Plant and Soil Science

Journal homepage: https://agriculturalscience.com.ua/en
Plant and Soil Science, 16(4), 34-46
Received: 13.07.2025 Revised: 01.11.2025 Accepted: 27.11.2025

UDC 581.15: 581.6: 547.9: 547.99: 634.19 (477)

DOI: 10.31548/plant4.2025.34

Serhii Kovalchuk
Postgraduate Student
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0001-8293-1797

Volodymyr Mezhenskyj*
Doctor of Agricultural Sciences, Senior Researcher
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-3154-1120

Biochemical composition and nutritional value of rowan-chockeberry hybrids (×*Sorbaronia fallax* (C.K. Schneid.) C.K. Schneid.) developed in Ukraine

Abstract. This study provided a comprehensive analysis of the biochemical composition and nutritional value of nine promising rowan-chokeberry hybrids (×*Sorbaronia fallax*) developed at the National University of Life and Environmental Sciences of Ukraine (NULES). These hybrids were compared to two established cultivars: 'Vseslava' and 'Nero'. The research aimed to evaluate the content of dry matter, soluble solids, total sugars, titratable acidity, pectin, ascorbic acid, polyphenolics, anthocyanins, and chalcones. Fruit samples were collected in 2023-2024 from NULES experimental orchards. The results showed significant differences between the genotypes. Specifically, genotype 5-84 exhibited the highest levels of dry matter, soluble solids, ascorbic acid, anthocyanins, and chalcones, while genotype 3-15 generally had the lowest levels. The effect of the cultivation year was only statistically significant for pectin content. Strong positive correlations were observed between dry matter and soluble solids ($r = 0.90$) and between anthocyanins and chalcones ($r = 0.99$). Overall, the hybrids surpassed the parent cultivar in several nutritional aspects, including sugar content, pectin, ascorbic acid, anthocyanins, and chalcones, highlighting their significant genetic potential. The findings of this study offered valuable information for breeding programmes focused on improving the nutritional traits of these fruits. Breeders and agronomists can use these results to select the best genotypes for further cultivation. Furthermore, producers of food and dietary supplements can leverage this data to develop new functional products

Keywords: ×*Sorbaronia fallax* subsp. *fallax*; genothypes; ascorbic acid; polyphenols; anthocyanidines

Suggested Citation:
Kovalchuk, S., & Mezhenskyj, V. (2025). Biochemical composition and nutritional value of rowan-chockeberry hybrids (×*Sorbaronia fallax* (C.K. Schneid.) C.K. Schneid.) developed in Ukraine. *Plant and Soil Science,* 16(4), 34-46. doi: 10.31548/plant4.2025.34.

*Corresponding author

INTRODUCTION

The development of contemporary horticulture is increasingly driven by the introduction of new fruit crops that offer enhanced resistance to abiotic and biotic environmental factors and possess a unique biochemical composition rich in biologically active substances. Many formerly wild fruit plants, such as blueberry, cranberry, kiwifruit, sea buckthorn, and black chokeberry, are cultivated on hundreds of thousands of hectares in many countries, providing people with valuable fruit for fresh and processed consumption. In the 20th century, a new fruit crop called black chokeberry, also known as black rowan, gained widespread popularity as a novel fruit crop. Its fruits are highly valued for their exceptional content of bioflavonoids. According to research by Z. Kobus *et al.* (2019), the therapeutic properties of bioflavonoids for cardiovascular health are highlighted. A. Sidor & A. Gramza-Michałowska (2019) pointed to the high antioxidant potential of the fruits, making them beneficial for a healthy diet. Furthermore, H. Yang *et al.* (2019) noted that due to their high anthocyanin content, the fruits are also used as a food colouring. Recent reviews, such as those by J. Xu *et al.* (2024), highlighted the diversification of chokeberry products into juices, fermented beverages, and functional foods, driven by growing market demand. This research underscores the numerous applications of chokeberry as a functional food, primarily due to the health benefits of its polyphenolic compounds and exceptional antioxidant properties, positioning chokeberries as an important source of natural functional ingredients. According to B. Strik *et al.* (2003) and B. Green *et al.* (2023), garden chokeberry cultivation has expanded beyond Europe to other continents.

Horticulturalists initially regarded the cultivated plant as a cultivated variety of *Aronia melanocarpa* (Michx.) Elliott. However, subsequent molecular studies definitively established it as a hybrid, resulting from the intergeneric cross between *Aronia melanocarpa* (black chokeberry) and *Sorbus aucuparia* L. (common rowan). Various names have been proposed for this hybrid by systematists: *Aronia mitschurinii* A. Skvortsov & Maitulina and ×*Sorbaronia mitschurinii* A. Skvortsov & Maitulina. However, the botanically correct name for hybrids between these parent species is ×*Sorbaronia fallax* (C.K. Schneid.) C.K. Schneid. (International code of..., n.d.). Morphologically, the new fruit plants are more similar to *Aronia* species, while *Sorbaronia fallax*, the preferred name for such hybrids, has leaves with an intermediate morphology between the simple leaves of *Aronia* species and the compound leaves of *Sorbus*. To address this, A. Stalažs & A. Bādere (2023) recognised two subspecies within *Sorbaronia fallax*: subsp. *fallax* with intermediate-structure leaves and subsp. *mitschurinii* A. Skvortsov & Maitulina with simple leaves. All cultivars of the garden chokeberry, also known as the black chokeberry sensu horticulturists, belong to ×*Sorbaronia fallax* subsp. *mitschurinii*. These plants are notable for their apomictic seed development, a trait that ensures seedlings largely retain the characteristics of the mother plant, thereby facilitating the establishment of industrial plantations using seed-derived planting material. Despite this, horticultural practice often favours varietal culture through the vegetative propagation of superior genotypes, which are then recognised as named varieties or cultivars. The first cultivar, *Sorbaronia fallax* subsp. *mitschurinii* 'Nero', was registered in Czechoslovakia in 1989. In subsequent years, other named cultivars of *Sorbaronia fallax* subsp. *mitschurinii* appeared in various European countries. Due to the apomictic development of their seeds, these cultivars were practically identical to each other.

