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CONTENT OF BIOLOGICALLY ACTIVE SUBSTANCES IN STRAWBERRY (*FRAGARIA* × *ANANASSA*) GROWN IN THE FOREST-STEPPE OF UKRAINE

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Aim. To investigate the impact of weather conditions in the Forest-Steppe of Ukraine and genetic specificities of cultivars on the content of vitamin C, polyphenols, flavonoids, and anthocyanins in strawberry fruits. **Methods.** The study was conducted in 2023–2025; strawberry fruits of 7 cultivars of different ripening periods were selected in the experimental plots of the Institute of Horticulture of the NAAS of Ukraine. The weather indices of the vegetation period prior to collecting strawberry fruits were taken from the meteorological station Vantage Pro2 Plus, located in the experimental plots of the strawberry. The analytical study was conducted by the method of determining the quality of fruit and berry products (Kondratenko et al., 2008), in particular, using spectrophotometry methods, the content of biologically active substances was determined and expressed in mg/100 g FW. The amount of vitamin C was determined using titration with the solution of 2,6-dichlorophenolindophenol, the content of polyphenolic substances was determined using the Folin-Denis reagent, the content of flavonoids — by measuring the absorption of the complex of flavonoids by aluminum chloride in the ethanol medium, the content of anthocyanins — by the difference method in two buffer systems: with potassium chloride, pH 1.0 (0.025 M) and sodium acetate, pH 4.5 (0.4 M). The statistical analysis of the study data was conducted in STATISTICA 13/1 (StatSoft, Inc., USA). **Results.** The weather indices of the period of growth and development of strawberry fruits had a considerable impact on the content of vitamin C, polyphenols, flavonoids, and anthocyanins in them. The content of vitamin C in the fruits of cultivar Herkules was the most stable and independent from weather conditions of the cultivation year, with a minimum of 50.4, a maximum of 57.6, and an average of 53.5 mg/100 g FW. The content of vitamin C in strawberry cultivars Florence and Vibrant was the most variable and dependent on the weather conditions of the cultivation year, the average content was 52.0 and 50.9 mg/100 g FW. The amount of vitamin C in strawberry fruits considerably depended on the average daily air temperatures; the correlation coefficients for the investigated group of cultivars were high, over 0.720, the increase in the average daily air temperatures promoted a decrease in the content of vitamin C. The amount of polyphenols in cultivars Herkules and Prezent had a significant correlation with the average daily air temperatures and the HTI for the period of their growth and development, but in the first case, the correlation was direct, and in the second one, — indirect. Among the investigated cultivars, the fruits of cultivars Veselka, Vibrant, and Florence were capable of accumulating the maximal amount of flavonoids, over 70 mg/100 g FW. The fruits of Prezent cultivar were capable of accumulating more than 20 mg/100 g FW of anthocyanins. The content of flavonoids in Prezent cultivar and that of anthocyanins in Veselka cultivar was homeostatic. **Conclusions.** It was determined that the content of biologically active substances in strawberry fruits was determined by genetic specificities of the cultivar and corrected by weather conditions for the period of their growth and development.

Keywords: strawberry, vitamin C, polyphenols, flavonoids, anthocyanins.

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INTRODUCTION

Strawberry (*Fragaria×ananassa*) is one of the most popular berry crops (Nagamatsu et al., 2021). According to the communication of SadyOgrody, as of 2024, more than 9 million tons of strawberries are grown in the world. Its fruits are an important source of biologically active substances, beneficial for human health. In addition, strawberry fruits have a nice color, harmonious taste, and pleasant aroma (Agehara & Nunes, 2021). Strawberry can accumulate a considerable amount of vitamin C, polyphenols, such as flavonoids (mainly, anthocyanins) and phenolic acids (hydroxybenzoic acid and hydroxycinnamic acid) (Hancock, 2000), which enhances its nutrition value (Giampieri et al., 2012); these components of biochemical composition are especially valuable for women of child-bearing age (Kishimoto et al., 2023). According to the epidemiological studies, phenols are responsible for decreasing the risk of chronic diseases, such as cancer and cardiac diseases (Afrin et al., 2016; Wang, 2021). Regular consumption of strawberries decreases the level of cholesterol in the blood (Moll et al., 2019). These health benefits make strawberries a relevant source of nutritious substances and compounds for treatment and prophylaxis (Mezzetti et al., 2018).

The commercial, consumption, and dietary qualities of strawberries depend on the cultivation conditions considerably (Fan et al., 2021; Newerli-Guz et al., 2024). Such meteorological factors as temperature, moisture level, and light intensity have a considerable impact not only on the blossoming and fruit-bearing, but also on the quality of strawberry fruits (Ariza et al., 2015). The variability of weather conditions may have a negative effect on the efficiency of strawberry production, which, in the long run, will decrease its market value (Pathak et al., 2016). According to the forecasts of American scientists, due to extreme temperatures and drought, the yield of strawberries in open ground will decrease by 10% by the middle of this century, and by 43% — by its end (Lobell & Field, 2011).

Since the biochemical composition of strawberry fruits changes according to the cultivar and cultivation conditions, the knowledge of its variability depending on weather conditions in the Forest-Steppe of Ukraine and their genotype is a relevant characteristic while evaluating the cultivar for its suitability for cultivation in a specific natural climatic zone.

