pomological cultivars was on a very low level with a range of fluctuations Vp=0.05-0.14%. The smallest stone weight (0.38 g under Vp=0.08%) was registered in a cultivar Vstrecha, but the fruit weight was big (7.87 g). The correlation of a stone weight to a fruit weight among 10 cultivars under study changed from 4.82 to 8.12%. The optimal correlation of a stone weight to a fruit pulp weight was determined for the cultivar Vstrecha (4.82%).

## 3.1 Determination of the Relationship Between the Processes of Fruit and Stone Mass Formation and Weather Factors

A dominating impact of the environmental conditions on the formation of a fruit and stone weight in sour cherry cultivars (Table 2) was established on the results of a two-factor dispersion analysis.

The environmental conditions of the research years (Factor A) had an impact rate of 52.10% for a fruit weight, and 59.72% for a stone weight. The impact of the varietal features (Factor B) on the formation of cherry fruit mass was less significant and equaled 23.98% and 17.45% respectively for both parameters under study.In conclusion, the sour cherry fruits of *Prunus cerasus* L. are characterized by a considerable variability of a fruit and stone weight depending on the year of study, that is on the environmental conditions of a particular season.

**Table 2:** The Results of Two-way Analysis of Variance Under the of Fruit and Stone Weight of Sour Cherry Fruits.

| Source of Variation | Sum of Squares | Degree of Freedom | Dispersion | Ffact | $F_{table095}$ | Impact, % |
|---|---|---|---|---|---|---|
| Fruit weight | | | | | | |
| Factor A (year) | 699.24 | 12.00 | 77.69 | 770.76 | 1.92 | 52.10 |
| Factor B (cultivar) | 321.80 | 9.00 | 35.75 | 354.71 | 1.79 | 23.98 |
| Interaction AB | 320.13 | 108.00 | 35.56 | 352.87 | 1.30 | 23.85 |
| Stone weight | | | | | | |
| Factor A (year) | 0.94 | 9.00 | 0.10 | 65.21 | 1.92 | 59.72 |
| Factor B (cultivar) | 0.27 | 12.00 | 0.03 | 19.06 | 1.79 | 17.45 |
| Interaction AB | 0.34 | 108.00 | 0.04 | 23.93 | 1.30 | 21.91 |

## 3.2 Construction of a Mathematical Model of Cherry Fruit and Stone Weight Formation Depending on Weather Factors and Variety

The weather factors which have paired correlation coefficients within the interval of , $|r_{YX_i}| > 0.55,\ i = 1$ were chosen according to the hypothesis testing $H_0$ relating to the significance of the correlation coefficients on Student's criteria under p=0.05. According to the research results 5 weather factors were chosen. The given weather factors significantly correlate with fruit and stone weight in sour cherry. Table 3 presents symbols for the factors. A matrix of paired correlation coefficients was built for a further analysis and is given in Table 4.

**Table 3:** Symbols for Factors.

| Factor (Xi) | Symbols for factors, (Xi) |
|---|---|
| $X_1$ | Average monthly amount of precipitation in May, mm |
| $X_2$ | Average annual amount of precipitation, mm |
| $X_3$ | Average minimal relative air humidity in May, % |
| $X_4$ | Number of days with rainfalls in May more than 1 mm, day |
| $X_5$ | Average monthly air humidity during a year, % |

The correlation coefficients (Table 4) among the factors which are close to ± 1 testify to a close correlation among the factors:

$X_1$ – average monthly amount of precipitation in May, mm and $X_2$ – average annual amount of precipitation, mm; $X_1$ – average monthly amount of precipitation in May,

mm and $X_3$ – minimal relative air humidity in May, %;
$X_2$ – average annual amount of precipitation, mm and $X_4$ – the number of days with rainfalls more than 1 mm in May, day;
$X_2$, – average annual amount of precipitation, mm and $X_5$ – average monthly air humidity per year, %;
$X_4$ – a number of days with rainfalls more than 1 mm in May, day and $X_5$ – average monthly relative air humidity per year, %.