The first variety of garden chokeberry of Ukrainian breeding, 'Vseslava', was included in the State Register of Plant Varieties of Ukraine in 2019 (Ministry of Agrarian Policy..., 2025). Uniquely among the widely cultivated varieties of this crop, 'Vseslava' belongs to *Sorbaria fallax* subsp. *fallax*. According to V. Mezhenskyj *et al.* (2024), while 'Vseslava' surpasses ×*Sorbaronia fallax* subsp. *mitschurinii* cultivars in fruit size and number of fruits per cluster, it exhibits lower levels of polyphenol compounds. Unlike *Sorbaronia fallax* subsp. *mitschurinii*, which produces genetically and morphologically homogeneous seedlings, 'Vseslava' seedlings exhibit significant variability. This variability provides a solid foundation for future breeding efforts aimed at enhancing the cultivation of garden chokeberry and garden rowan, which are both RCH's.

Therefore, this study specifically aimed to investigate the biochemical variability of selected ×*Sorbaronia fallax* subsp. *fallax* 'Vseslava' seedlings, providing insights into their potential for further horticultural development.

MATERIALS AND METHODS

Plant Materials. The breeding fund, consisting of 'Vseslava' seedlings, was cultivated using a 3 × 1 m planting scheme in the Fruit & Vegetable Garden at the National University of Life and Environmental Sciences of Ukraine (NULES) in Kyiv. The study used nine RCH's genotypes from this collection: 2-49, 2-50, 2-63, 3-6, 3-15, 3-42, 3-88, 5-58, and 5-84. Cultivars 'Nero' and 'Vseslava' from the collection orchard of the Educational, Research and Productive Laboratory of Genetic Resources, Introduction and Breeding of Rare Fruits and Ornamental Plants at the Department of Horticulture of NULES, near Kyiv, were also used. The plants were cultivated according to the standard agricultural practices employed for fruit crops in the region, with due consideration given to the local soil and climatic conditions. Fruit samples of these hybrids and cultivars were harvested in mid-August of consecutive years (2023 and 2024) when the pomes were visually assessed as ripe based on their black colour at maturation. The study was conducted in compliance with the ethical standards of the Convention on Biological Diversity (1992) and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1976).

Dry matter. To determine dry matter, fruit samples (3-4 g) were dried to a constant weight in an SNOL 58/350 (Ukraine) drying cabinet at 98-100°C. The results are expressed as a percentage.

Soluble solids. Soluble solids were measured using a PAL-1 ATAGO (China) portable refractometer. For the analysis, 15-20 fruits were homogenised, and a drop of the resulting juice was placed on the refractometer glass. The data are also expressed as a percentage.

Organic titrated acids. To extract the acids, 25 g crushed sample was extracted with hot distilled water. After cooling and filtering, 20 ml of the extract was titrated with 0.1 N sodium hydroxide using phenolphthalein as an indicator until a stable pink colour appeared. The acid content was then calculated using an equation that includes a conversion factor to citric acid and expressed as a percentage of the raw mass.

Sugars. Sugars were extracted from the fruit with hot distilled water. The extract was then purified to remove proteins and pigments. Sucrose was hydrolysed into glucose and fructose by heating with 10% hydrochloric acid. The resulting sugars were oxidised using Fehling's solution, and the optical density of the solution was measured at 640 nm with a ULAB 102UV (China) spectrophotometer. A standard curve, created from glucose solutions of known concentrations, was used to calculate the final sugar content, which was expressed as a percentage of the original mass.

Pectin Substances. To determine the content of pectin substances, the sample was first purified with ethyl alcohol to remove sugars and pigments. Soluble pectin was then extracted with water, and protopectin was extracted with 1N sulphuric acid. The protopectin was hydrolysed to galacturonic acid by heating. A coloured complex was formed by adding a 0.2% carbazole solution and concentrated sulphuric acid to both the soluble pectin and protopectin extracts. The optical density of these solutions was measured at 535 nm using a ULAB 102UV spectrophotometer. The final pectin content was calculated using a calibration graph based on galacturonic acid standards, with results expressed as a percentage.

Ascorbic Acid. To determine ascorbic acid, a sample was mashed and extracted with a solution of 2% oxalic acid and 1% hydrochloric acid. The filtered extract was then titrated with a 2.6-dichlorophenolindophenol solution (Tilmans' paint). The ascorbic acid content was calculated using an equation based on the titration results and expressed as mg per 100 g of raw mass.

Total polyphenolic. The total polyphenolic content was extracted from a mashed sample using ethyl alcohol. The resulting extract was then combined with distilled water, Folin-Denis reagent, and a saturated sodium carbonate solution. After a one-hour reaction period, the optical density was measured at 640 nm using a ULAB 102UV spectrophotometer. The final content was calculated using a standard curve prepared with chlorogenic acid solutions and expressed as mg/100 g of raw mass.

Anthocyanin and Chalcone. Anthocyanin and chalcone content were determined spectrophotometrically. An alcohol extract from an acidified plant homogenate (containing 3.5% hydrochloric acid) was prepared, and its absorption was measured at 530 nm and 364 nm, respectively, using a ULAB 102UV spectrophotometer. The results are expressed in mg/100 g of raw mass.