MATERIALS AND METHODS

The study was conducted in 2023-2025. The experimental plots of strawberry were located at the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine (the IH of the NAAS of Ukraine), in the natural climatic zone of the Forest-Steppe of Ukraine. The distance from the Kyiv boundaries was 4 km, the geographic coordinates were 50°21′16″ north latitude, 30°27′16″ east longitude. The fields of strawberries were created in 2022, kept without watering, and the inter-rows are mulched with straw. The planting scheme is 0.3 x 0.9 m, the soil in the inter-rows is mulched with straw, which is replaced each year. The soil of the strawberry fields is grey, loess, and medium clay. The fertilization of the fields was conducted based on the results of soil diagnostics. The main fertilizers (NPK) were introduced in the form of ammonium nitrate phosphate fertilizer prior to planting strawberries, 1.3 kg per one hundred square meters. During the vegetation process, the strawberry was fertilized three times: at the beginning of vegetation, immediately after fruit-bearing, and one month after the last fertilization. For this purpose, the fertilizer of the "Chystyi lyst" brand was used; the norm was calculated according to the manufacturer's recommendations. The protection of the strawberry fields from leaf spots and gray rot was performed using "Swich" preparation, the norm of which was calculated according to the manufacturer's recommendations. The list of 7 cultivars, the fruits of which were investigated, is presented in *Table 1*.

The content of biologically active substances in strawberry fruits was determined in the Laboratory of the Department of storing, processing, and analytical investigation of the IH of the NAAS of Ukraine. The weight of the sample for the determination of biochemical components was one kilogram, according

Table 1. The cultivars of strawberry, the fruits of which were investigated for the content of biologically active substances

Term of ripening	Cultivar	Country of origin
Early	Olviia Veselka	Ukraine Ukraine
Medium	Herkules Prezent	Ukraine Ukraine
Late	Atlantyda Vibrant Florence	Ukraine UK UK

to the method of evaluating the quality of the fruit and berry products (Kondratenko et al., 2008). The fruits for the study were selected in the state of consumption readiness during the second massive harvesting. The content of ascorbic acid, polyphenols, flavonoids, and anthocyanins was determined on the day of selecting samples. All the studies were done in three repeats.

Ascorbic acid. For the extraction of ascorbic acid, the sample was mashed in a porcelain mortar with the addition of broken glass and a mixture of 2% oxalic and 1% hydrochloric acids (80+20, vol+vol), transferred to a volumetric flask with a capacity of 100 ml. The content of the flask was adjusted to the mark with a mixture of 2% oxalic acid and 1% hydrochloric acid (80+20, vol+vol) and filtered. The resulting extract was titrated with a solution of 2,6-dichlorophenolindophenol (Tilmans paint). The content of ascorbic acid in the sample was calculated by the formula using the Tilmans paint titer. The data was expressed as 1 mg per 100 g of raw mass.

Total phenolic content (TPC). For the extraction of total phenolic content, the sample was mashed in a porcelain mortar with a small amount of ethyl alcohol and filtered using a vacuum on the Büchner funnel through a blue ribbon paper filter into a Bunsen flask. The residue on the filter was washed with small amounts of ethyl alcohol until the sample was completely discolored. The volume of used alcohol (ml) was traced. 7.9 ml of distilled water, 0.1 ml of extract, 1 ml of Folin-Denis reagent were added to the tube, stirred and after 3 minutes 1 ml of saturated sodium carbonate solution was added and stirred again. For an hour, the optical density of the contents of the tubes was recorded on a ULAB 102UV spectrophotometer at a wavelength of 640 nm. As a control, a mixture prepared as follows was used: 8 ml of distilled water and 1 ml of Folin-Denis reagent were poured into a tube, stirred, after 3 minutes 1 ml of saturated sodium carbonate solution was added and stirred again. At least 3 parallel measurements were carried out and the average value of the optical density index was found. The total phenolic content in the sample was calculated according to the formula, using the indicators of the graduated graph. Standard solutions of chlorogenic acid with different concentrations were used to construct a graduated graph of the dependence of optical density (unit of optical density) on the concentration of chlorogenic acid ($\mu g\ ml^{-1}$). The data were expressed as a mg per 100 g of raw mass.

Flavonoids. The flavonoid content was determined by the spectrophotometric method (Vronska, 2018), which is based on measuring the absorption of a complex of flavonoids with aluminum chloride in an ethanol medium (70%). Absorption of extracts was measured on a ULAB 102UV spectrophotometer at a wavelength of 410 nm. Quantitative content was converted into rutin. The absorption of the standard rutin solution (comparison solution) was measured simultaneously. The results were expressed in mg of anthocyanin per 100 g of fresh fruit.

Anthocyanins. The content of anthocyanins was determined by the pH difference method (Giusti & Wrosltad, 2001), in which the extracts were dissolved (1 : 150) in two buffer systems: potassium chloride pH 1.0 (0.025 M) and sodium acetate pH 4.5 (0.4 M). The absorption of extracts was measured on a ULAB 102UV spectrophotometer at a wavelength of 520 and 700 nm. The content of anthocyanins was calculated on cyanidin-3-glucoside (molar absorption — 29,600, molecular weight — 449.2). The results were expressed in mg of anthocyanin per 100 g of fresh fruit.

The weather data for the years of research were obtained at the Vantage Pro2 Plus weather station, located in the research area of the IH of the NAAS of Ukraine. The hydrothermal coefficient was calculated by dividing the amount of precipitation for a certain growing season by the sum of active temperatures of 10 ºC and above, and multiplying the result by 10.