**Table 4:** Correlation Matrix, Analysis of Factors.

| | x1 | x2 | x3 | x4 | x5 |
|---|---|---|---|---|---|
| x1 | 1 | 0.7072 | 0.8032 | 0.5177 | 0.5553 |
| x2 | 0.7072 | 1 | 0.6452 | 0.8211 | 0.8074 |
| x3 | 0.8032 | 0.6452 | 1 | 0.5720 | 0.6273 |
| x4 | 0.5177 | 0.8211 | 0.5720 | 1 | 0.8609 |
| x5 | 0.5553 | 0.8074 | 0.6273 | 0.8609 | 1 |

It confirms the existence of multicollinearity effect. It was suggested to use the Redge-regression method in order to build a regression model under conditions of multicollinearity. Redge-regression method (Eq. 1) regularizes the parameters and allows to build a regression model whose parameters are not biased by the parameters values of a corresponding generalized model. To determine the parameter λ, crossvalidation was done and the optimal parameter λ indicators were established. For a regression model of $Y_1$ dependence (fruit weight) was established parameter (λ=78.47) by using crossvalidation. For a regression model of dependence(fruit stone weight) on weather factors was established parameter (λ=206.91)

The regression model (Eq. 2) of dependence of $Y_1$ (fruit weight) on weather factors (in normalized factors, which were calculated by Eq. 3 is the following:

$$\hat{Y}_1 = 2.41 \cdot 10^{-2} X_1 + 0.32 \cdot 10^{-2} X_2 - 0.14 \cdot 10^{-2} X_3 + 0.56 \cdot 10^{-2} X_4 - 3.05 \cdot 10^{-2} X_5$$

where $\hat{Y}_1$ is the forecasted fruit mass parameter, and $X_1$ is the average monthly amount of precipitation in May, mm, and $X_3$ is the average minimal relative air humidity in May, %, and $X_4$ is the number of days with rainfalls more than 1 mm in May, mm, and $X_5$ is the average monthly relative air humidity during a year, %. Determination coefficient, calculated on the basis of a designed model equals $R^2$= 0.9440, and it confirms the fact that weather factors have a considerable influence on the fruit mass as compared with accidental errors.

The regression model (Eq. 2) of dependence of (fruit stone weight) on weather factors (in normalized factors, which were calculated by Eq. (3)) is the following:

$$\hat{Y}_2 = 3.15 \cdot 10^{-4} X_1 + 1.60 \cdot 10^{-4} X_2 - 1.83 \cdot 10^{-5} X_3 - 8.48 \cdot 10^{-5} X_4 - 8.24 \cdot 10^{-4} X_5$$

where $\hat{Y}_1$ is the forecasted stone weight parameter, and $X_1$ is the average monthly amount of precipitation in May, mm, and $X_3$ is the average minimal relative air humidity in May, %, and $X_4$ is the number of days with rainfalls more than 1 mm in May, mm, and $X_5$ is the average monthly relative air humidity during a year, %. Determination coefficient, calculated on the basis of a designed model equals $R^2$=0.784, and it confirms the fact that weather factors have a considerable influence on the stone weight in sour cherry fruits as compared with accidental errors.

### 3.3 Determination of the Proportion of the Dominant Weather Factors Influence on the Formation of Fruit Weight and Stone Weight of Cherries

Table 5 presents the calculated coefficients of paired correlation $(r_{Y_j x_i})$, the indicators of the degree of influence ($\Delta_i$) and ranks of weather factors which influence the formation of fruit and stone weight in sour cherry cultivars. Common five weather factors were ranged according to the degree of their significance. All factors appeared to be humidity indicators: average monthly amount of precipitation in May ($X_1$), average annual amount of precipitation ($X_2$), average minimal relative air humidity in May ($X_3$), number of days with rainfalls more than 1mm in May ($X_4$), average monthly relative air humidity during a year ($X_5$). The degree of influence of weather factors $\Delta_i$on the formation of a fruit weight of the cherry cultivars under study was within 4.33–40.74%. The degree of influence of the factors under study on the formation of a stone weight in sour cherry cultivars was within 1.08-53.26% (Table 5). Maximal influence on the formation of cherry fruit and stone weight had such factors as: average monthly amount of precipitation in May, mm ($X_1$) and average monthly relative air humidity during a year, % ($X_5$). These weather factors received 1st and 2nd ranks. On the

3rd rank level, factor ($X_3$) – average minimal relative air humidity in May had a considerable influence ($\Delta_{X3}$ – 16.87%) on the formation of a cherry fruit weight. Factor ($X_2$) – average annual amount of precipitation, mm ($\Delta_{X2}$ –14.74%) belongs to rank 3. Other factors belong to 4th and 5th ranks.