Statistical analyses. Descriptive statistics were used to analyse the data obtained and calculate the average values, standard deviation (SD), and coefficient of variation (CV%) for each trait over two years. The percentage change between 2023 and 2024 for each biochemical composition trait was determined, as was the range of fluctuations. An independent two-sample Welch's t-test was performed to detect significant differences between cultivars for each parameter, assuming unequal variances and a significance level of $\alpha = 0.05$. The effect of year and genotype on each selection parameter was assessed separately using a two-factor analysis o f variance (ANOVA) in Microsoft Excel. Fisher's least significant difference (LSD) test was used to determine significant differences between means at a 95% confidence level ($p \leq 0.05$). Results are presented as the mean ± standard deviation. To assess the linear relationships between the measured parameters, Pearson correlation coefficients were calculated using Microsoft Excel. The dendrogram of genotypes was constructed using the Python programming environment. Data normalisation was performed using Z-score (StandardScaler), and hierarchical clustering was carried out by Ward's method (Ward's linkage) with the aid of the scikit-learn and SciPy libraries. Visualisation was performed using Matplotlib.

RESULTS AND DISCUSSION

Two cultivars were included in the study: *Sorbaronia fallax* subsp. *mitschurinii* 'Nero', a typical example of garden chokeberry; and *Sorbaronia fallax* subsp. *fallax* 'Vseslava', the mother cultivar of the nine RCH's genotypes studied. Due to the different growing conditions, these varieties cannot be used as controls for these RCH's genotypes. However, a comparative analysis of biochemical parameters enables to identification of common features and differences. The biochemical composition of these cultivars is presented in Table 1 and Table 2.

Table 1. Biochemical composition of two cultivar fruits, %

Genotype	Dry matter	Soluble solids	Total sugar	Titratable acidity	Sugar/Acid ratio	Pectin substances
'Nero'	22.56 ± 5.93	17.91 ± 3.83	6.91 ± 0.42	1.58 ± 0.21	4.41 ± 0.83	0.99 ± 0.01a
'Vseslava'	17.90 ± 1.83	17.76 ± 0.93	5.70 ± 1.41	1.49 ± 0.07	3.81 ± 0.77	0.72 ± 0.01b

Note: the data represent average values for 2023-2024 (x ± SD, n = 2), where SD – standard deviation, n – number of replicates. Different letters within a column indicate a statistically significant difference ($p < 0.05$, Welch's t-test). Letters are assigned from the highest to the lowest mean value
Source: compiled by the authors

Table 2. Biologically active compounds of two cultivar fruits, mg/100 g

Genotype	Ascorbic acid	Total polyphenols	Anthocyanins	Chalcons
'Nero'	12.44 ± 2.63	3,318.45 ± 193.11a	148.92 ± 11.77	74.35 ± 22.27
'Vseslava'	13.72 ± 2.22	2,111.45 ± 147.86b	113.47 ± 22.44	42.00 ± 7.35

Note: the data represent average values for 2023-2024 (x ± SD, n = 2), where SD – standard deviation, n – number of replicates. Different letters within a column indicate a statistically significant difference ($p < 0.05$, Welch's t-test). Letters are assigned from the highest to the lowest mean value
Source: compiled by the authors

Welch's t-test successfully demonstrated that most traits were not statistically significant ($p > 0.05$). However, statistically significant differences were observed between 'Vseslava' and 'Nero' for pectin substances and total polyphenol content only. The anthocyanins and chalcones traits approached statistical significance. Specifically, 'Vseslava' accumulates lower amounts of both pectin substances and total polyphenols in its fruits compared to 'Nero'. Research by S. Kulling & H. Rawel (2008) showed that the pectin content in fresh chokeberry fruits ranges from 0.30 to 0.75%. This range is supported by the study by M. Trenka *et al.* (2020), who reported a pectin content of 0.35-0.50%. Notably, the pectin content in 'Vseslava' under experimental conditions was significantly higher than the reported ranges.

Cultivars of garden chokeberry belonging to ×*Sorbaronia fallax* subsb. *mitschurinii* are valued precisely for their extremely high total polyphenol content. The lower quantity of these compounds in the fruits of *Sorbaronia fallax* subsb. *fallax* 'Vseslava' may indicate a reduced value of this cultivar in terms of this biochemical trait. These data align with earlier comparative studies of *Aronia* and garden chokeberry cultivars. For example, V. Mezhenskyj *et al.* (2024) propose that the total polyphenol content decreases in the following order: *Aronia melanocarpa* > ×*Sorbaronia fallax* subsp. *mitschurinii* > ×*Sorbaronia fallax* subsb. *fallax*. M. Brand *et al.* (2017) also reported a higher content of total polyphenols in chokeberry species compared to garden chokeberry cultivars.

Nevertheless, 'Vseslava' demonstrated the capacity to accumulate total polyphenols as some cultivars of ×*Sorbaronia fallax* nothosubsp. *mitschurinii*, and the fruits of its seedlings can have a higher content of total polyphenols (Gürer *et al.*, 2023; Mezhenskyj *et al.*, 2024). Considering that 'Vseslava' possesses significantly better productivity characteristics (such as the number of fruits per cluster and their mass) compared to ×*Sorbaronia fallax* subsb. *mitschurinii* cultivars, it represents a valuable source for garden chokeberry breeding. Therefore, a breeding fund of several hundred 'Vseslava' seedlings was established. Nine genotypes, selected based on the aforementioned morphological fruit characteristics, were analysed for their fruit biochemical composition (Tables 3, 4).