The statistical analysis of the study data was performed using STATISTICA 13/1 software (StatSoft, Inc., USA). The results were presented as mean values with their standard errors ($x \pm SE$). The Shapiro-Wilk test was used to evaluate the assumptions of normality and homogeneity of dispersions. Significant differences between mean values were determined using one-way ANOVA analysis. The results were presented at a confidence level of $P < 0.05$. The correlation analysis of the dependence of the content of biologically active substances in strawberry fruits on the weather in May and June was performed in Excel, the data analysis tab.

RESULTS

The period of growth and development of strawberry fruits in the Forest-Steppe zone of Ukraine lasts 28-30 days. In 2023, to conduct analytic studies, the fruits of early cultivars were selected on May 5, those of medium ripening terms — on June 10, and the late ones — on June 16. In the following year, 2024, the analysis of the fruits of early cultivars for the determination of the content of biologically active substances was conducted on day 7, that of medium cultivars — on day 3, and the late ones — one day earlier than the previous year. In 2025, the dates of analyses in terms of ripening were as follows: early cultivars — June 2, medium cultivars — June 9, and late cultivars — June 19.

The weather conditions in the abovementioned periods of the study years differed considerably both in air temperature indices and precipitation. In terms of average daily air temperatures, the warmest periods of growth and development of early and medium cultivars were registered in 2023, when the mentioned temperatures were 17.2°C for early cultivars, and 18.8°C for medium cultivars. The fruits of late cultivars grew and developed under the warmest weather conditions in 2024, the average daily air temperature was 20.4°C, the coolest period was in 2025, when the average daily temperature was 18.9°C (*Table 2*).

The sums of active temperatures of 10°C and higher during the period of growth and development of strawberry fruits of all the maturity groups were the lowest in 2025, amounting to 411.9°C for early, 459.4°C for medium and 577.3°C for late maturity cultivars. In 2024, they were 451.8; 602.5 and 632.2°C, and in 2023 — 541.2; 602.5 and 613.2°C according to the ripening groups.

The largest amount of precipitation, at the level of 42.5 (early), 46.6 (medium), and 47 mm (late), during the period of growth and development of strawberry fruits, was in 2025. It was under 10 mm during the periods of growth and development of early strawberry fruits in 2023 and 2024. In 2023, the strawberry fruits of medium cultivars grew and developed with the precipitation amount of 12.6, and in 2024 — 11.4 mm, and those of late cultivars — in 2024, with the precipitation amount of 15.6, and in 2023 — 11.4 mm. Under the mentioned indices of air temperature and precipitation amount, the hydrothermal index (HTI) for the period of growth and development of strawberry fruits in 2023 and 2024 differed inconsiderably both by years of study and by groups of fruit ripening, being within 0.1–0.3. In 2025, the HTI was 0.8 during the period of growth and development of strawberry fruits of late cultivars, 1.0 — of early ones, and 1.1 — of medium ones (*Table 2*).

The content of vitamin C in strawberry fruits in 2023 varied within the minimum of 41.1 and the maximum of 65.4 with the average inter-cultivar value of 49.7 mg/100 g FW. In 2024, the highest amount of vitamin C was in the fruits of Herkules cultivar (50.4 mg/100 g FW), and the least — in Vibrant cultivar (37.9 mg/100 g FW). In 2025, the maximum amount of this vitamin was accumulated by the fruits of cultivars Vibrant (51.6) and Atlantyda (59.3 mg/100 g FW). In 2025, the fruits of all investigated cultivars contained more than 50 mg/100 g FW of vitamin C. The least amount was registered in strawberry fruits in 2024 — 41.5 mg/100 g FW. The average intercultivar value of vitamin C content in 2025 was 6.2 mg higher than in 2023 and 14.1 mg higher than in 2024 (*Table 2*).

Among the investigated strawberry cultivars, the highest variability in vitamin C content was registered for Florence, Prezent, and Vibrant; the variation coefficients were 26, 23, and 22%, respectively. An insignificant variability in vitamin C content was in early cultivars Olviia and Veselka, and the medium cultivar Herkules — 14, 12, and 7%, respectively (*Fig. 1*).

The amount of polyphenols in strawberry fruits, depending on the cultivar and the study year, varied from the minimum of 301 mg in Herkules in 2024 to the maximum of 742 mg/100 g FW in Veselka in 2025. By the average intercultivar index in 2023, strawberry accumulated 96 mg more polyphenols than in 2024 and 70 mg more than in 2025. In 2023, the variability of the content of polyphenols in strawberry

Table 2. The weather indices for the period of growth and development of strawberry fruits, 2023–2025

Ripening	Average daily t°C			Sum of active t of 10°C and above			Sum of precipitation, mm			HTI		
	2023	2024	2025	2023	2024	2025	2023	2024	2025	2023	2024	2025
Early	17.2	16.5	13.9	541.2	451.8	411.9	6.6	4.3	42.5	0.1	0.1	1.0
Medium	18.8	17.7	16.2	602.5	522.9	459.4	12.6	14.0	46.6	0.2	0.3	1.1
Late	19.2	20.4	18.6	613.2	632.6	577.3	11.4	15.6	47.0	0.2	0.2	0.8

