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Morpho-physiological characteristics of plants and biochemical parameters of rowan berries, common rowan, and domestic rowan grown in the conditions of the Northern Forest-Steppe of Ukraine

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Abstract. The relevance of this subject lies in the comparative evaluation of different species of rowan to increase their significance and use in the system of ornamental and fruit horticulture, in the technologies of processing plant raw materials, and in the production of products for healthy nutrition. The purpose of the study is to examine the morpho-physiological characteristics of plants and the biochemical parameters of the fruits of different species (varieties, forms) of the genus Sorbus. Based on the results of

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practical research, original data on the morphology and economic characteristics of representatives (varieties and forms) of *Sorbus intermedia* Pers., *Sorbus aucuparia* L., *Sorbus domestica* L. are presented. Biological properties of the plants and biochemical parameters of the fruits are highlighted. It is established that all studied representatives of the genus *Sorbus* have high winter hardiness (1.5 points according to S.Ya. Sokolova), in addition, Scandinavian rowan plants have high drought resistance (4.5 points according to S.S. Pyatnitsky) compared to common rowan plants. Phenological observations of plants of different rowan species allowed for the conditions of the Forest-Steppe of Ukraine to determine the time of onset of ontogenesis phases: development of vegetative buds, appearance of leaves, shoot growth, budding, and flowering, formation and development of ovaries, ripening and fruiting, changes in leaf colour, and leaf fall. Subphases that more accurately characterise the time of onset, peak, and end of a certain phase of development have also been identified, which is a scientific achievement for strategies in the system of ornamental and fruit horticulture. The growth intensity of varieties and forms of representatives of the *Sorbus* genus in height was studied, and the general condition of plants for viability is evaluated. Preparatory work on the preparation of rootstocks, the selection of scions, and grafting allowed the formation of model plants in the collection nursery and additional assessment of their growth strength, the onset and passage of individual phases of development, assessment of drought and winter hardiness, age of fruiting, and more. Biometrics and descriptions of stem, branches, vegetative and generative buds, leaves, inflorescences, and fruits are also conducted. The taste characteristics of the fruits are described in the materials of the paper. Biochemical analysis of the fruits allowed establishing their suitability for processing and the production of products for healthy nutrition

Keywords: *Sorbus intermedia* Pers.; *Sorbus aucuparia* L.; *Sorbus domestica* L.; morphological features; physiological features of plants; biochemical properties of fruits

INTRODUCTION

The world needs effective plant species in the system of ornamental and fruit horticulture and safe resources of their raw materials. Preference is often given to niche fruit crops, including species belonging to the genus *Sorbus* L., 1753 (*Rosaceae*, Juss., 1789). Since rowan species are valuable for ornamental, medicinal, and fruit-bearing purposes, and eight of them grow in Ukraine, with the majority of their harvest being important for processing and the production of healthy food products, further research into the morpho-physiological characteristics of plants and biochemical studies of plant raw materials of varieties (forms) of fruit representatives of the genus *Sorbus*: common rowan, domestic rowan, and Swedish rowan, is highly relevant for expanding the database of information for the improvement of directions in plant biology, breeding, and biochemistry for the industries of processing and producing environmentally safe and high-quality food products (jellies, jams, blended juices, beverages, wines, etc.).

The examination of the patterns of the emergence and development of external characteristics of plants and their organs in the genus *Sorbus* has been the subject of several works, such as those by Z. Qiu *et al.* (2023), which allow tracking changes that occurred in the plant forms during ontogeny (individual development) and phylogeny (historical development) and changes induced by the environment. These practical data have been used to enrich fundamental research in botany, plant morphology and physiology, fruit-bearing, breeding, genetics, biochemistry, fruit processing, pharmacology, pharmaceuticals, and more.

According to botanical research by J. Levin *et al.* (2019), new species have been discovered and described in the Baltic Sea basin, specifically in Gotland and the Åland Islands. These are intermediate species between *Sorbus* aucuparia and *S. hybrida*. A. Hajrudinovi´c-Boguni´c *et al.* (2023) note that this diversity results from the interaction of polyploidisation, hybridisation, and apomixis, leading to exceptional diversity in the *Sorbus* genus (*Rosaceae* family), which generates various new genetic and morphological forms requiring further investigation.

Systematised data on the morphology of *Sorbus* representatives are necessary as they allow specialists to choose suitable components for orchard design in the system of ornamental and fruit horticulture. As V. Sarv *et al.* (2020) argue, many species of the *Sorbus* genus are widely used in food production and traditional medicine, necessitating further study of the organic compounds in rowan berries. Therefore, as indicated by M. Räty *et al.* (2016), Sorbus species, varieties (forms) are important in the system of ornamental and fruit horticulture, serving as vital components of forest stands in parks, squares, and gardens. However, there is a challenge – climate change is pushing their localisation to higher altitudes and further north. In the future, it is expected that they will lose their presence in southern, central, and eastern Europe.

Given the above, it can be said that the study of representatives of the *Sorbus* genus is important in the context of current climate fluctuations worldwide. The selection of the best genotypes with high bio-potential and their targeted introduction could expand the range of valuable species for ornamental and, for the most part, fruit-bearing purposes. This is particularly relevant as practically all rowan species are relatively disease-resistant, cold-resistant, and some, such as *Sorbus*

aria (Silver Whitebeam), *Sorbus hybrida* (Swedish Whitebeam), and *Sorbus intermedia*, are highly drought-resistant, which is essential not only for agroforestry and horticulture but also for the food industry due to the high fruit quality.

As noted by M. Sarv *et al*. (2020), there is also an issue regarding the insufficient use of plant raw materials from representatives of the *Sorbus* genus, including fruits, for preparing food products, nutraceuticals, and as sources of polyphenolic compounds and high antioxidant potential. This, according to J. Rand (2018), is possibly linked to the reduction in rowan orchards worldwide. Therefore, there is a need for a comprehensive approach in further research and dissemination of information about representatives of the *Sorbus* genus in a systematic manner to improve the knowledge base in the fields of biology, breeding, fruit-bearing, processing, and the development of technologies for producing medicinal phytopreparations for disease prevention and healthy food products (Lytovchenko *et al.*, 2021).

Thus, the analysis of literature sources indicates the inadequacy of research on the morphology, physiology, and ecology of plants of the species *Sorbus intermedia* Pers., *Sorbus aucuparia* L., *Sorbus domestica* L., and their significance in ornamental and fruit horticulture, including the utilisation of their fruits in processing and producing healthy food products. This highlights the relevance of further research in these areas. The purpose of the study is to evaluate various species (varieties, forms) of representatives of the genus *Sorbus* according to the morpho-physiological characteristics of plants and biochemical parameters of fruits.