Table 3. Biochemical composition of RCH fruits, %

Genotype	Dry matter	Soluble solids	Total sugar	Titratable acidity	Sugar/Acid ratio	Pectin substances
2-49	20.74 ± 0.90cd	18.31 ± 0.98bc	7.44 ± 1.10	1.36 ± 0.42	5.88 ± 2.65	0.97 ± 0.02b
2-50	19.04 ± 0.63d	16.36 ± 3.20cd	6.77 ± 0.41	1.64 ± 0.02	4.12 ± 0.30	1.09 ± 0.01a
2-63	23.91 ± 0.16abc	21.02 ± 1.16ab	7.76 ± 0.04	1.17 ± 0.07	6.65 ± 0.43	0.86 ± 0.06d
3-6	23.38 ± 0.74bc	20.36 ± 2.35bc	7.16 ± 0.14	1.44 ± 0.04	4.97 ± 0.25	0.74 ± 0.02f
3-15	18.67 ± 4.67d	15.11 ± 0.72d	6.71 ± 1.06	1.23 ± 0.16	5.55 ± 1.56	0.59 ± 0.01g
3-42	24.47 ± 0.04ab	21.66 ± 1.36a	7.27 ± 0.72	1.07 ± 0.07	6.84 ± 1.13	0.96 ± 0.01b
3-88	22.16 ± 1.70bcd	18.26 ± 2.49bc	6.11 ± 0.03	1.07 ± 0.34	6.01 ± 1.88	0.83 ± 0.02e
5-58	20.75 ± 0.85ab	20.76 ± 1.22ab	6.52 ± 1.40	1.14 ± 0.02	5.76 ± 1.34	0.58 ± 0.01g
5-84	27.24 ± 2.00a	23.01 ± 1.71a	6.27 ± 0.85	1.02 ± 0.09	6.10 ± 0.28	0.92 ± 0.01c

Note: the data represent average values for 2023-2024 (x ± SD, n = 2), where SD – standard deviation, n – number of replicates. Different letters indicate values that are significantly different within one column according to results of the LSD test ($p \leq 005$). Letters are assigned from the highest to the lowest mean value
Source: compiled by the authors

Table 4. Biologically active compounds of RCH fruits, mg/100 g

Genotype	Ascorbic acid	Total polyphenols	Anthocyanins	Chalcons
2-49	19.90 ± 0.42b	1,617.70 ± 280.40	93.30 ± 8.35ab	40.05 ± 4.88ab
2-50	21.56 ± 1.39a	1,564.55 ± 129.32	42.31 ± 6.81c	25.15 ± 1.48c
2-63	20.78 ± 0.55ab	1,699.60 ± 184.78	41.70 ± 0.28c	26.90 ± 0.57c
3-6	18.82 ± 1.66bc	1,357.55 ± 561.94	78.78 ± 22.79b	36.80 ± 0.00b
3-15	6.17 ± 2.08d	1,644.00 ± 768.17	20.10 ± 0.71c	20.85 ± 0.78c
3-42	21.07 ± 0.70ab	2,021.90 ± 357.96	101.27 ± 5.43ab	44.00 ± 6.79b
3-88	16.95 ± 0.97c	1,919.70 ± 99.42b	91.66 ± 5.47ab	38.20 ± 4.10ab

Table 4, Continued

Genotype	Ascorbic acid	Total polyphenols	Anthocyanins,	Chalcons
5-58	20.00 ± 0.28ab	2,215.95 ± 383.18	119.32 ± 6.10a	47.20 ± 5.52a
5-84	21.08 ± 0.42ab	2671.40 ± 261.06	114.53 ± 24.08a	46.70 ± 8.49a

Note: the data represent average values for 2023-2024 (x ± SD, n = 2), where SD – standard deviation, n – number of replicates. Different letters indicate values that are significantly different within one row according to results of the LSD test (p ≤ 005). Letters are assigned from the highest to the lowest mean value
Source: compiled by the authors

A two-factor ANOVA revealed statistically significant differences (p ≤ 0.05) between genotypes for most biochemical parameters under study, except total sugars, titratable acidity, the sugar-acid index, and total polyphenols. This finding underscores the substantial genetic control over these traits and highlights the crucial role of genotype in determining desirable fruit quality characteristics. For instance, genotype 5-84 consistently exhibited the highest levels of dry matter, soluble solids, ascorbic acid, anthocyanins, and chalcones, whereas genotype 3-15 generally showed the lowest levels of these substances. Furthermore, genotypes 2-50, 2-63, 3-42, and 5-58 demonstrated ascorbic acid content comparable to genotype 5-84, while genotypes 2-49, 3-88, and 5-58 were similar in their anthocyanin and chalcone accumulation. Although there were no significant differences in total polyphenol content among genotypes, potentially due to the limited number of observations, genotypes 5-58 and 5-84 numerically exhibited the highest levels of anthocyanins, chalcones, and overall total polyphenols. Significant differences in pectin content were also identified across almost all genotypes, with genotype 2-50 notably accumulating the highest level, which was also associated with the highest ascorbic acid content.

The fruits of the studied genotypes exhibited high sugar content and a favourable sugar-to-acid ratio, contributing positively to their nutritional value and taste. These characteristics generally positioned them as superior to the two reference cultivars, including the 'Vseslava' parent cultivar. However, it is important to acknowledge that differences in soil conditions across cultivation sites might have influenced these characteristics (Yavorovskyi & Brovko, 2014). Furthermore, the accumulation of high amounts of pectin supports the nutritional value of these genotypes and enhances their suitability for fruit processing. According to A. Sidor & A. Gramza-Michałowska (2019) and J. Xu *et al.* (2024), biologically active substances with high antioxidant potential, such as ascorbic acid and bioflavonoids, are crucial components of a healthy modern diet. Fruits of the RCH seedlings, in particular, demonstrated higher ascorbic acid content than the cultivars under study, with some genotypes also exhibiting comparable levels of bioflavonoids. According to the two-factor ANOVA, the effect of the year of cultivation was statistically significant (p ≤ 0.05) exclusively for pectin content. This indicates that while certain parameters may exhibit inter-annual variation influenced by weather conditions, the primary determinant for most characteristics resides at the genetic level. Table 5 provides a summary of the statistics for each chemical trait across the two growing years (2023 and 2024), offering valuable insights into the mean values, variability, and dynamic changes in the fruit's chemical composition among the studied genotypes.