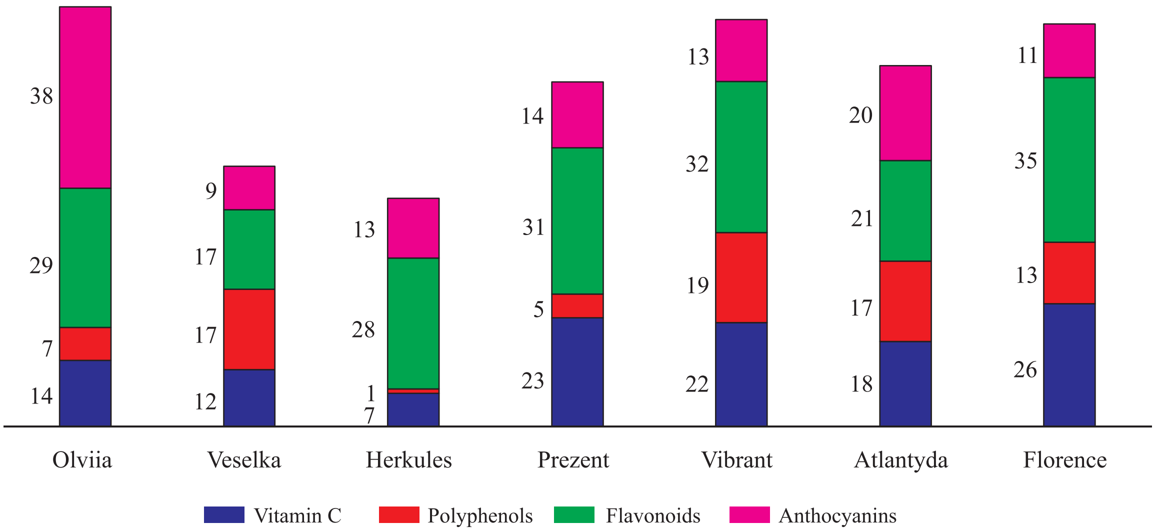

Fig. 1. The variability of the content of biologically active substances in strawberry fruits depending on the weather conditions during the period of their growth and development, %

fruits equalled the variation coefficient of 19.5%. A considerably higher content of the mentioned substances in that year, in addition to Veselka, was observed in Vibrant (564) and Florence (541 mg/100 g FW). In 2024, higher than average inter-cultivar amount (398 mg/100 g FW) of polyphenols was accumulated in the fruits of Veselka and Prezent (433 and 444 mg/100 g FW). The inter-cultivar coefficient of variation in 2024 was 11.9%. In 2025, in addition to Veselka, the highest content of polyphenols was present in the fruits of Vibrant (482) and Florence (498 mg/100 g FW), a much smaller amount compared to the average was noted in the fruits of cultivars Herkules and Atlantyda (297 and 382 mg/100 g FW). The variation coefficient demonstrates an average variability in the content of polyphenols in the investigated cultivars in 2025 (*Table 3*).

Compared to the average index for three study years, a considerably higher content of polyphenols was noted for Veselka cultivar (501 mg/100 g FW), and a considerably lower one — for Herkules (301 mg/100 g FW). The variability in the content of these substances in the former was at the level of the average value, and the variation coefficient was 17%, and in the latter, this index equalled one which demonstrated a stably low content of polyphenols, the accumulation

Table 3. The content of vitamin C and polyphenols in strawberry (mg/100 g FW)

Cultivars	Vitamin C				Polyphenols			
	2023	2024	2025	average	2023	2024	2025	average
Olviia	43.2±2.6^{c}	40.2±2.6	52.7±2.7^{a}	45.4±3.8	453±17	408±13	398±10	420±17
Veselka	42.2±2.6^{c}	41.0±2.2	51.1±2.5^{a}	44.8±3.2	597±15^{ac}	433±13^{bc}	742±12^{c}	501±49^{c}
Herkules	52.5±3.1	50.4±3.0^{c}	57.6±2.5	53.5±2.1	305±11^{d}	301±16^{d}	297±12^{d}	301±2^{d}
Prezent	41.1±2.6^{d}	39.1±2.7	57.3±1.8^{a}	45.8±6.2	480±15^{a}	444±13^{c}	443±12	456±12
Vibrant	56.1±3.1^{c}	37.9±2.3^{b}	59.6±1.6^{a}	50.9±6.6	564±11^{c}	383±15^{b}	482±14^{c}	476±52
Atlantyda	45.2±2.5	42.7±2.7	59.3±2.0^{a}	49.1±5.2	518±12^{a}	398±18	382±13^{d}	433±43
Florence	65.6±3.8^{ac}	39.0±2.5^{b}	51.3±2.7	52.0±7.7	541±14^{ac}	417±11^{b}	498±12^{c}	485±36
Average ± SE	49.4±2.9	41.5±2.6	55.6±2.5^{a}	48.7±2.1	494±16^{a}	398±12	424±14	439±29
V (%)	18.5	10.2	6.7	7.2	19.5	11.9	17.7	15.3

Notes: * the upper indices (a, b) in the rows next to the indicators indicate significantly different values of vitamin C and polyphenols in strawberry fruits compared to the average (x) for the cultivar over the years of research at $p < 0.05$; the upper indices (c, d) in the rows next to the indicators indicate significantly different values of vitamin C and polyphenols in strawberry fruits compared to the average (x) for the group of cultivars studied at $p < 0.05$; **SE — standard error of the average value.

of which did not depend on weather conditions during the period of growth and development of strawberry fruits (*Fig. 1*).