MATERIALS AND METHODS

The analysis of the morpho-physiological characteristics was conducted in research plots at the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine (NAAS) and its research network (Chernihiv and Lviv regions) during 2017-2021. The main methods used for morphological analysis of rowan plants included observation and description, serving as a fundamental comparative method for studying their development, both individual (ontogenetic) and historical (phylogenetic). By measuring the height of rowan plants, the height of the crown's beginning, the height of the largest diameter of the crown, and the lower limit of dead branches' presence, essential parameters for subsequent biometric assessments were determined. Throughout the vegetation period of the rowan plants, dates of phenophase onset were recorded based on phenological observations, which were conducted from a week before the beginning of vegetation to the end of the vegetation period (2017-2021). The assessment included the flowering and fruiting intensity, field winter hardiness, drought resistance following S.I. Melnyk's (2016) criteria

The beginning of the development phase was considered the date when a specific phase occurred in 10% of the observed plants, and the end of the phase when it finished in 90% of the plants. Average start and end dates for the development phase were used. Additionally, plant height was measured annually after the vegetation period using a special ruler with markings to assess the growth intensity. Three categories were used, considering the average height and stem diameter: low-productive (which grew worse than the average indicators by more than 15-20%), medium-productive (growth height did not exceed average indicators), and high-productive (growth exceeded average indicators by up to 10%).

In parallel with growth assessment, the overall health of the plants was considered, reflecting vitality. This was assessed based on resistance to phytopathogens, growth patterns, leafiness, and was expressed on a scale from poor (1 point) to excellent (9 points), where poor condition indicated partial or complete withering of branches or tree death, unsatisfactory condition showed below-average growth with signs of wilting and leaf disease, satisfactory condition indicated average growth with moderate leafiness and slight signs of disease, good condition meant high growth, healthy dark green or green leaf colour, moderate leafiness, and the absence of damage from adverse environmental factors.

Biochemical analysis of the rowan fruit was conducted in the laboratory specialising in post-harvest quality of fruit and berry products, and the experts performed the analysis. The weight and quality of the samples met the requirements of the Methodology for Assessing the Quality of Fruit and Berry Products (Kondratenko *et al.*, 2008) and DSTU ISO 874-2002 (2003). The content of dry matter was determined by drying method, soluble solids were determined according to DSTU 2173:2007 (2009), sugars according to DSTU 4954:2008 (2009), organic acids according to DSTU 4957:2008 (2009), polyphenolic compounds according to DSTU 4373:2005 (2006), pectin substances according to DSTU 8069:2015 (2017), vitamin C according to DSTU ISO 6557-2:2014 (2015), anthocyanins and chalcones by V. I. Krivenkov's method, and oxidation-reduction potential and pH of the juice were determined using a pH meter/ORP meter from HANNA. The study was conducted with threefold replication and statistically processed in Excel. During the research, the requirements of the Convention on Biological Diversity (1992) were followed.

RESULTS

Only after the establishment of a collection nursery and the conduct of expeditionary work to determine model plants of the *Sorbus* genus, data from morphological analysis and physiological research were accumulated, processed, and systematised. This allowed for the formulation of objective descriptive conclusions about each investigated form of rowanberry plants. In general, the results of phenological observations on representatives of the *Sorbus* genus identified the main phases

and subphases of plant development, starting from the moment when the average daily temperature reaches +5°C. Regarding the main phases of development, the focus was on the phase of vegetative bud development and its subphases: swelling and the beginning of budburst (on average, occurring from the end of the third decade of March to the first decade of April); leaf appearance and subphases of the beginning and full leaf unfolding, and full leaf coverage (from the end of the first to the middle of the second decade of April); shoot growth, beginning (beginning of the second decade of April), and end (first decade of August); flowering phase, which includes the subphases of budding (third decade of April), beginning (end of the first to the beginning of the second decade of April), full (middle and end of the second decade of May), and the end of flowering (beginning of the third decade of May); phase of fruit formation and development (first decade of June); the phase of fruit ripening, beginning (third decade of August), and end (end of September); fruit drop (for domestic and Scandinavian rowanberry plants) and subphases of the beginning (end of the third decade of August to the first decade of September), mass (second decade of September), and final (third decade of September), leaf colour change – yellow (second decade of September) and crimson (third decade of September to the first decade of October), and the final phase – leaf drop, subphases of the beginning (second decade of October), mass (third decade of October), and final (first decade of November).

Phenological studies allowed for understanding that the period between the start and completion of the vegetative bud phase lasts 6-9 days, after which bud unfolding and leaf growth begin. The budding and flowering phase lasts approximately 14 days, but this can vary depending on weather conditions. It was also noted that temperature and air humidity significantly affect the duration of the fruit ripening phase, with dry and hot weather causing it to shorten by 36 days, with most fruits falling prematurely. Low air temperatures during the completion of fruit development subphases also influence fruit drop rates, particularly for Scandinavian and domestic rowanberry plants. It is worth mentioning that fluctuations in the weather-climate regime during the vegetation period determine the dates of the onset and duration of rowanberry plant development phases and may vary from year to year. In parallel with phenological observations, morphological and physiological research was conducted. Height measurements of plants after the completion of vegetation each year allowed for determining the intensity of rowanberry plant growth (Table 1).

Table 1. *Growth rate by height of Rowanberry plants (end of growing season)*

Variety/form	Growth intensity category
Domestic Rowanberry Form F. 1	highly productive
Domestic Rowanberry Form F. 2	highly productive
Common Rowanberry Form F. 3	moderately productive
Common Rowanberry (seedling of unknown origin)	moderately productive
Common Rowanberry, Burka variety	moderately productive
Common Rowanberry, Businka variety	moderately productive
Scandinavian Rowanberry, Brouwers variety	highly productive

Source: *compiled by the authors*

Subsequently, the overall condition of rowanberry plants was considered, evaluating them for resistance to phytopathogens, growth characteristics, foliage density, and expressing it in scores (Table 2).

Table 2. *Overall condition of Rowanberry plants by vitality*

Variety/form	Overall condition	
	score	manifestation
Domestic Rowanberry Form F. 1	9	excellent
Domestic Rowanberry Form F. 2	9	excellent
Domestic Rowanberry Form F. 3	5	satisfactory
Common Rowanberry (seedling of unknown origin)	5	satisfactory
Common Rowanberry, Burka variety	7	good
Common Rowanberry, Businka variety	7	good
Scandinavian Rowanberry, Brouwers	9	excellent

Source: *compiled by the authors*

Thus, based on growth intensity, highly productive rowanberry plants were Domestic Rowanberry Form F. 1 and F. 2, and Scandinavian Rowanberry Brouwers variety, which also exhibited excellent overall condition (9 points). It was found that by the growth intensity category, the plants of Domestic Rowanberry Form F. 3, Common Rowanberry (seedling of unknown origin), and Common Rowanberry varieties Burka and Businka were moderately productive, with a good overall condition (7 points). Plants of Common Rowanberry Form F. 3 and Common Rowanberry (seedling of unknown origin) had a satisfactory overall condition (5 points) as they exhibited moderate foliage density and signs of mild disease damage, which locally caused necrosis.

Based on the analysis of long-term data, it was determined that the variety of rowanberry, which is intermediate or Swedish rowanberry (*Sorbus intermedia* (Ehrh.) Pers., 1806, or *Sorbus scandica* (L.) Fr.) Brouwers since 1956, listed in the State Register of Plant Varieties of the Netherlands, is a tree in terms of its life form, with a growth strength of approximately 0.4 metres. The tree studied had an average height of 4 metres. Although the mother plants from which scions were taken for grafting in the park of the Institute of Horticulture of the National Academy of Agricultural Sciences of Ukraine reach heights of over 10 metres. On the tree, the number of skeletal branches is average (⩽10), their orientation is semi-vertical, and branching is strong. Regarding their position relative to the trunk and the angle of placement, they diverge from the trunk at a height of 1.5 metres at an angle >65° from various points. The crown shape of the tree is round-pyramidal, with density being high, and its habit is conical.