Table 5. Statistics describing the chemical composition of the fruits of the genotypes that were studied for each trait (n = 9)

Trait	Year	x ± SD	CV, %	Min – max	Change, % (2024 compared to 2023)
Dry matter	2023	23.04 ± 2.77	12.01	19.49–28.72	-6.76
	2024	21.48 ± 3.21	14.94	15.36–25.75	
Soluble solids	2023	20.47 ± 2.73	13.33	15.62–24.22	-10.00
	2024	18.39 ± 2.72	14.81	14.10–21.80	

Table 5, Continued

Trait	Year	x ± SD	CV, %	Min – max	Change, % (2024 compared to 2023)
Total sugar	2023	6.89 ± 0.69	9.96	5.66–7.78	-3.22
	2024	6.60 ± 0.94	13.43	5.53–8.21	
Titratable acidity	2023	1.23 ± 0.29	23.85	0.83–1.66	2.09
	2024	1.25 ± 0.20	16.26	1.02–1.66	
Sugar-Acid Ratio	2023	5.86 ± 1.21	20.59	4.01–7.34	-3.26
	2024	5.67 ±1.40	24.66	3.90–7.75	
Pectin substances	2023	0.82 ± 0.17	20.98	0.57–1.08	3.21
	2024	0.85 ± 0.18	20.72	0.58–1.10	
Ascorbic acid	2023	18.27 ± 5.28	28.91	4.70–21.56	2.27
	2024	18.69 ± 4.47	23.95	7.64–22.54	
Total phenolics	2023	1885.89 ± 486.78	25.81	1101.00–2856.00	-2.95
	2024	1830.23 ± 503.76	27.52	970.10–2486.90	
Anthocyanins	2023	78.54 ± 38.12	48.53	19.60–131.56	-1.09
	2024	77.68 ± 34.61	14.55	20.60–115.00	
Chalcons	2023	37.79 ± 11.74	31.05	20.30–52.70	-8.38
	2024	34.62 ± 8.34	24.09	21.40–43.50	

Source: compiled by the authors

The inherent variability of plants can be described by the coefficient of variation, where 5-24% is the "lower" norm, 25-44% is the "upper" norm, and 45-63% is "large variation" (Mezhenskyj, 2021). Most biochemical composition traits of the genotypes under study generally fluctuated within normal ranges, with the notable exception of anthocyanidin content in 2023. This anomaly was primarily influenced by the low anthocyanidin content observed in genotype 3-15, which, unlike the other genotypes and both cultivars, produces purple rather than characteristic black fruits. Nevertheless, the coefficient of variation for this trait decreased to the 'lower' norm the following year due to a smaller range of fluctuations. The decrease in the coefficient of variation for anthocyanins in 2024 could be because genotypes responded more uniformly to this year's conditions. In general, secondary metabolites, such as ascorbic acid and compounds of flavonoid complex, have a higher coefficient of variation within the "upper" range. A higher coefficient of variation indicates significant genotypic variability in this trait, which is desirable for breeding purposes, as it enables the selection of genotypes with a high concentration of these compounds. Such pronounced genotypic diversity, evidenced by a wide range of values, is crucial for breeding programmes aimed at improving fruit quality. Importantly, some genotypes were found to possess higher total content of polyphenols, anthocyanins, and chalcones compared to the original 'Vseslava' cultivar.

Comparison of annual averages revealed distinct trends in biochemical composition. Specifically, from 2023 to 2024, the content of dry matter, soluble solids, total sugars, total polyphenols, anthocyanins, chalcones, and the sugar-acid ratio, decreased by 1.09-10.00%. Conversely, titratable acidity, pectin substances, and ascorbic acid content increased by 2.09-3.21%. These fluctuations suggest that the stability of chemical component expression across different genotypes is influenced by yearly environmental conditions. Genotypes, therefore, can adapt to varying environmental conditions by altering both the average level and the degree of variability of biochemical indicators within the population. The linear relationships between the measured biochemical parameters of the fruit are shown in Table 6.

Table 6. Pearson correlation coefficients between indicators (r)

Indicator	Dry matter	Soluble solids	Total sugar	Titratable acidity	Sugar/Acid Ratio	Pectin substances	Ascorbic acid	Total poly-phenols	Antho-cya-nins	Chalcons
Dry matter	1									
Soluble solids	0.90	1								
Total sugar	0.03	0.11	1							
Titratable acidity	-0.58	-0.55	0.28	1						
Sugar/Acid ratio	0.56	0.57	0.24	-0.85	1					
Pectin substances	0.23	0.09	0.23	0.30	-0.08	1				
Ascorbic acid	0.49	0.65	0.22	0.07	0.09	0.62	1			
Total polyphenols	0.58	0.61	-0.54	-0.74	0.46	-0.02	0.25	1		
Anthocyanins	0.52	0.69	-0.31	-0.48	0.34	0.03	0.54	0.65	1	
Chalcons	0.57	0.74	-0.25	-0.51	0.40	0.02	0.53	0.66	0.99	1

Source: compiled by the authors

Following the classification by V. Mezhenskyj (2021), the relationship between the traits is considered weak with a correlation coefficient of 0.1-0.29, moderate with a coefficient of 0.3-0.49, noticeable with a coefficient of 0.5-0.69, high with a coefficient of 0.7-0.89, and very high with a coefficient of 0.9-0.99. As anticipated, a very strong positive correlation (r = 0.90) was observed between dry matter and soluble solids, given that soluble solids constitute the primary component of dry matter. Interestingly, despite the common association between dry matter and sugars, this study revealed only a weak correlation between soluble solids and sugar content. This suggests that other components of fruit composition, possibly the flavonoid complex, have a stronger influence on soluble solids. Soluble solids exhibit a noticeable or high positive correlation with the sugar/acid ratio (r = 0.57), total polyphenols (r = 0.61), ascorbic acid (r = 0.65), anthocyanins (r = 0.57), and chalcones (r = 0.74). Conversely, high negative correlations were observed between titratable acidity and the sugar-acid index (r = -0.85) and total polyphenols (r = -0.74). A noticeable negative relationship also existed between titratable acidity and dry matter, soluble solids, and chalcones (r = -0.58 to -0.51). This suggests that, as the product ripens and acidity decreases, the concentration of these phenolic compounds, which often contribute to colour and antioxidant properties, increases.