In 2023, the highest amount of flavonoids was accumulated by strawberry fruits of cultivars Vibrant (98 mg/100 g FW) and Florence (97 mg/100 g FW). That year, a considerably smaller average value was noted for Herkules, Atlantyda, and Olviia — 45, 48, and 52 mg/100 g FW, respectively. The inter-cultivar coefficient of variation for that year was 32.5%, which demonstrated high variability in the content of flavonoids in strawberry fruits in 2023. In the following year of 2024, the average inter-cultivar content of flavonoids was 46 mg/100 g FW, which was lower than in 2023 and in 2025, by 26 and 25 mg, respectively. In 2024, an amount of flavonoids, considerably higher than the average for the mentioned group, was accumulated by the fruits of Vibrant cultivar (51 mg/100 g FW), and the least amount — by Prezent (41 mg/100 g FW). The variation coefficient for flavonoids in the mentioned year was low — 11%. In 2025, the average inter-cultivar index of the content of flavonoids in the investigated group of cultivars was 71 mg/100 g FW, which was only one mg/100 g FW lower than in 2023. A considerably higher than average amount of flavonoids for the investigated group of cultivars was accumulated by the fruits of Veselka and Vibrant — 84 and 78 mg/100 g FW, respectively. Their least amount was observed for Olviia (63) and Atlantyda (60 mg/100 g FW). The variation coefficients in the mentioned year were insignificant, 12% (*Table 4*).

According to the average value for each cultivar of over 70 mg/100 g FW, the amounts of flavonoids, accumulated by the fruits, were as follows: Veselka (74), Vibrant (76) and Florence (71 mg/100 g FW) (*Table 4*). The variation coefficients for the mentioned cultivars were 17, 32, and 35%, which demonstrated the average stability for the content of flavonoids in Veselka and high instability of these substances in two other cultivars (*Table 4*, *Fig. 1*).

The content of anthocyanins in the investigated strawberry cultivars in terms of the average inter-cultivar index varied from 13.1 in 2023 to 16.4 mg/100 g FW in 2024. During the first of the mentioned years, their content value, considerably exceeding the average one, was registered in the fruits of Prezent (21.8) and Vibrant (15.2 mg/100 g FW), and a smaller one — in Herkules (8.0), Atlantyda (11.3) and Florence (9.8 mg/100 g FW). That year, the coefficient of inter-cultivar variability in the content of anthocyanins was high — 33.8%. In the following year, all the investigated cultivars contained more anthocyanins than in the previous one. Like the previous year, the highest amount was present in the fruits of Prezent (23.7 mg/100 g FW), and the least one — in Florence (12.2 mg/100 g FW), the variation coefficient in 2024 was 22.8%. In 2025, the mentioned coefficient of the inter-cultivar difference was also average, amounting to 18.2% (*Fig. 1*). The same year, similar to two previous ones, the highest amount of anthocyanins was accumulated by the fruits of Prezent cultivar (18.2 mg/100 g FW), the variation coefficient was 14% (*Fig. 1*). In addition to Prezent, an amount of

Table 4. The content of flavonoids and anthocyanins in strawberry (mg/100 g FW)

Cultivars	Flavonoids				Anthocyanins			
	2023	2024	2025	average	2023	2024	2025	average
Olviia	$52±4.0^{d}$	45±4.0	$63±2.9^{ad}$	53±5.2	13.7±0.9	$14.3±1.0^{d}$	$16.3±0.7^{a}$	14.7±0,8
Veselka	$88±8.5^{a}$	$51±2.9^{b}$	$84±2.8^{c}$	74±11.9	12.9±1.1	16.6±1.0	15.4±0.5	15.0±1.1
Herkules	$45±3.8^{d}$	46±4.5	$74±3.3^{a}$	55±9.3	$8.0±1.7^{bd}$	$17.9±0.8^{a}$	$12.9±0.8^{d}$	13.0±2.9
Prezent	76±6.4	$41±2.2^{bd}$	76±3.2	64±11.9	$21.8±1.1^{c}$	$23.7±1.7^{c}$	$18.2±0.4^{bc}$	$21.2±1.6^{c}$
Vibrant	$98±6.4^{ac}$	$51±4.1^{bc}$	$78±3.2^{c}$	76±13.5	$15.2±0.5^{bc}$	16.2±1.1	$19.8±0.6^{ac}$	$17.1±1.4^{c}$
Atlantyda	$48±3.8^{d}$	$39±1.9^{bd}$	$60±1.7^{ad}$	49±6.0	$11.3±0.3^{d}$	$13.8±1.0^{d}$	$16.9±0.8^{a}$	14.0±1.6
Florence	$97±8.1^{ac}$	$49±2.9^{b}$	66±3.2	71±14.2	$9.8±0.3^{bd}$	$12.2±0.5^{d}$	$11.5±0.5^{d}$	$11.2±0.7^{d}$
Average	72±5.8	$46±1.4^{b}$	71±2.9	63±8.6	$13.1±0.8^{b}$	$16.4±0.7^{a}$	15.9±0.6	15.2±1.0
V (%)	32.5	11.0	12,1	17,0	33.8	22.8	18.2	21.3

Notes: * the upper indices (a, b) in the rows next to the indicators indicate significantly different values of flavonoids and anthocyanins in strawberry fruits compared to the average value (x) for the cultivar over the years of research at $p < 0.05$; the upper indices (c, d) in the rows next to the indicators indicate significantly different values of vitamin C and polyphenols in strawberry fruits compared to the average value (x) for the group of studied cultivars at $p < 0.05$. ** SE — standard error of the mean value.

anthocyanins, much higher than the average inter-cultivar value, was accumulated by the fruits of Vibrant (19.8 mg/100 g FW). Similar to previous years, a considerably smaller amount of anthocyanins was present in the fruits of Herkules (12.9) and Florence (11.5 mg/100 g FW), the variation coefficients were 13 and 11%, respectively (Table 4, Fig. 1).