**Table 5:** Paired Correlation Coefficients ($r_{Y_jX_i}$), Coefficients of a Share of Factors Influence ($\Delta_i$) and Weather Factors Ranks (Xi), Which Influence the Formation of Fruit and Stone Weight in Sour Cherry Cultivars.

| $X_i$ | Factors | Fruit weight | | | Stone weight | | |
|---|---|---|---|---|---|---|---|
| | | Paired correlation coefficients ($r_{Y_1X_i}$) | Coefficients of the share of factors influence ($\Delta_i$, %) | Rank | Paired correlation coefficients ($r_{Y_1X_i}$) | Coefficients of the share of factors influence ($\Delta_i$, %) | Rank |
| $X_1$ | Average monthly amount of precipitation in May, mm | 0.912 | 40.74 | 1 | 0.70 | 25.51 | 2 |
| $X_2$ | Average annual amount of precipitation, mm | 0.713 | 4.33 | 5 | 0.80 | 14.74 | 3 |
| $X_3$ | Average minimal relative air humidity in May, % | 0.626 | 16.87 | 3 | 0.51 | 1.08 | 5 |
| $X_4$ | Number of days with rainfalls in May more than 1 mm, day | 0.697 | 7.31 | 4 | 0.55 | 5.39 | 4 |
| $X_5$ | Average monthly relative air humidity during a year, % | 0.543 | 30.72 | 2 | 0.56 | 53.26 | 1 |

## 4. Discussion

Fruit weight is one of the main technical indicators of the quality and marketability of fruit products. Sour cherry fruits, which were harvested during an experiment, with an average weight of 6.03 g (Table 1) were similar to those harvested by the Polish researchers (Borowy et al., 2018). But S. Proietti et al. established that the average fruit weight of sour cherry fruits under conditions of Central Italy equaled 2.5 g, minimal and maximal indicators were 1.8 and 3.6 g respectively (Proietti et al., 2019). According to A. Khadivi et al. under the conditions of Iran the average fruit weight was 2.04 g (Khadivi, Mohammadi, & Asgari, 2019). Most cherry cultivars under study formed the fruits with an average weight of more than 4.15 g under conditions of Poland (Wojdyło et al., 2014). The average fruit weight in our studies was higher than that found by K. Rutkowski (Rutkowski et al., 2015) and R. Wang (Wang et al., 2021). The results of the research show that the cherry cultivars under study differ in the fruit weight (Table 1). This conclusion is supported by the data received by other researchers (Borowy et al., 2018; Šebek, 2019; Siddiq et al., 2011). The study conducted by M. Siddiq et al. established that the fruit weight of sour cherry fruits fluctuated over a wide range (from 3.95 to 8.17 g) depending on the cultivar (Siddiq et al., 2011). The cultivar Balaton had the biggest fruit weight (8.7 g).

According to G. Šebek, under conditions of Montenegro the fruits of the cultivar Oblačinska had the smallest weight (3 g), and the fruits of the cultivar Heimanns Konservenweichsel had the biggest weight (5.7 g) (Šebek, 2019). Fruit weight variations, depending on the cultivar, were studied earlier. The average weight of a cherry fruit in the studies by A. Wojdyło et al. fluctuated from 2.10 g (Stevensbaer) to 6.10 g (Ksiazėcą) (Wojdyło et al., 2014), by y N. Papp et al. from 3.40 g (Oblachinskha) to 7.17 g (Pándy 279) (Papp et al., 2010), by R. Pérez-Sánchez et al. from 3.2 g (Guindo del País 1) to 4.72 g (Guindo Tomatillo 2) (Sánchez, Gómez-Sánchez, & Corts, 2008), by R. Wang et al. from 2.495 g (BS 5) to 5.890 g (Earey hungazihn) (Wang et al., 2021). Morphological and pomological variability of 62 sour cherry accessions was estimated by A. Khadivi et al. under conditions of Iran. High variability of features in studied accessions was established. Thus, the fruit weight of sour cherry fruits varied from 1.36 to 2.67 g (Khadivi et al., 2019). On the whole, the fruits of sour cherry cultivars were smaller as to their mass than the sweet cherry fruits (Gonçalves et al., 2021; Ivanova et al., 2022; Rodrigues et al., 2008; Sánchez et al., 2008).