Generally, sugar content shows a weak or moderate correlation with almost all indicators (r = 0.23-0.31), and this relationship can be either positive or negative. However, the correlation between sugars and total polyphenols is notably negative (r = -0.54). Pectin substances exhibit weak to moderate positive and negative correlations (r = 0.02-0.30) with all other biochemical composition parameters, except ascorbic acid, with which they exhibit a high correlation coefficient (r = 0.62). This suggests that pectin content may be less directly influenced by, or correlated with, changes in sugars, acids, and phenolic compounds that occur during maturation. The weak relationship between ascorbic acid and both titratable acidity and sugar content may suggest independent metabolic pathways. Ascorbic acid's highest correlations were observed with soluble solids (r = 0.65), pectin substances (r = 0.62), and anthocyanins (r = 0.54).

An extremely strong positive correlation almost suggests that anthocyanins and chalcones are chemically very closely related, perhaps in their accumulation patterns within the product. It could also indicate that chalcones are precursors to anthocyanins (Samota *et al.*, 2024). They are common subclasses of flavonoids in fruits and vegetables (Zheng *et al.*, 2025). J. Mahoney *et al.* (2022) provide a detailed description of the biosynthetic pathway of anthocyanins in chokeberry, confirming that the synthesis of flavonoids, including anthocyanins, begins with the formation of chalcones. However, the relationship between these two flavonoids and total polyphenols is only noticeable (r = 0.65-0.66).

Although anthocyanins and chalcones are part of the total polyphenols, they only constitute a certain fraction. The accumulation patterns of other polyphenolic compounds may differ, which blurs the direct correlation. Different groups of biologically active compounds accumulate in different ways, reflecting the complexity of the chemical composition of garden chokeberry fruit. The main polyphenols in chokeberry fruits are catechol and chlorogenic acid (Yang *et al.*, 2019).

A noticeable positive correlation (r = 0.53-0.54) was also observed between anthocyanins/chalcones and ascorbic acid. This indicates a tendency for increased ascorbic acid content, another important bioactive compound in fruits, alongside higher levels of anthocyanins and chalcones, and vice versa. These findings align with previous research by N. Dobros *et al.* (2024), who reported correlations between anthocyanins, ascorbic acid, and other antioxidants varying with the ripening stage of chokeberry fruit. Indeed, the co-accumulation of ascorbic acid and anthocyanins contributes to the high antioxidant capacity of fruits, a finding supported by E. Guerrero-Álvarez *et al.* (2023). Furthermore, H. Yang *et al.* (2019) reported that unripe chokeberry fruits exhibit higher antioxidant activity due to their comparatively greater abundance of flavonoids, phenolic compounds, and total polyphenols compared to fruits at full ripeness. Overall, the correlation analysis not only confirmed established biochemical relationships but also elucidated specific associations within the studied genotypes. These insights are valuable for optimising breeding strategies, facilitating the simultaneous improvement of multiple interrelated fruit quality traits. Hierarchical clustering analysis, visualised through the dendrogram, provides valuable insights into the biochemical diversity and relationships among the genotypes under study (Fig. 1).

Within the first major cluster, genotypes 2-49 and 3-6 formed the tightest subgroup, merging at the lowest level of dissimilarity and exhibiting similar profiles across most parameters. Another distinct subgroup within this cluster comprises genotypes 2-63 and 3-42. These genotypes showed high levels of dry matter and soluble solids, a relatively high sugar-acid ratio, and low titratable acidity, alongside generally high concentrations of polyphenols and anthocyanins, though they displayed some variations in the specific levels of total polyphenols, anthocyanins, and chalcones. These two subgroups (genotypes 2-49/3-6 and 2-63/3-42) subsequently joined at a Euclidean distance of 4, forming a central cluster characterised by more average or balanced biochemical profiles across all measured traits.

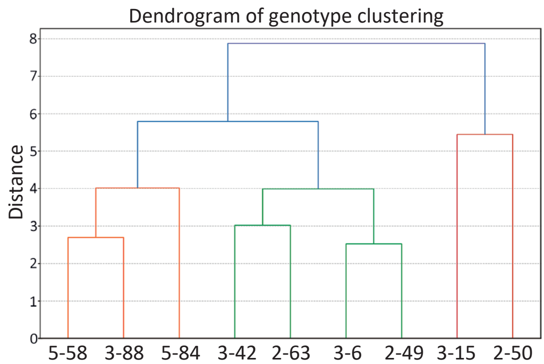

Figure 1. Dendrogram of genotype clustering based on biochemical characteristics
Source: compiled by the authors

The second major cluster was initiated by the close association of genotypes 3-88 and 5-58, merging at a Euclidean distance of approximately 2.7. This pair was then joined at a Euclidean distance of about 4.0 by genotype 5-84, which notably exhibited the highest levels of dry matter and soluble solids in both ripening years. This entire group (genotypes 3-88, 5-58, and 5-84) distinguished itself with exceptionally high levels of total polyphenols, anthocyanins, and chalcones, in addition to generally high levels of dry matter and soluble solids. Despite their initial association being at a slightly higher dissimilarity than that of the tightest cluster (genotypes 2-49 and 3-6), these three genotypes formed a distinct and relatively homogeneous cluster. These genotypes represent valuable sources of bioactive compounds, making them ideal candidates for the development of natural dyes and functional food additives.

Forming a distinct outlier group, genotypes 2-50 and 3-15 exhibited profiles notably different from each other and the main clusters.

They were generally characterised by a low content of anthocyanins and chalcones, as well as lower dry matter and soluble solids content. Genotype 3-15, in particular, displayed significantly lower ascorbic acid values. Conversely, genotype 2-50 is notable for its consistently highest pectin content over both study years. These two genotypes subsequently joined the previously described clusters at a remarkably high Euclidean distance of approximately 7.8, underscoring their significant biochemical dissimilarity from all other genotypes studied. This distinct group, while generally possessing lower levels of the main biochemical composition parameters, is characterised by other unique attributes. Specifically, genotype 3-15 is distinguished by its large, juicy, burgundy fruits. V. Mezhenskyj *et al.* (2024) pointed out that this makes it morphologically more similar to the rowan-like cultivar 'Titan' than to typical chokeberry-like cultivars. This variability highlights their potential for diverse applications, from fresh consumption to specific industrial processing, showcasing the wide genetic diversity within the hybrids under study.