The pair correlation dependence was used to determine a strong indirect association between average daily air temperatures during the period of growth and development of strawberry fruits and the accumulation of vitamin C in all the cultivars without exception; the correlation coefficients were above 0.700. As for cultivars Olviia and Veselka, a strong direct association was found between the content of vitamin C and HTI for the abovementioned period; the correlation coefficients were 0.974 and 0.993, respectively. No considerable dependence between the accumulation of vitamin C and the hydrothermal coefficient was found for the investigated cultivars during the period of growth and development of the fruits (*Table 5*).

The content of polyphenols in cultivars Olviia, Herkules, and Prezent correlates strongly with the average daily air temperatures during the period of growth and development of fruits; this dependence is direct, the correlation coefficients are 0.781, 0.999 and 0.840, respectively. A strong though reverse association was found for cultivars Veselka (0.950), Vibrant (0.790) and Florence (0.855). A strong indirect association between the content of polyphenols and the HTI during the period of growth and development of the fruits was determined for cultivars Herkules and Prezent, the correlation coefficients were above 0.900. As for the rest of cultivars, no considerable dependence of the amount of polyphenols on HTI was found (*Table 5*).

A dense indirect association between the content of flavonoids and the average daily air temperatures during the period of growth and development was determined for most investigated cultivars, except for Prezent and Florence, with the correlation coefficients of over 0.800. The hydrothermal coefficient in the mentioned period had a strong direct association with the content of flavonoids in the fruits of cultivars Olviia (0.921) and Atlantyda (0.704), and an indirect association — in Herkules (0.793) (*Table 5*).

The anthocyanin component of cultivars Olviia and Veselka had a strong indirect association and that of Herkules had a direct association with the average daily air temperatures during the period of the growth and development of the fruits, the correlation coefficients were 0.999, 0.950 and 0.793, respectively. A close and direct correlation was determined between the content of anthocyanins and HTI during the period of the growth and development of the fruits of Olviia (0.972), Herkules (0.998) and Atlantyda (0.898) (*Table 5*).

DISCUSSION

According to Osatuke & Pritts (2021), under a subtropic climate, the strawberry fruits of one cultivar may demonstrate high variability of their quality traits from year to year. Agehara & Nunes (2021) note that the harvest quality is highly impacted by environmental conditions. In addition, the content of biologically active substances in strawberry fruits considerably depends on the cultivation conditions (Cervantes et al., 2019). For instance, the content of vitamin C in blue honeysuckle may change depending on the cli-

Table 5. The correlation dependence between the content of biologically active substances in the strawberry and the hydrothermal index (HTI)

Cultivars	Vitamin C		Polyphenols		Flavonoids		Anthocyanins	
	average daily t°C	HTI	average daily t°C	HTI	average daily t°C	HTI	average daily t°C	HTI
Olviia	–0.908	0.974	0.781	–0.639	–0.824	0.921	–0.999	0.972
Veselka	–0.950	0.993	–0.950	–0.291	–0.950	0.245	–0.950	0.189
Herkules	–0.748	0.131	0.999	–0.999	–0.923	–0.793	–0.418	0.998
Prezent	–0.864	–0.629	0.840	–0.955	–0.086	–0.543	0.713	0.442
Vibrant	–0.998	0.601	–0.790	0.054	–0.800	0.071	–0.481	0.978
Atlantyda	–0.751	–0.587	–0.228	–0.587	–0.916	0.704	–0.256	0.898
Florence	–0.728	–0.042	–0.855	0.168	–0.629	–0.176	0.587	0.228

mate and cultivation conditions, genotype, ripening stage, and time of harvesting (Ochmian et al., 2012). The growth, development, and ripening of strawberry fruits in the Forest-Steppe of Ukraine occur during the period from the third decade of April till the third decade of June. The weather was considerably different during this period of the study years. In 2025, it was the coldest in May and June, and the sum of active temperatures of 10°C and above during the period of growth and development of strawberry fruits of early cultivars in 2023 was higher by 129.3, and in 2024 — by 39.9°C. In 2025, the period of growth and development of the fruits of medium and late cultivars was also noted for lower average daily air temperatures than in the previous years. For instance, in 2023, during the period of growth and development of medium cultivars, it was by 2.6°C warmer, and for late cultivars — 0.6°C warmer, and in 2024, — by 1.5°C and 1.8°C warmer, respectively, than in 2025. Such weather conditions in the last-mentioned year were found to be beneficial for the fruits of the investigated cultivars to synthesize vitamin C. As a result, the average inter-cultivar amount of this vitamin in the strawberry fruits of the 2025 harvest was 55.6 mg/100 g FW as compared to 49.4 in 2023, and 41.5 mg/100 g FW in 2024. The tendency towards a higher amount of vitamin C in strawberries in 2025 was observed for all the investigated cultivars except for Florence, in which the content of vitamin C was higher in 2023. The fact of beneficial lower temperatures and humid weather for the synthesis of vitamin C was highlighted by Pokorná & Matuškovič (2009). Nevertheless, there is another opinion, for instance, Moor et al. (2005) reported that high air temperature promoted the accumulation of vitamin C in strawberry fruits.