In the studies, the weight of the cherry stone ranged from 0,29 g (Shalunia) to 0,50 g (Ihrushka), depending on the characteristics of the variety (Table 1). Our results are consistent with other research data as to the formation of an average fruit stone weight in sour cherry fruits. Thus, stone weight in sour cherry fruits fluctuated from 0.26 g (Oblačinska) to 0.42 g (Rexelle) under conditions of Montenegro (Šebek, 2019). The optimum ratio of stone weight to total fruit weight tends to be minimal. According to the data obtained (Table 1), the optimal ratio of stone to cherry fruit pulp was calculated for the

“Vstriecha” variety. The fruits with a smaller correlation between a fruit stone and a total fruit weight attract the customers more (Maglakelidze et al., 2017).

The studies revealed a significant influence of weather conditions on the formation of fruit and stone weight in cherry varieties (Table 2). The results of the researchers’ studies were confirmed by the results of our research data relating to the influence of genotypes as well as to the conditions in the years of cherry growing on a large variability of the parameters under study (Borowy et al., 2018; Grafe & Schuster, 2014; Ivanova et al., 2022). According to the researchers, cherry fruit weight is a cultivar sign, which can fluctuate depending on the climatic and agricultural conditions (Karagiannis et al., 2021; Šebek, 2019; Wang et al., 2021; Wojdyło et al., 2014). The study of the abiotic factors influence on the formation of marketability indicators of fruit products is an important aspect for predicting the volume of high-quality fruit raw materials and stabilising the functioning of the fruit and vegetable and canning industries.

The proposed approach makes it possible to evaluate each variety of cherries by the main commodity parameters of fruit raw materials and to divide products into commodity classes. In this context, the issue of predicting the weight of the fruit and stone depending on the proportion of influence of abiotic stress factors is useful for further improving the technology of transportation, storage and processing of fruit raw materials. The future development of the study may include a forecast of the potential preservation of cherry fruit in a zero-waste fruit processing chain to address food preservation issues during the post-war reconstruction of countries. In addition, expanding the scope of the study to other fruits will reduce food security risks by redistributing raw materials in the zero-waste chain.

## 5. Conclusion

Average cherry fruit weight under the conditions of the South of Ukraine equals 5.93 g, and the average stone weight in sour cherry fruits equals 0.39 g. The cultivars Griot Melitopolskyi (7.58 g), Siyanets Turovtsevoi (7.59 g) and Vstrecha (7.87 g) had the biggest average fruit weight. During all the years of study the cultivar Igrushka was characterized by the biggest stone weight in the fruits of sour cherry cultivars – 0.50 g, and the cultivar Shalunia was characterized by the smallest stone weight – 0.29 g. Maximal fruit weight under optimal variability was established for two sour cherry cultivars – Siyanets Turovtsevoi (Vp=16.68%) and Vstrecha (Vp=18.82%). The cultivar Vstrecha was distinguished among the cultivars under study by the optimal correlation between the fruit stone and the fruit pulp (4.82%). The environmental conditions during the research years had a dominating influence on the formation of fruit weight (Vp=52.1%) and stone weight (Vp=59.72%) in sour cherry cultivars. Mathematical models of the formation of fruit and stone weight of cherries depending on weather factors and variety were built. The regression model of the dependence type of the fruit weight $(\hat{Y}_1)$ on weather factors is as follows:

$$\hat{Y}_1 = 2{,}41 \cdot 10^{-2} X_1 + 0{,}32 \cdot 10^{-2} X_2 - 0{,}14 \cdot 10^{-2} X_3 + 0{,}56 \cdot 10^{-2} X_4 - 3{,}05 \cdot 10^{-2} X_5$$

The regression model of the dependence of bone weight $(\hat{Y}_2)$ on weather factors is as follows:

$$\hat{Y}_2 = 3{,}15 \cdot 10^{-4} X_1 + 1{,}60 \cdot 10^{-4} X_2 - 1{,}83 \cdot 10^{-5} X_3 - 8{,}48 \cdot 10^{-5} X_4 - 8{,}24 \cdot 10^{-4} X_5$$

The greatest influence on the formation of fruit and stone weight in sour cherry fruits had 5 air humidity indicators. Two factors – average monthly amount of precipitation in May (mm) and average monthly air humidity during a year (%) had a decisive role. These factors received the 1st and the 2nd ranks according to their influence on fruit and stone weight.

The obtained results will make it possible to predict the ratio of fruit weight and stone weight in cherries depending on stressful weather conditions. This will make it possible to further develop a waste-free cycle of cherry fruit use to address food system problems in countries with constant environmental vulnerability and political instability.

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## Conflict of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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