CONCLUSIONS

A comprehensive two-year study (2023-2024) of the biochemical composition of fruits from nine RCH genotypes identified the key factors shaping their quality. Analysis of variance showed a highly statistically significant effect of genotype ($p < 0.05$) on most of the fruit quality parameters examined. This highlights the substantial genetic control over these traits and the critical role of genotype in forming desirable characteristics. Conversely, the effect of the cultivation year was statistically significant only for pectin content. Specifically, genotype 5-84 consistently demonstrated the highest levels of dry matter, soluble solids, ascorbic acid, anthocyanidins, and chalcones. In contrast, genotype 3-15 generally exhibited the lowest values for these compounds. This differentiation is exceptionally valuable for breeding purposes. Genotype 5-84 represents a promising donor for programmes aimed at creating varieties with enhanced nutritional and antioxidant properties. Furthermore, genotype 2-50 stood out with the highest pectin content, making it a valuable candidate for the processing industry. Other genotypes, such as 3-42, 5-58, 2-49, and 3-88, also showed high or comparable levels of ascorbic acid, anthocyanidins, and chalcones, thus broadening the breeding pool.

Correlation analysis revealed strong interrelationships between key fruit quality parameters. Notably, the strong positive correlation between dry matter and soluble solids ($r = 0.90$) has significant practical value for selection. It allows breeders to use a quick and simple refractometry method to measure soluble solids as a reliable indicator for assessing the total dry matter content in large sample sets, which substantially accelerates the selection process. An extremely strong correlation was also found between anthocyanidins and chalcones ($r = 0.99$). This enables the analysis of only one of these parameters during selection for an indirect assessment of the total bioflavonoid content, which is crucial for selecting genotypes with high antioxidant activity. The visualisation of samples in Euclidean distance space confirmed genotypic differentiation, indicating their unique biochemical profiles. The obtained data underscore the significant genetic potential of the studied genotypes for use in breeding programmes aimed at improving nutritional traits. These results provide a robust foundation for further research and the development of new varieties with enhanced biochemical characteristics. Further research could focus on analysing other bioactive compounds in these genotypes to more comprehensively assess their value, and investigating how specific annual conditions impact the biochemical composition of the fruit.

ACKNOWLEDGEMENTS

None.

FUNDING

This research received no external funding.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Brand, M.H., Connolly, B.A., Levine, L.H., Richards, J.T., Shine, S.M., & Spencer, L.E. (2017). Anthocyanins, total phenolics, ORAC and moisture content of wild and cultivated dark-fruited *Aronia* species. *Scientia Horticulturae,* 224, 332-342. doi: 10.1016/j.scienta.2017.06.021.

[2] Convention on Biological Diversity. (1992, June). Retrieved from https://www.cbd.int/doc/legal/cbd-en.pdf.

[3] Convention on the Trade in Endangered Species of Wild Fauna and Flora. (1976, March). Retrieved from https://treaties.un.org/doc/publication/unts/volume%20993/volume-993-i-14537-english.pdf.

[4] Dobros, N., Zielińska, A., Siudem, P., Zawada, K.D., & Paradowska, K. (2024). Profile of bioactive components and antioxidant activity of *Aronia melanocarpa* fruits at various stages of their growth, using chemometric methods. *Antioxidants,* 13(4), article number 462. doi: 10.3390/antiox13040462.

[5] Green, B.V., Aroh, B., Fiorellino, N.M., Ristvey, A.G., & Volkis, V.V. (2023). Effect of cultural management and plant age on the yield, °Brix, and antioxidant content of *Aronia mitschurinii* grown in Maryland. *ACS Omega,* 8(4), 4060-4071. doi: 10.1021/acsomega.2c06988.

[6] Guerrero-Álvarez, E.G., Arias, S.M., & Cifuentes-Colorado, G.A. (2023). Vitamin C content, anthocyanins and antioxidant capacity of fruits of *Rubus glaucus* Benth. (mora de Castilla) with and without prickles grown in Risaralda, Colombia. *Revista Brasileira de Fruticultura,* 45, article number e-509. doi: 10.1590/0100-29452023509.

[7] Gürer, E.S., Karadağ, A.E., & Altıntaş, A. (2023). Comparison of chemical profiles of *Aronia melanocarpa* fruit extracts. *Turkish Journal of Agriculture - Food Science and Technology*, 11(2), 323-328. doi: 10.24925/turjaf.v11i2.323-328.5744.

[8] International code of nomenclature for algae, fungi, and plants. (n.d.). Retrieved from https://www.iapt-taxon.org/nomen/main.php.

[9] Kobus, Z., Nadulski, R., Wilczyński, K., Kozak, M., Guz, T., & Rydzak, L. (2019). Effect of the black chokeberry (*Aronia melanocarpa* (Michx.) Elliott) juice acquisition method on the content of polyphenols and antioxidant activity. *Plos One*, 14(7), article number e0219585. doi: 10.1371/journal.pone.0219585.

[10] Kulling, S.E., & Rawel, H.M. (2008). Chokeberry (*Aronia melanocarpa*) – a review on the characteristic components and potential health effects. *Planta Medica,* 74(13), 1625-1634. doi: 10.1055/s-0028-1088306.

[11] Mahoney, J.D., Wang, S., Iorio, L.A., Wegrzyn, J.L., Dorris, M., Martin, D., Bolling, B.W., Brand, M.H., & Wang, H. (2022). De novo assembly of a fruit transcriptome set identifies AmMYB10 as a key regulator of anthocyanin biosynthesis in *Aronia melanocarpa*. *BMC Plant Biology*, 22, article number 143. doi: 10.1186/s12870-022-03518-8.