Weather fluctuations during the periods of growth and development of the strawberry in the study years had a negative impact on the synthesis of biologically active substances in the fruits. For instance, in 2024, the fruits accumulated less vitamin C, polyphenols, and flavonoids. In 2024, polyphenols were 96 mg less than in 2023, and 26 mg less than in 2025, and flavonoids — 26 mg less than in 2023 and 25 mg less than in 2025. The results of our study are in agreement with the statement of Zheng (2013) that the main environmental factor impacting the level of biologically active substances in the fruits is the average air temperature. The effect on the chemical composition of strawberry fruits is made by high air temperature as well, but the effect limitations depend on the cultivar (Asadpoor & Tavallali, 2015). Cosmulescu et al. (2023) noted that the influence of the cultivar genotype on the content of biologically active substances is higher than that of the cultivation year. This statement is in full agreement with the results, obtained in the study regarding some cultivars. For instance, the strawberry cultivar of Ukrainian breeding, Herkules, had a stable similar content of vitamin C, the variation coefficient in the study years was 7%, the range of the content was within the minimum of 50.4 and the maximum of 57.6 mg/100 g FW. The mentioned level of vitamin C content in the Herkules cultivar was at the level of 40–70 mg/100 g FW, determined by Sapei & Hwa (2014). Other scientists highlight larger margins of its content in strawberry fruits: from 27.80 to 138.03 mg/100 g FW (Ali & Serce, 2022). The maximum of vitamin C, accumulated by strawberry fruits, grown in Turkey, was 25.08 mg/100 g FW (Urün et al., 2021), which was considerably less than that in the investigated cultivars.

Depending on the cultivation year and cultivar, the investigated strawberry cultivars contained 301–742 mg/100 g FW of polyphenols which is considerably lower than the amount in blackberries — 528–845 mg/100 g FW (Shevchuk et al., 2023) but more than in blueberries (280–494 mg/100 g FW) (Shevchuk et al., 2021). Yet, according to the statements of scientists from Turkey, Urün et al. (2021), the strawberry, grown in their conditions, accumulated from 99.00 to 158.37 mg/100 g FW of polyphenols, which was considerably below the investigated cultivars. The fruits of the cultivars, investigated by Italian scientists Contessa et al. (2013), contained more polyphenols (196.0–398.67 mg/100 g FW) than those grown in Turkey, but less than those, studied by Vasco et al., (2008), where the content margins were 238–355.3 mg/100 g FW.

According to Sarıdaş (2021), the mechanisms of accumulating polyphenols vary for strawberry cultivars even under the same cultivation conditions. In addition, their reaction to different weather conditions is different. The confirmation of the fact that the cultivar genotype defines the content of polyphenols and their homeostasis may be stable can be found in the content of the mentioned substances in the fruits of Olviia, Herkules, and Prezent, where the variation coefficients were 8.0, 1.0 and 5.0%, respectively. The content margins of polyphenols in Olviia caried from 398 to 453, in Herkules — from 297 to 305, and in Prezent — from 443 to 480 mg/100 g FW, respectively. Although the variability margins for the content of polyphenols in the abovementioned cultivars were insignificant, a considerable indirect dependence of their amount on the HTI for the period of growth and development of fruits was found. For instance, in 2023, when the HTI in the mentioned period was within 0.1-0.2, the number of polyphenols in the fruits of Olviia was 453, in Herkules — 305, and in Prezent — 480 mg/100 g FW. In 2025, the HTI for the period of growth and development of fruits was 0.8–1.1, the content of polyphenols in Olviia was 55 mg lower, in Herkules — 8 mg lower, and in Prezent — 37 mg lower; the correlation coefficients were 0.639, 0.999, and –0.955, respectively.

Flavonoids are a group of natural polyphenols that are in large amounts in fruits and are responsible for their color, aroma, and taste characteristics (Jaakola, 2013). The content of flavonoids, as per Khattab et al. (2016), depends on genetic inheritance and epigenetic modification as mechanisms of plant reaction to ecological stress. Peng et al. (2020) determined that the biosynthesis of flavonoids is regulated not only by internal genetic factors but also by external factors, including light and temperature. Wang and Zheng (2001) stated that higher temperatures enhance the accumulation of flavonoids considerably. However, there is an opposite opinion that higher air temperatures slow down the synthesis of biochemical components (Krüger et al., 2012; Osatuke & Pritts, 2021), which is in agreement with our study. In particular, as for the content of flavonoids, we determined a close indirect correlation between their amount in the fruits and average daily air temperatures, the correlation coefficients of over 0.800 for cultivars Olviia, Veselka, Herkules, Vibrant, and Atlantyda.

The synthesis of anthocyanin is initiated by ultraviolet radiation, and the increase in the anthocyanin accumulation is often explained by the impact of highly intensive light during the development of the fruits (Cervantes et al, 2019). Wang & Camp (2000) noted that the strawberry, grown under the highest temperatures (30/22°C) was dark red and had the most colored surface. According to Kadomura-Ishikawa et al., (2013), in strawberries, anthocyanins are quickly accumulated in the late stages, starting from the moment when the fruits become white. This statement is plausible in case of cultivars Veselka, Herkules, Prezent, and Florence. In 2023, when the sums of active temperatures of 10 oC and above during the periods of growth and development of the fruits of the mentioned cultivars were higher than in 2024, the content of anthocyanins was higher than in 2024 — in Veselka by 1.2 mg, in Herkules by 5.0 mg, in Prezent by 9.1 mg, and in Florence by 2.4 mg, and higher than in 2025 — by 1.6, 4.9, 2.5 and 1.0 mg, respectively. The coefficients of correlation between the average daily air temperatures and the amount of anthocyanins in the fruits of the mentioned cultivars were significant, above 0.800, and the dependence was indirect.