One-year-old shoots, with a thickness of 8.6 mm during their period of intensive growth, exhibit a weak anthocyanin colouring at their tips. The colour of the bark of the one-year-old shoot is olive-grey-light-brown, and the size of the base of the bud on it is large (8 mm). The vegetative bud is slightly inclined or inclined relative to the shoot and is of medium size (>8 mm). It is dark brown in colour and has moderate stickiness of the outer scales. The tip of the vegetative bud is wide-conical-elongated, while for the generative bud, the tip is pointed. The time of the onset of development of vegetative buds is average (end of the third decade of March to the beginning of the first decade of April). The time of bud burst (appearance of leaves) is also average (second decade of April). The density of leaf arrangement at the end of the shoot is significant, with 8 leaves present. The leaves are simple, entire, broadly elliptical or elongated-egg-shaped, doubly serrate, weakly pinnately lobed. The leaf tip type is obtuse, the base shape is round, the margin is biserrate, and the venation type is palmate-pinnate. The number of leaflets or ovate leaflets along the length of 3.7 cm is 9-13, and the petiole is short (2.7 cm) in length. The leaf size is medium (11.6×7.8 cm), the cross-sectional profile is straight, and the intensity of green colouration is intensive. The anthocyanin colouration intensity is absent or weak. The leaves have a moderate to high glossiness, with slight pubescence on the upper side and moderate to strong pubescence on the lower side. The onset of yellow leaf colouration is average (beginning of the third decade of September), while the onset of red leaf colouration is average (end of the third decade of September). Leaf fall occurs in the mid-early period (second decade of October).

The inflorescence type is a corymb with a diameter of 15 cm, and the number of flowers on it is average (52 flowers). The flower diameter is smaller than average (d=1.2 cm). There are 5 petals on each flower, their position is horizontal, and their arrangement is non-touching. There are 20 stamens per flower, and their shape is elliptical. The flower stalk is long (⩽2 mm) and characterised by strong pubescence. The time of flowering onset is late (third decade of May to the first decade of June). The degree of flowering (signs) is 4 (good, 60-80%). Self-fertility is very high (90%). The primary colour of the fruit pulp is light brown or light orange, while the skin is brick-red. The skin has moderate glossiness. The fruit is semi-spherical in shape, with a height that is low or medium (7 or 1.2 mm) and a width that is small (1-1.2 mm). The average number of fruits on a corymb is 20. The weight of 1000 fruits is 0.811 kg. The number of seeds in a fruit is low (2 seeds), and the weight of 1000 seeds is low (16.2 g). The onset of fruit ripening is moderately late (second to third decade of September). The ripening group is late.

The taste of the fruits is weakly acidic, weakly sweet, without bitterness. The fruits are rich in nutrients, including a vitamin C content of 69.3 mg/100 g, a total sugar content of 18.9% on a fresh weight basis, dry matter content of 43.5%, soluble dry matter content of 34.4%, titrated organic acid content of 0.7%, pectin content of 1.96% on a fresh weight basis, polyphenolic compounds content of 1056 mg/100 g of fresh weight, flavonoids content of 217.5 mg, anthocyanins content of 3.3 mg, chalcones content of 13.8 mg/100 g of fresh weight. The sugar-acid index is 27.1, and the sensory evaluation on a 9-point scale is 2.7 (average).

It is worth noting that the Brouwers variety plants are highly and moderately resistant to pear mites (*Eriophyes piri* Pagenst.) – 8 points, and rowan aphids (*Dentatus sorbi* Ralt.) – 7 points. They are also highly winter-hardy – 1.5 points (according to S.Ya. Sokolova) and drought-resistant – 4.5 points (according to S.S. Pyatnitsky). The fruiting cycle of Scandinavian rowan plants is annual, the abundance of fruiting is moderate (3.5 points), and the time (age) of maximum fruiting from seedlings is late (8-11 years), while the time (age) of maximum fruiting on a graft is early (2-3 years). The variety "Nevyazhynska Yellow Common Rowan" (Sorbus aucuparia L., 1753) is a deciduous tree in terms of life form. The researched plants were up to 3 metres tall

with an elongated-round crown shape. The maternal plants used for grafting reached 8 metres in height. The crown density is average, and the habit is slightly sprawling. The number of skeletal branches on the tree is low (≤5). The bark of one-year-old flexible branches is greyish-brown, while that of two-year-old and skeletal branches is grey or dark grey.

The leaves are alternate, odd-pinnate, medium-sized, up to 18.7 cm long, and composed of 7-15 broadly lanceolate serrated leaflets. The upper side of the leaf blade is dark green, and the lower side is pale green with pubescence. The flowers are arranged in complex corymbose inflorescences with a diameter of about 12 cm. The flowers are small, about 1.3 cm in diameter, and have five petals with a cream-white colour. During mass flowering, the flowers emit a strong, unpleasant odour. The peak of flowering occurs in the third decade of May. These plants are self-unfruitful. It was found that for the Nevyazhynska Yellow variety, the best pollinator is the Businka variety.

The fruit is apple-shaped, somewhat elongated-round with distinct angular ribs, about 1.4 cm in diameter. The number of fruits on a cluster ranges from 79 to 126. The fruit's weight is 0.6 g, and the weight of 100 fruits is about 57.6 g. The skin of the fruit is dark yellow to yellow-orange. The pulp is pale yellow, sweet-sour in taste. The seeds are small and dark brown. The fruits have moderate keeping quality. The intended use of the fruits is versatile. The juice content of the Nevyazhynska Yellow variety is 34%, which is higher than for the Brouwers variety but lower than for the Burka and Businka varieties, which exceed 45%.

The Businka variety of common rowan (*Sorbus aucuparia* L., 1753) is a moderately tall tree, reaching up to 3 metres in height. The number of skeletal branches on the tree is low (≤5). These plants are self-fruitful. It was found that these plants tolerate partial shade, although they prefer full sun. The average fruit weight is 1.2 g (maximum – 1.85-2.06 g). The skin colour is red or bright red. The pulp is pale yellow to cream-coloured, with a sweet-sour taste that is refreshing and pleasant, without bitterness. Fruiting begins at 3-5 years of age, and fruit ripening occurs in the first decade of September. The intended use of the fruits is versatile. The transportability of the fruits is high (9 points). This variety is characterised by high drought, winter, and frost resistance (9 points). The fruiting cycle of the Businka variety plants is annual, and the abundance of fruiting is high (5 points).

The Burka variety of common rowan (*Sorbus aucuparia* L., 1753) is a slow-growing tree, reaching a height of up to 2-2.3 metres, forming a compact crown with a round or spherical shape. The leaves are pinnately lobed and dark green in colour. The flowers are fragrant, small, five-petaled, arranged in a shield-like inflorescence. The petals of the flower are white, and the anthers of the stamens have a pinkish tint. The generative buds are light greyish-brown and pubescent, formed on two-year-old shoots. The flowering phase begins in the third decade of May. These plants are self-fruitful. The fruits are round and slightly flattened. The fruit skin is thin and dark brown or dark pink in colour. The flesh is juicy, with a sweet-sour taste and hints of bitterness. Fruit ripening occurs in the first decade of September. The fruiting cycle is annual, starting from the 3rd or 4th year, with maximum fruiting occurring in the 5th year.