[12] Mezhenskyj, V.M. (2021). *Fundamentals of scientific research in horticulture. Calculations in Microsoft Excel: Study guide*. Kyiv: Lira-K.

[13] Mezhenskyj, V.M., Shevchuk, L.M., Kovalchuk, S.P., Havryliuk, O.S., Levchuk, L.M., Babenko, S.M., & Vintskovska, Y.Y. (2024). Phytochemical analysis of *Aronia melanocarpa* and ×*Sorbaronia fallax* fruit. *Regulatory Mechanisms in Biosystems*, 15(1), 49-54. doi: 10.15421/022407.

[14] Ministry of Agrarian Policy and Food of Ukraine. (2025). *State register of plant varieties suitable for distribution in Ukraine*. Retrieved from https://minagro.gov.ua/file-storage/reyestr-sortiv-roslin.

[15] Samota, M.K., Yadav, D.K., Koli, P., Kaur, M., Kaur, M., Rani, H., Selvan, S.S., Mahala, P., Tripathi, K., & Kumar, S. (2024). Exploring natural chalcones: Innovative extraction techniques, bioactivities, and health potential. *Sustainable Food Technology*, 2, 1456-1468. doi: 10.1039/d4fb00126e.

[16] Sidor, A., & Gramza-Michałowska, A. (2019). Black chokeberry *Aronia melanocarpa* L. – a qualitative composition, phenolic profile and antioxidant potential. *Molecules*, 24(20), article number 3710. doi: 10.3390/molecules24203710.
[17] Stalažs, A., & Bādere, A. (2023). ×*Sorbaronia fallax* (C.K. Schneid.) C.K. Schneid. nothosubsp. *mitschurinii* (A.K.Skvortsov & Maitulina) *nothosubsp*. *nov*., with taxonomical notes on *Aronia ×prunifolia* "Floribunda" *sensu* Cinovskis (Maleae, Amygdaloideae, Rosaceae). *Phytotaxa,* 630(3), 171-182. doi: 10.11646/phytotaxa.630.3.1.
[18] Strik, B., Finn, C., & Wrolstad, R. (2003). Performance of chokeberry (*Aronia melanocarpa*) in Oregon, USA. *Acta Horticulturae*, 626(626), 447-451. doi: 10.17660/ActaHortic.2003.626.61.
[19] Trenka, M., Nawirska-Olszańsk, A., & Oziembłowski, M. (2020). Analysis of selected properties of fruits of black chokeberry (*Aronia melanocarpa* L.) from organic and conventional cultivation. *Applied Sciences,* 10(24), article number 9096. doi: 10.3390/app10249096.
[20] Xu, J., Li, F., Zheng, M., Sheng, L., Shi, D., & Song, K. (2024). A comprehensive review of the functional potential and sustainable applications of *Aronia melanocarpa* in the food industry. *Plants*, 13(24), article number 3557. doi: 10.3390/plants13243557.
[21] Yang, H., Kim, Y.-J., & Shin, Y. (2019). Influence of ripening stage and cultivar on physicochemical properties and antioxidant compositions of aronia grown in South Korea. *Foods,* 8(12), 598. doi: 10.3390/foods8120598.
[22] Yavorovskyi, P., & Brovko, O.F. (2014). Adaptation reactions of seedlings of wild ash ordinary to insufficient level of moistening of soils. *Ukrainian Journal of Forest and Wood Science*, 167-172.
[23] Zheng, X., Zhang, X., & Zeng, F. (2025). Biological functions and health benefits of flavonoids in fruits and vegetables: A contemporary review. *Foods,* 14(2), article number 155. doi: 10.3390/foods14020155.

Сергій Ковальчук
Аспірант
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0001-8293-1797

Володимир Меженський
Доктор сільськогосподарських наук, старший науковий співробітник
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-3154-1120

Біохімічний склад і харчова цінність гібридів горобиноаронії (×*Sorbaronia fallax* (C.K. Schneid.) C.K. Schneid.) дібраних в Україні

Анотація. У цьому дослідженні комплексно проаналізовано біохімічний склад та харчову цінність дев'яти перспективних гібридів горобиноаронії (×*Sorbaronia fallax*), створених у Національному університеті біоресурсів і природокористування України (НУБіП). Їх порівнювали з двома сортами: 'Всеслава' та 'Nero'. Метою було оцінити вміст сухої речовини, розчинних сухих речовин, цукрів, титрованої кислотності, пектинових речовин, аскорбінової кислоти, поліфенолів, антоціанідинів та халконів. Зразки плодів збирали у 2023-2024 роках в дослідних садах НУБіП України. Результати показали значні відмінності між генотипами. Зокрема, генотип 5-84 мав найвищий вміст сухої речовини, розчинних сухих речовин, аскорбінової кислоти, антоціанідинів та халконів, тоді як генотип 3-15 – найнижчий. Вплив року вирощування був значущим лише для вмісту пектину. Виявлено сильні позитивні кореляції: між сухою речовиною та розчинними сухими речовинами ($r = 0{,}90$), а також між антоціанами та халконами ($r = 0{,}99$). Гібриди загалом перевершили батьківський сорт за вмістом цукрів, пектину, аскорбінової кислоти, антоціанідинів та халконів, що свідчить про значний генетичний потенціал. Результати дослідження надали цінну інформацію для селекційних програм, спрямованих на покращення харчових властивостей плодів. Вони можуть бути використані селекціонерами та агрономами для добору найкращих генотипів для подальшого культивування. Крім того, виробники продуктів харчування та дієтичних добавок можуть використовувати ці дані для розробки нових функціональних продуктів

Ключові слова: ×*Sorbaronia fallax* subsp. *fallax*; генотипи; аскорбінова кислота; поліфеноли; антоціани