In addition to the impact of the environmental factors, the content of biocomponents in strawberry fruits is affected by the cultivar. This is confirmed by the data, obtained by scientists from different countries. The strawberry, grown in Italy, contained from 200 to 600 mg/kg DW anthocyanins (da Silva et al., 2007), in their other publications, da Silva Pinto et al. (2008) noted that the content of the mentioned substances fluctuated from 124 to 442 mg/kg-1 FW. According to the data of the research of Chinese scientists, the average content of anthocyanins equalled 57.68 mg/100 g FW (Chen et al., 2024). The amount of anthocyanins in strawberry, grown in Slovakia, varied within the interval of 121.98–212.73 mg/kg^{-1} FW (Musilová et al., 2013), which is in agreement with the data, obtained in the study, namely, the minimal content of anthocyanins, grown in the Forest-Steppe of Ukraine, was 11.3 (Atlantyda) in 2023, and the maximal content of 23.7 mg/100 g FW (Prezent) was registered the same year. Higher indices of total anthocyanins, within 226.8–274.0 mg/kg^{-1} FW, were determined by Oszmiański and Wojdylo (2009). Castro et al. (2002) noted that the amount of anthocyanins in strawberry fluctuated within the interval of 299.8 — 481.9 mg/100 g FW^{-1}. Their content in the hybrids, investigated by Sirijan et al. (2020), was within these values (31–38 mg/100 g FW). A considerably higher variability in the content of anthocyanins, from 8.5 to 65.9 mg/100 g FW, was found in the strawberry fruits by Aaby et al. (2012).

CONCLUSIONS

The study determined that the content of biologically active substances in the strawberry fruits depended on the cultivar genotype and the weather conditions of the cultivation year. The margins of the content of vitamin C in the investigated cultivars were 37.9–95.6 mg/100 g FW, polyphenols — 301–

742 mg/100 g FW, flavonoids — 39–98 mg/100 g FW, anthocyanins — 11.2–23.7 mg/100 g FW. The least variable and independent of weather conditions of the cultivation period was the content of vitamin C in the fruits of Herkules, polyphenols in the same cultivar as well as in Prezent and Olviia, and anthocyanins in Olviia. The variation coefficients over 17% demonstrate high variability in the flavonoid component of the fruits of the investigated strawberry cultivars. The correlational dependence was used to determine a strong association between the content of vitamin C and the average daily air temperatures, and the association between flavonoids and HTI during the period of growth and development of the fruits. The dependencies were considerably different in terms of the bioactive components of the fruits and the cultivar.

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ВМІСТ БІОЛОГІЧНО АКТИВНИХ РЕЧОВИН У СУНИЦІ (*FRAGARIA×ANANASSA*) ВИРОЩЕНІЙ В ЛІСОСТЕПУ УКРАЇНИ

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Мета. Дослідити вплив погодних умов Лісостепу України та генетичних особливостей сортів на вміст вітаміну С, поліфенольних речовин, флаваноїдів та антоціанів у плодах суниці. **Методи.** Дослідження проводили протягом 2023–2025 рр., плоди суниці 7 сортів різних термінів достигання, відбирали в дослідних насадженнях Інституту садівництва НААН України. Показники погоди періоду вегетації до збирання плодів суниці брали з метеостанції Vantage Pro2 Plus, яка розташована в дослідних насадженнях суниці. Аналітичні дослідження виконували за методикою "Визначення якості плодово-ягідної продукції" (Кондратенко та ін., 2008) зокрема, спектрофотометричними методами, визначали вміст біологічно активних речовин та виражали в mg/100 g FW. Кількість вітаміну С визначали з допомогою титрування розчином 2,6-дихлорфеноліндофенолу, поліфенольних речовин — з допомогою реактиву Фоліна-Дені, флаваноїдів — вимірюванням поглинання комплексу флавоноїдів з алюмінію хлоридом у середовищі етанолу, антоціанів методом різниці у двох буферних системах: хлориду калію pH 1,0 (0,025 М) і ацетату натрію pH 4,5 (0,4). М). Статистичний аналіз даних дослідження проводили за допомогою програми STATISTICA 13/1 (StatSoft, Inc., США). **Результати.** Показники погоди періоду росту та розвитку плодів суниці мали істотний вплив на вміст у них вітаміну С, поліфенолів, флаваноїдів та антоціанів. Найбільш стабільним та не залежними від погодних умов року вирощування був вміст вітаміну С у плодах сорту Геркулес, мінімум — 50,4, максимум — 57,6, середнє — 53,5 mg/100 g FW. Найбільш варіабельним і залежним від погодних умов року вирощування виявився вміст вітаміну С у суниці сортів Флоренс та Вайбрант, середній вміст становив 52,0 і 50,9 mg/100 g FW. Кількість вітаміну С у плодах суниці істотно залежить від середньодобових температур повітря, коефіцієнти кореляції для досліджувано групи сортів були високими, понад 0,720, збільшення середньодобових температур повітря сприяє зменшенню вмісту вітаміну С. Кількість поліфенолів у сортів Геркулес та Презент істотно корелює, як із середньодобовими температурами повітря та з ГТК періоду їх росту та розвитку, але в першому випадку зв'язок прямий, а в другому не прямий. Максимальну кількість флаваноїдів, більше 70 mg/100 g FW, серед досліджуваних сортів спроможні накопичувати плоди Веселки, Вайбранти і Флоренс. Антоціанів більше 20 mg/100 g FW спроможні накопичували ягоди Презента. Гомеостатичним є вміст флаваноїдів у сорту Презент, антоціанів у сорту Веселка. **Висновки.** Встановлено, що вміст біологічно активних речовин у плодах суниці визначається генетичними особливостями сорту, а також корегуються погодними умовами періоду їх росту та розвитку.

Ключові слова: суниця, вітамін С, поліфеноли, флаваноїди, антоціани.