It is noted that the fruits become sweeter in taste after autumn frosts or artificial freezing in freezer chambers. These plants are characterised by high drought resistance (4.5 points), winter resistance (1.5 points), and frost resistance (1.5 points). However, they negatively respond to prolonged soil waterlogging. The seedling of common rowan (*Sorbus aucuparia* L., 1753) of unknown origin is a small tree, not exceeding 3.5 metres in height during the research period. The bark of the trunk and skeletal branches is grey. The bark of one-year-old branches is grey-brown. The crown is dense and oval in shape. The leaves are 15.7 cm long, alternate, odd-pinnate, and generally consist of 13 lanceolate, pointed leaflets with serrated edges. The flowers are small, arranged in a complex shield-like inflorescence with pubescence. The average diameter of the inflorescence is 11.5 cm. The flower stalk is characterised by weak or strong pubescence. The flower calyx consists of five sepals. The number of petals in the flower is five, and they are white in colour. The corolla has a diameter of 1.5 cm, with one pistil, three stamens, and a lower style. The number of stamens is numerous. The fruit is apple-shaped, with an orange or dark orange skin. These plants are characterised by high drought, winter, and frost resistance (9 points). The fruiting cycle is fixed at 7 years. For the description of common rowan plants based on morphological characteristics, Form F.3 was selected. The Form F.3 of common rowan (*Sorbus domestica* L., 1753) is a moderately tall tree, approximately 1.45 metres in height during the study. The approximate height of the maternal tree does not exceed 12 metres. The crown shape is inversely egg-shaped, and the growth rate is moderate. The number of skeletal branches is low (4 branches).

The bark of young plants is rough with numerous lentils, and it is grey in colour. One-year-old shoots are grey, shiny, almost without pubescence, and the buds on them are sticky and not pubescent. Vegetative buds are large, elongated, or round, while generative buds are mixed and form a rosette with 3-4 leaves during budding. The leaves are complex, 18 cm long, alternate, odd-pinnate, with an average of 13 lanceolate, pointed leaflets with serrated edges. The leaflets are arranged alternately and are 3.5 cm long and 1.2 cm wide. The upper side of the leaves is green and smooth, while the lower side is pale green. The leaflet petioles are pubescent with fine hairs. The plant's inflorescence is a wide pyramidal shield, up to 9 cm in diameter. The flowers

are small, up to 1.5 cm in diameter, with a distinct bitter almond aroma. The petals of the flower are white and roughly oval in shape. There are 20-30 stamens in each flower, and up to 68 flowers can be found in a single shield. The small branches of the shield have dense pubescence. The flowering phase occurs at the end of the third decade of April or the beginning of the first decade of May.

The fruit is apple-shaped, weighs 10.21 grams, and has slightly elongated pear-like characteristics with dimensions of 2.5×2.7 cm. It is yellow-green with a blush, has firm, sweet, and aromatic mealy flesh with a moderate amount of stony cells. Each cluster can contain 5-16 fruits. The seeds are brown or dark brown, with a seed weight of 0.02 grams. It is highly drought-resistant (4.5 out of 5 points) and moderately winter-hardy (2.5 out of 5 points).

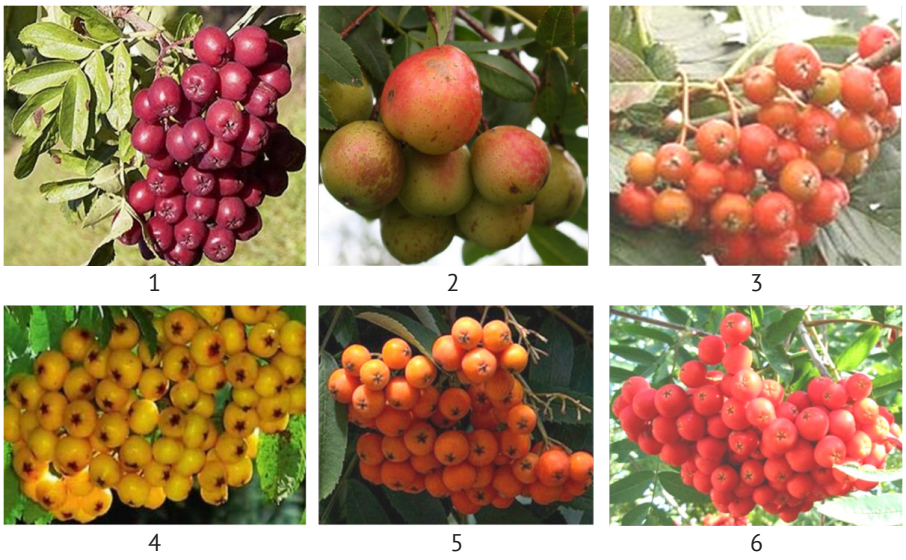

Figure 1. *Rowanberry species: 1 – Common Rowan (Variety: Burka); 2 – Domestic Rowan; 3 – Scandinavian Rowan (Variety: Brouwers); 4 – Common Rowan (Variety: Yellow Nevyezhenska); 5 – Common Rowan (Seedling of Unknown Origin); 6 – Common Rowan (Variety: Businka)*
Source: *photographed by the authors*

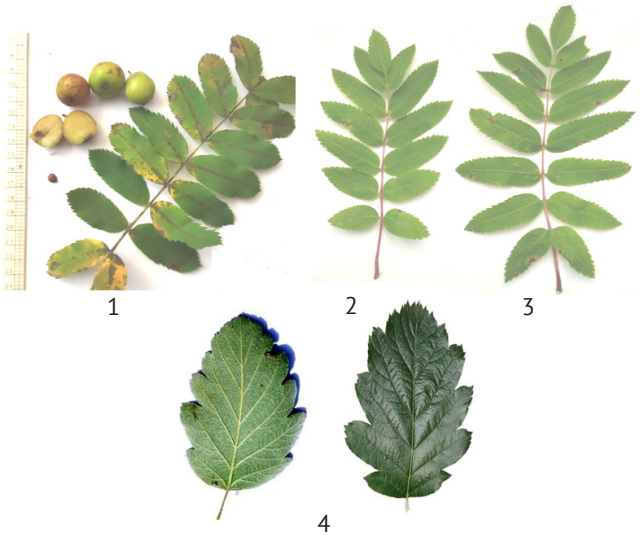

Figure 2. *Rowanberry leaves: 1 – Domestic Rowanberry; 2 – Common Rowanberry (seedling of unknown origin); 3 – Common Rowanberry Variety Yellow Nevezhenska; 4 – Scandinavian Rowanberry Variety Brouwers*
Source: *photographed by the authors*

After completing morpho-physiological studies, it was planned to conduct a biochemical analysis of the rowanberry fruits, the results of which demonstrated their suitability for various types of processing. For all six samples of rowanberries, analyses were conducted to determine the content of organic and biologically active substances. It was found that the highest dry matter content was in the fruits of Scandinavian Rowan

(Variety: Brouwers) (43.5±0.3%) and common rowanberries (from an unknown source) (36.6±0.3%). Below the average value (33.9±0.1) for the group of studied rowanberry species, the dry matter content was observed in rowanberries of domestic Form 3 (27.0±0.3%) and domestic Form 2 (29.2±0.3) (Fig. 3).

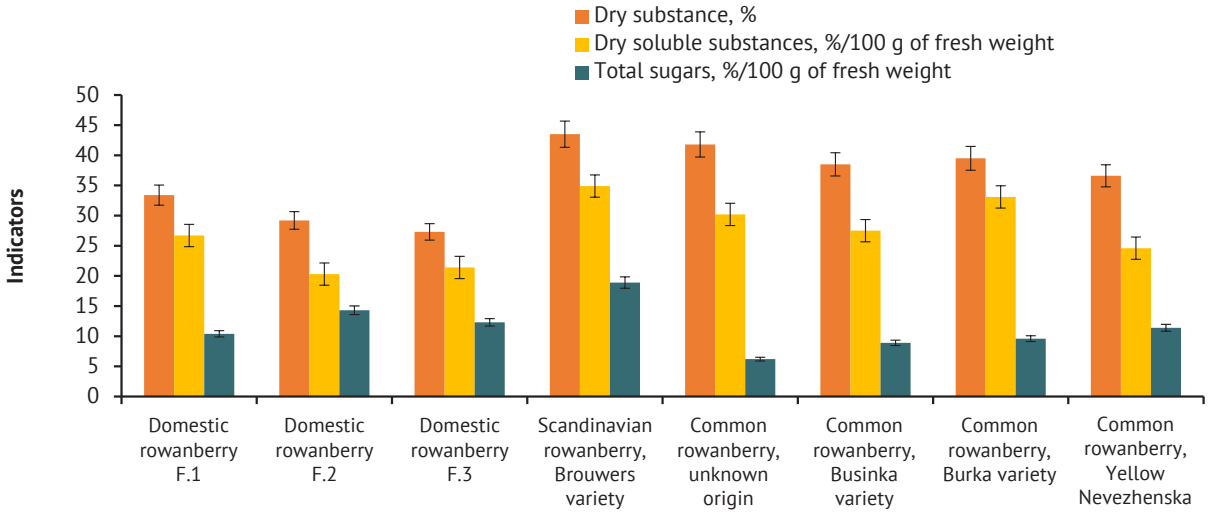

Figure 3. *Content of dry substances, dry soluble substances, and total sugars in rowanberry fruits*

Soluble dry substances in rowanberry fruits of the studied species varied within the range of the highest content of 33.4 (Scandinavian Rowanberry Variety Brouwers) and the lowest of 21.4±0.7% (Domestic Rowanberry Form 3). The average inter-species content was 25.89±0.38%. Rowanberry fruits of the Businka variety (22.6±0.3) and Domestic Rowanberry Form 1 (25.7±0.4%) accumulated less dry soluble substances than the average. Rowanberry of the common variety accumulated the driest soluble substances in its fruits. The overall content of dry soluble substances in rowanberry fruits was adequate for most of the studied species. The highest amount of sugars was accumulated in the fruits of Scandinavian Rowanberry (18.9±0.4% of fresh weight) and Domestic Rowanberry Form 2 (14.3±0.21%). Rowanberry Form 3 (12.0±0.3), Domestic Rowanberry Form 1 (10.4±0.37%), and Common Rowanberry (6.2-11.5%) had lower sugar content on average. Among the common rowanberry varieties, the highest sugar content was observed in the fruits of the Yellow Nevezhenska variety (>11%).

Titrated acids, expressed as malic acid equivalents, in the fruits of the studied rowanberry species varied from 2.78±0.13% (Common Rowanberry, seedling from open pollination) to 0.65±0.02% (Domestic Rowanberry Form 3) (Table 3).

Table 3. *Content of organic substances in rowanberry fruits*

Variety/hybrid	Titrated acids	Pectin substances	SAR
	%/100 g of fresh weight		
Domestic Rowanberry Form 1	1.15±0.03	1.99±0.18	9.1
Domestic Rowanberry Form 2	0.99±0.05	1.07±0.04	14.5
Domestic Rowanberry Form 3	0.65± 0.02	1.68±0.19	18.5
*Common Rowanberry (seedling of unknown origin)	2.78±0.13	0.68±0.18	2.2
Common Rowanberry Variety Burka	1.12±0.17	0.63±0.09	4.8
Common Rowanberry Variety Businka	1.43±0.07	0.79±0.11	3.5
Scandinavian Rowanberry Variety Brouwers	0.70±0.10	1.96±0.21	27.1

Note: ** the content of titrated acids and pectin substances is similar to their content in the fruits of the Yellow Nevezhenska variety. SAR – Sugar-to-Acid Ratio*
Source: *compiled by the authors*

The fruits of common rowanberry varieties Burka and Businka are characterised by titrated acid content close to the average, at 1.12 and 1.43% per 100 g of fresh weight, respectively. In the rest of the studied species (varieties/forms), their quantity was lower than the average content of 1.25±0.02%, with values of 0.70±0.10 (Scandinavian Rowanberry Variety Brouwers), 0.99±0.05 (Domestic Rowanberry Form 2), and

1.15±0.03% (Domestic Rowanberry Form 1). The highest sugar-to-acid ratio (SAR) was found in the fruits of Scandinavian Rowanberry Variety Brouwers (27.1) due to their high sugar content (18.97±0.4%) and low titrated acid content (0.7±0.1%). High SAR values were also observed in Domestic Rowanberry Form 2 (14.5) and Domestic Rowanberry Form 3 (18.5). Common Rowanberry (2.2-4.8) and Domestic Rowanberry Form 1 (9.1) had moderate SAR values. Fruits of Scandinavian Rowanberry Variety Brouwers and Domestic Rowanberry Form 1 had a higher content of pectin substances, amounting to 1.99±0.18% and 1.96±0.21% of fresh weight, respectively. Domestic Rowanberry Form 3 had the highest content of pectin substances (1.68±0.19%) among all studied species. Other species had lower pectin content, with Domestic Rowanberry Form 2 (1.07±0.04%) and Common Rowanberry (0.63-0.79%) having the least.

The content of ascorbic acid in the fruits of the studied rowanberry species varied widely, ranging from 33.41-42.04 mg/100 g in Common Rowanberry to 3.49±0.22 mg/100 g in Domestic Rowanberry Form 3. The content of ascorbic acid was lower than average in the fruits of other species and ranged from 4.9±0.23 (Domestic Rowanberry Form 2) to 9.53±0.32 mg/100 g (Scandinavian Rowanberry). Polyphenols, a group of biologically active substances, were found in varying amounts in the fruits of different rowanberry species. The highest levels of polyphenolic compounds were found in Domestic Rowanberry Forms 1 and 2, with values of 3793±52 and 3729±72 mg/100 g of fresh weight, respectively. Domestic Rowanberry Form 3 had a slightly lower content of polyphenols (3031±57 mg/100 g). Other species had lower polyphenol content, with Common Rowanberry varieties Businka, Yellow Nevezhenska, and Burka having values of 1064, 1242, and 1443 mg/100 g, respectively. Scandinavian Rowanberry and Common Rowanberry had polyphenol content of 1056±30 and 818±16 mg/100 g of fresh weight, respectively (Fig. 4).

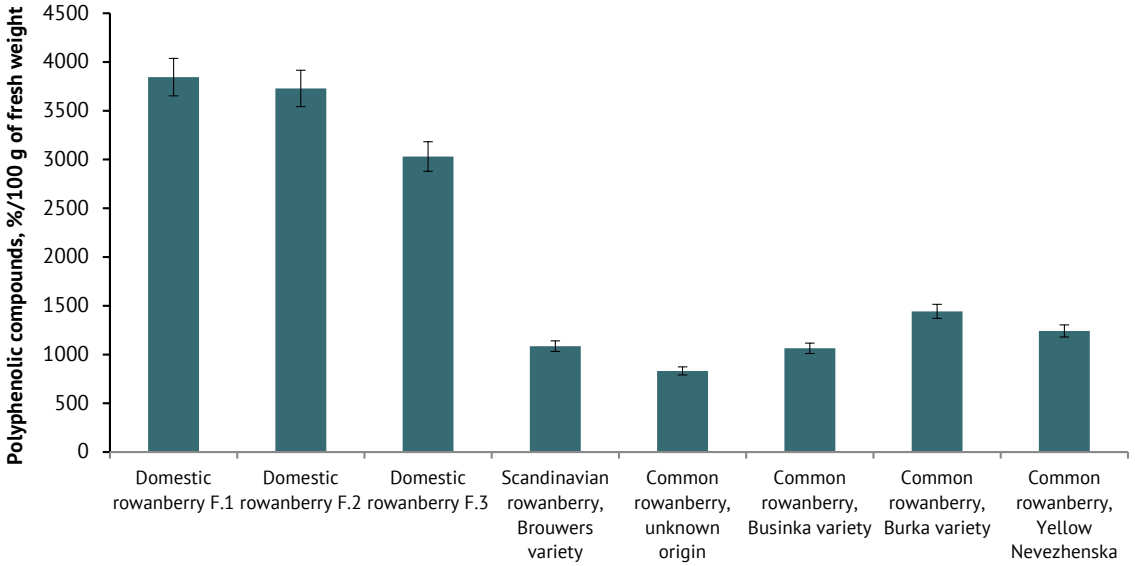

Figure 4. *The content of polyphenolic compounds in the fruits of various rowanberry species*
Source: *compiled by the authors*

Flavonoids, which are biologically active compounds with antioxidant properties, were present in small amounts in the fruits of the studied rowanberry species. The flavonoid content ranged from 217.5±2.0 mg/100 g in Scandinavian Rowanberry to 257.5-303.5 mg/100 g in Common Rowanberry. Domestic Rowanberry Forms 1 and 2 had higher levels of flavonoids (250.0±8.2 and 251.0±0.6 mg/100 g of fresh weight, respectively).

The content of anthocyanin pigments in the fruits of different rowanberry species was relatively low, with a maximum of 6.03±0.3 mg/100 g in Common Rowanberry and a minimum of 1.5±0.2 mg/100 g in Domestic Rowanberry Form 1. Other rowanberry varieties had anthocyanin content slightly above or below the average, with values of 2.63±0.26 mg/100 g in Domestic Rowanberry Form 2, 3.3±0.2 mg/100 g in Domestic Rowanberry Form 3, and 3.3±0.15 mg/100 g in Scandinavian Rowanberry.

In contrast, the content of chalcones in the rowanberry fruits was somewhat higher, with an average value of 13.5±0.14 mg/100 g. Common Rowanberry had the highest chalcone content, ranging from 20.4-24.6 mg/100 g. Other rowanberry varieties had chalcone content below the average, with values of 12.3±0.3 (Common Rowanberry Form 3), 10.8±0.5 (Domestic Rowanberry Form 2), 10.5±0.3 (Domestic Rowanberry Form 1), and 13.80±0.44 mg/100 g (Scandinavian Rowanberry) (Fig. 5).

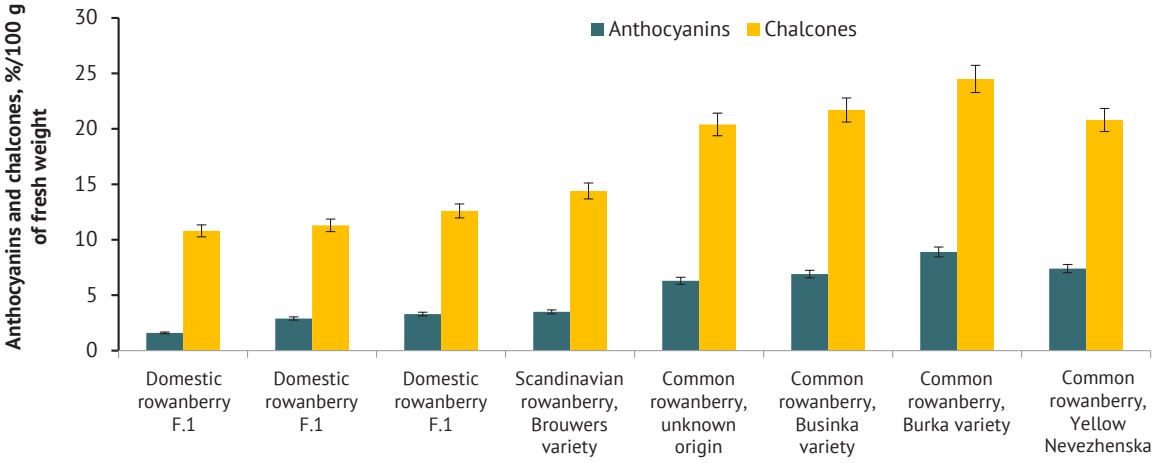

Figure 5. *The content of anthocyanins and chalcones in rowanberry fruits*
Source: *compiled by the authors*

Considering the pH levels of the juice in fruits of other studied crops, which varied within relatively narrow limits, the pH of the juice in the studied rowanberry species showed significant differences. Scandinavian Rowanberry had the highest pH (4.4±0.3), slightly lower in the fruits of Domestic Rowanberry Form 2 (4.1±0.1). Values below the average for this group were observed in Common Rowanberry (3.5±0.3), Common Rowanberry Form 3 (3.8±0.2), and Domestic Rowanberry Form 1 (3.9±0.2). The rowanberry species studied exhibited significant variation in their oxidative-reductive potential (ORP), with Scandinavian Rowanberry having the highest ORP at 243 mV. Fruits of Common Rowanberry Form 3 had an ORP of 251.1±4.3 mV (Table 4).

Table 4. *Average juice pH and redox potential values of fruits from different varieties of rowanberry*

Variety/hybrid	juice pH	redox potential, MV
Common Rowanberry Form 1	3.9±0.2	243.8±12.1
Common Rowanberry Form 2	4.1±0.1	230.3±10.9
Common Rowanberry Form 3	3.8±0.2	251.1±4.3
Common Rowanberry (Unknown Origin)	3.5±0.3	241.7±9.8
Scandinavian Rowanberry (Brouwers Cultivar)	4.4±0.3	230.7±9.9

Source: *compiled by the authors*

Due to the high dry matter content in the fruits of Scandinavian rowanberry (43.55±0.29%) and common rowanberry (36.6-41.3%), they can be used for producing reconstituted juices or fruit powders. The high content of dry soluble substances in the fruits of all studied rowanberry species makes them suitable for the production of therapeutic and preventive beverages, infusions, and compotes. Specifically, the polyphenolic content of over 3000 mg/100 g of fresh weight in common rowanberry Forms 1-3 characterises their high antioxidant properties, which is a distinctive feature of these *Sorbus* species. The indicator of sweetness and suitability for fresh consumption, and for making pastilles, is the high sugar content and pH level. Fruits of Scandinavian rowanberry, as well as common rowanberry Forms 3 and 2, possess these characteristics, making them suitable for desserts and direct consumption. The presence of over 1% pectin in the fruits of common rowanberry Forms 1 and 2, along with titratable acidity levels within ±1.0%, provides a basis for considering them as excellent raw materials for making jelly products. Therefore, valuable source material has been prepared for further breeding to create new varieties with a complex of valuable agricultural traits.

DISCUSSION

Representatives of the genus *Sorbus* are deciduous trees and shrubs belonging to the Tracheophyta clade, comprising about a hundred species (hybrids, forms) with an area covering regions with a temperate climate in the Northern Hemisphere (Rand, 2018). The diversification of European rowanberries was driven by the hybridisation of four common diploid species, namely *Sorbus aria* L. Crantz, *Sorbus aucuparia* L., *Sorbus chamaemespilus* L. Crantz, and *Sorbus torminalis* L. Crantz, and subsequent backcrossing with their parent species, resulting in the formation of several aloploid species, mostly triploids and tetraploids, reproducing via apomixis and restricted to various-sized geographical

regions. As noted by N. Meyer & L. Meierott (2021), many species of the *Sorbus* genus have been individually studied and described.

A. Hajrudinovi´c-Boguni´c *et al.* (2023) report that the clonal structure within and among populations of these rowanberry species is maintained through apomixis. Hybridisation, polyploidisation, and apomixis are the primary drivers of *Sorbus* diversification in Europe. Notably, dominant rowan forests (*Sorbus aucuparia*) are found in the Central and Southern Alps (Graubünden and Ticino, Switzerland – Verbania-Cusio-Ossola province, Northern Italy, etc.). Domestic rowanberry (*Sorbus domestica* L.; synonym *Cormus domestica* L. Spach, 1834) has a significant range as well. As described by V. Moskalets *et al.* (2022), its territory includes Ukraine, particularly Crimea and Transcarpathia, and is somewhat localised in the Forest-Steppe region, and other countries, including the United Kingdom, France, Switzerland, Italy, Montenegro, Serbia, the Czech Republic, Algeria, Tunisia, and countries in the Eastern Mediterranean, the western part of Asia Minor. However, in some regions, this species is endangered, such as Austria, Germany, and Spain. Plants of domestic rowanberry are significant because, as D. Drvodelić *et al.* (2018) indicate, their fruits vary in morphophysiological properties and are consumed both fresh and processed into healthy food products, including marmalade, pastille, jam, preserves, liqueurs, kvass, cider, etc. In a dried and ground form, they are added to flour for making confectionery, tea blends, and sourdough. It has been proven that extracts and jams from domestic rowanberry fruits exhibit antioxidant properties. As noted by M. Rutkowska *et al.* (2019), the plant material of domestic rowanberry, especially its leaves, has increased bioactivity, with extracts made from them showing high antioxidant activity.

However, to produce high-quality products, forms that produce fruits with high quality are needed, which requires additional research. In particular, G. Sebek (2020) notes that in France and Germany, phenological observations of domestic rowanberry plants and the study of their fruit morphology have allowed for the selection of valuable forms. These fruits can be valuable raw materials in processing and food industries.

According to W. Pusz *et al.* (2019), the intermediate or Scandinavian rowanberry (*Sorbus intermedia* (Ehrh.) Pers.) also holds significant importance. Although this species has a very limited natural range, found only in southern Scandinavia and along the Baltic Sea coast, except for the Gulf of Finland, it is now introduced in horticultural and agroforestry practices in many regions, including Ukraine. Z. Mrkonjić *et al.* (2019) showed that extracts from both *S. domestica* and *S. intermedia* exhibit antioxidant properties that inhibit the growth of certain clinically significant bacterial strains, which is a medical breakthrough. As mentioned by A. Ritala *et al.* (2022), the nutritional value of the fruits of common rowanberry (*Sorbus aucuparia* L.) has also been confirmed in practice, particularly in terms of protein content and dietary fibres. Equally significant is the pharmacological property of *Sorbus* L. fruits, as stated by K. Zymone *et al.* (2018), which is attributed to their unique composition of bioactive compounds. For instance, fruits of the "Burka" variety of common rowanberry, distinguished by their exclusive phytochemical composition, are used to produce powders with high antioxidant properties. Furthermore, according to Y. Lykholat *et al.* (2021), the skin of *Sorbus* genus representatives' fruits contains more antioxidant compounds than the flesh, along with elevated levels of polyphenolic compounds.

Researchers, such as M. Bozhuyuk *et al.* (2020), conduct extensive studies involving morphological descriptions of plants, fruit biochemistry of new forms of various *Sorbus* species to form a knowledge base for future use in science, particularly in breeding and nursery practices. It has also been established that the diversity of biotypes of rowanberry (*Sorbus aucuparia* L.) obtained from seeds is characterised by varying organic content in the fruits. This is crucial when choosing the species or variety of *Sorbus* for fruit harvesting and processing, as mentioned by M. Ognyanov *et al.* (2022). For example, in the fruits of common rowanberry, soluble sugars (fructose and glucose) constitute the majority of total carbohydrates, pectin makes up a significant portion of polysaccharides, and malic acid is one of the dominant organic acids. Among the studied common rowanberry varieties, the highest content of total anthocyanins is found in the fruits of the "Burka" (871 mg/kg dry weight) and "Businka" (856 mg/kg dry weight) varieties (Mikulic-Petkovsek *et al.*, 2017).

The nutritional value of rowanberry fruits is undeniable, and as asserted by R. Bobinaitė *et al.* (2020), the antioxidant, antimicrobial, and antiproliferative activity of extracts from these fruits is relevant in various sectors. Consequently, there is a prospect of expanding the use of rowanberry plant material in natural remedies, cosmetics, and as innovative food ingredients, as indicated by V. Sarv *et al.* (2020). These ingredients are expected to have broad applications in the production of food products and in ethnopharmacology for the natural treatment of bacterial, viral, inflammatory diseases, including tumors, and in the prevention and treatment of neurological and cardiovascular disorders.

It is worth noting the effectiveness of rowanberry preparations in inducing apoptosis, a process necessary for the physiological regulation of the body's cell count. Apoptosis is vital for eliminating old cells, generating lymphocytes that are not reactive to their antigens (autoantigens), shedding leaves from plants in autumn, the cytotoxic action of killer T lymphocytes, embryonic development, and more (Kobylinska *et al.*, 2021; Zyablitsev *et al.*, 2022). For instance, S. Moon *et al.* (2021) demonstrated that a water extract from rowanberry fruits induces apoptotic cell death through the active oxygen species (ROS-dependent) pathway.

The bioactive potential of *Sorbus norvegica* fruit extracts in the treatment of type 2 diabetes has been investigated (Broholm *et al.*, 2019). There are also prospects for using the extract to alleviate colitis (Akkol *et al.*, 2020). Information is available on the impact of rowanberry fruits on protein glycation, a process in which sugar molecules react with proteins, causing them to form cross-links and lose functionality, leading to what is known as glycation or "sweet ageing" (Boiarska, 2019). Therefore, as noted by M. Rutkowska *et al.* (2019), organic compounds in *Sorbus aucuparia* L. fruits in the form of fractionated extracts inhibit glycation or the protein glycation process and oxidative/nitrative damage to human plasma components.

In summary, the increased attention of agrarians to representatives of the *Sorbus* genus, along with the search and selection of valuable species (forms, varieties) based on morphological, physiological, valuable, and biochemical research, can lead to the production of valuable consumption products for the domestic market. Even in small quantities, these products can meet the human body's essential nutrient requirements, preventing diet-related diseases, slowing down the ageing process, and boosting immunity. Moreover, they can address vitamin and antioxidant deficiencies and provide essential micronutrients, promising further development in this field.

CONCLUSIONS

Based on the results of phenological observations, it was determined that during dry and hot weather, the duration of the fruit ripening phase is shortened, leading to a significant portion of the fruits falling prematurely and unripe. Fruit drop was also observed during low air temperatures at the end of the developmental phase, particularly for Scandinavian and domestic rowanberry plants. It was found that fluctuations in the weather-climate regime during the vegetation period of rowanberry plants determine the dates and duration of developmental phases, which often differ from year to year. It was established that, in terms of growth intensity by plant height, Scandinavian rowanberry (Brouwers variety) and domestic rowanberry (Forms 1 and 2) are highly productive, while domestic rowanberry (Form 3) and common rowanberry (hybrid seedling and varieties Businka and Burka) are moderately productive.

Scandinavian rowanberry (Brouwers variety) and domestic rowanberry (Forms 1 and 2) plants exhibit distinct overall conditions in terms of disease resistance, growth pattern, and foliage, whereas domestic rowanberry (Form 3) and common rowanberry (seedling of unknown origin) have satisfactory conditions. It was found that the vegetative buds of Scandinavian rowanberry plants have a broadly conical elongated shape, while the generative buds have a pointed tip, with the average start of their development in the conditions of the Northern Forest-Steppe occurring in the late third decade of March to early April. Vegetative buds of domestic rowanberry plants and common rowanberry plants have a conical shape, while generative buds are rounder and larger in size.

It was noted that for the studied common rowanberry plants, flowering begins in the third decade of May, Scandinavian rowanberry blooms from the third decade of April to the first decade of May, and domestic rowanberry blooms at the end of the second decade of May. The aroma of the flowers of each rowanberry species was determined, with domestic rowanberry having a distinct bitter almond-like aroma, common rowanberry having a specific unpleasant scent. It was determined that common rowanberry plants of the Nevyazhynska yellow variety are self-sterile, while for common rowanberry of the Burka variety, domestic rowanberry, and Scandinavian rowanberry (Brouwers variety), self-fertility exceeds 90%.

It was shown that the fruits of different rowanberry species vary in skin colour, with the skin of Scandinavian rowanberry (Brouwers variety) being brick-red, domestic rowanberry Form 1 – yellow-green, Form 2 and Form 3 – green-yellow, common rowanberry of the Nevyazhynska yellow variety – yellow-orange, Burka variety – dark pink or dark burgundy, Seedling – dark orange, Businka variety – bright red, respectively. For all examined rowanberry species (varieties), the fruit-bearing cycle is annual. Considering the high dry matter content in the fruits of Scandinavian rowanberry (43.5±0.3%) and common rowanberry (36.6±0.3%), they can be used to produce reconstituted juices or fruit powders. The high content of soluble solids in the fruits of all examined rowanberry species makes their fruits suitable for the production of medicinal and preventive beverages, tinctures, and compotes. For domestic rowanberry Form 1-Form 3, the content of polyphenolic compounds, exceeding 3000 mg/100 g of fresh weight, indicates their high antioxidant capacity.

It was established that the fruits of Scandinavian rowanberry and domestic rowanberry Form 2 and Form 3 are characterised by dessert qualities and are suitable for consumption in both fresh form and for making pastilles due to their high sugar content and juice pH, indicating their nutritional value. It was also investigated that the fruits of domestic rowanberry Form 1 and Form 2, with a pectin and titratable acid content of over 1.0%, are considered quality raw materials for making jelly products. The studied varieties and forms of Scandinavian rowanberry, common rowanberry, and domestic rowanberry are recommended for use in the decorative and fruit gardening system.

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CONFLICT OF INTEREST

None.

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Морфо-фізіологічні особливості рослин та біохімічні параметри плодів горобини скандинавської, горобини звичайної і горобини домашньої, вирощених в умовах Північного Лісостепу України

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Анотація. Актуальність даної теми полягає в порівняльному оцінюванні різних видів горобини для підвищення їх значимості та більшого використання системі декоративного і плодового садівництва, в технологіях переробки рослинної сировини і виготовлення продукції для здорового харчування. Головною метою дослідження було вивчити морфо-фізіологічні характеристики рослин і біохімічні параметри плодів різних видів (сортів, форм) роду Sorbus. За результатами практичних досліджень представлено оригінальні дані про морфологію й господарську характеристику представників (сортів і форм) видів *Sorbus intermedia* Pers., *Sorbus aucuparia* L., *Sorbus domestica* L., висвітлено біологічні властивості рослин, біохімічні параметри плодів. З'ясовано, що всі вивчені представники роду *Sorbus* володіють високою зимостійкістю (1,5 бали за С.Я. Соколовою), крім цього рослини горобини скандинавської мають високу посухостійкість (4,5 балів за С.С. П'ятницьким), порівняно з рослинами горобини звичайної. Проведені фенологічні спостереження за рослинами різних видів горобини дозволили для умов Лісостепу України з'ясувати час настання фаз онтогенезу: розвитку вегетативних бруньок, появи листків, росту пагонів, бутонізації і цвітіння, утворення і розвитку зав'язей, достигання і плодів, зміни забарвлення і опадання листків, а також підфаз, які більш точніше характеризують час настання, пік і кінець певної фази розвитку, що є науковим доробком для стратегій в системі декоративного і плодового садівництва. Досліджено інтенсивність росту сортів і форм представників роду *Sorbus* за висотою рослин горобини, а також проведено оцінювання загального їх стану за життєздатністю. Підготовчі роботи з підготовки підщеп, добору живців і проведення щеплення дозволили сформувати в колекційному розсаднику модельні рослини та додатково оцінити їх за силою росту, настанням і проходженням окремих фаз розвитку, оцінити їх за посухо- і зимостійкістю, віком настання плодоношення та ін. Також проведено біометрію і опис стовбура, гілок, вегетативних і генеративних бруньок, листків, суцвіття і плодів. Охарактеризовано плоди за смаком, про що зазначено в матеріалах статті. Біохімічний аналіз плодів дозволив встановити їх придатність до переробки і виготовлення продуктів здорового харчування

Ключові слова: *Sorbus intermedia* Pers.; *Sorbus aucuparia* L.; *Sorbus domestica* L.; морфологічні ознаки; фізіологічні особливості рослин; біохімічні властивості плодів